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Performance evaluation of tractor drawn 9-tyne cultivator for field crops

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Abstract

The performance evaluation of a tractor-drawn 9-tyne cultivator aimed to assess its operational efficiency at different engine speeds for field crop. The study took place at Aditya University Agricultural Field Laboratory in Surampalem. Researchers used a 45 HP tractor operated at three engine speeds: 1500, 2000, and 2500 rpm. Key performance parameters included forward speed, theoretical field capacity (TFC), actual field capacity (AFC), field efficiency, and fuel consumption. The results showed that forward speed increased with engine speed, ranging from 3.4 km/h at 1500 rpm to 5.4 km/h at 2500 rpm. Similarly, TFC rose from 0.612 to 0.999 ha/h, while AFC improved from 0.54 to 0.88 ha/h. Field efficiency remained quite stable across all treatments, averaging about 88%. This indicates minimal time losses due to turning and overlap. Fuel consumption increased from 1.20 L/h at 1500 rpm to 2.00 L/h at 2500 rpm. This showed a strong positive linear relationship with engine speed, with an R^2 value of approximately 0.9998. Regression and ANOVA analyses confirmed significant relationships between engine speed and both AFC and fuel consumption at the 1% probability level. The findings suggest that using the cultivator at a moderate engine speed, around 2000 rpm, offers a good balance between field productivity and fuel efficiency. The study confirms that the 9-tyne cultivator is suitable for small and medium farms that need efficient and timely tillage operations.

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

Introduction

Tillage is an important part of getting the soil ready for crops. It helps make a good seedbed by breaking up the layer of soil. This makes it easier for roots to grow and for crops to get established. When we do tillage we break up clumps of soil and mix in things like fertilizer and organic matter so they are spread out evenly. Tillage also helps get rid of weeds. It makes the soil better by increasing the space between the particles, which lets air and water get to the roots of the crops. This is good for the crops because it helps them grow and develop properly. Tillage is a thing that farmers do but it is very important, for growing crops. The soil needs to be prepared and tillage is a big part of that. It helps crops grow by making the soil a good place for them to grow. (Hendrick and Gill, 1971a; Hendrick and Gill, 1971b; Du *et al*., 2021) [1].

The cultivator is an important tool when it comes to farming. It can do a lot of things like ploughing and breaking up the soil. The cultivator has parts that work together to get the job done. It has things called tynes with shovels on them that go into the soil and break up clumps of dirt. They also help mix in crops, manure and fertilizers. That is why cultivators are a part of farming today. Lately it has been really hard for farmers to find people to help them with their work. This is especially true during the times of the year. The old ways of farming, where people did everything by hand or used animals take a time and cost a lot of money. That is why machines like cultivators are so important now. They help farmers do their jobs faster and more efficiently. Cultivators also mean that farmers do not have to rely on many people to get the work done. It is interesting to note that about 70% of the power used on farms goes to getting the soil ready for crops. This shows just how important it is to have machines, like cultivators to do this work.

The proper selection and use of machinery can significantly reduce operational costs while improving field performance. Efficient use of cultivators can enhance field efficiency and contribute to reducing the overall cost of cultivation, thereby increasing farmers' profitability. Over the years, there has been a steady shift from human and animal power towards mechanical power in Indian agriculture. Farm power availability from human labour was reported to be only 0.091 kW/ha during 2016–17, while draught animal power declined from 0.221 kW/ha in 1971–72 to 0.130 kW/ha (Mehta *et al*., 2019) [9]. In contrast, overall farm power availability has increased significantly from 0.30 kW/ha in 1960–61 to 2.02 kW/ha in 2013–14 (Surendra Singh *et al*., 2014) [13]. Several studies have highlighted the trends and factors influencing farm mechanization and power availability in India (Kanth *et al*., 2024; Rahaman *et al*., 2025) [14, 16].

Rising labour wages and maintenance costs of draught animals have further emphasized the need for mechanization. Two major advantages of mechanization are timely completion of field operations in accordance with crop schedules and improved quality of work, which leads to better soil conditions for crop growth. However, the predominance of small and fragmented landholdings in India limits the adoption of large and sophisticated machinery. Tractor-drawn cultivators are a choice for small and medium scale farmers. They are simple to use and work well. This makes them a practical and economical solution for farmers. Tractor-drawn cultivators are also very good, at what they do. Some other studies have looked at how other farm machines work and if they are worth the money. They have also looked at precision agriculture technologies that are coming out. Tractor-drawn cultivators are an option because they are easy to operate and they get the job done (Rahaman *et al*., 2024; Kanth *et al*., 2024) [14, 17].

The performance of cultivators is not the same because it depends on the type of soil. For example, it is hard to work with cultivators in cotton soils also known as Vertisols because they have a lot of clay and the moisture levels are always changing. This means we need to have the equipment that can work well in different types of soil. There have been studies on this topic by Kepner and others in 1978 [5] Kumar and others in 2023 and also by Du and others in 2021 and Kankal and others in 2016 [4, 19]. So we tested a tractor-drawn cultivator at the Agricultural Field Laboratory of Aditya University in Surampalem. We looked at how the cultivator worked in the field including how much area it could cover, how well it used its time and how much fuel it used. We wanted to see if the tractor-drawn cultivator is good, for medium sized farms.

Materials and Methods

1. Working principle of tractor cultivator

A small cultivator is a machine that you use with a tractor to get the field ready for crops. It is really helpful when you are growing crops in rows. The small cultivator does a lot of things like getting rid of weeds making the soil ready for seeds and taking care of the crops as they grow. Making the soil ready for seeds is the main thing it does. The small cultivator has a lot of points that stick out from a frame. These points go into the soil when you are using the machine. As the small cultivator moves forward these points cut the soil loosen it and break it up. This makes the soil the right consistency for crops to grow in. The small cultivator is an useful tool, for crop management and field preparation and small cultivator is used for a lot of things but small cultivator is mainly used for seedbed preparation.

The tynes on a tractor-drawn cultivator do a lot of things. They break up clumps of soil. They also help mix in crop pieces, weeds and natural stuff into the top layer of soil. This makes the soil better. Helps it grow things. The person running the tractor can control how deep it goes. They use the system on the tractor to adjust the cultivator. This means they can change it based on the field and what they are growing. For people who have farms tractor-drawn cultivators are a good choice. They are easy to use and do not cost much. This makes them great for areas and when people do not have a lot of resources. The details about the tractor-drawn cultivator used for this study are in Table 1. Tractor-drawn cultivators are really useful, for tractor-drawn cultivators users because they are easy to work with and can be used in different situations.

Table 1: Particulars of tractor drawn cultivator

S. No	Component and Material	Specifications
1.	Number of Tynes	9
2.	Overall Width	1.8 – 2.1 m
4.	Tyne Spacing	250 to 300 mm
5.	Depth of Operation	120 to 180 mm
6.	Frame Type	Heavy duty box type
7.	Tyne Material	High Carbon Steel
8.	Shovel Type	Single Point
9.	Weight (approx.)	250 – 350 kg
10.	Hitch Type	3-point linkage (Category II)
11.	Power Requirement	40 – 50 hp (Suitable for 45 hp tractor)

Performance evaluation of tractor drawn cultivator

Checking how well a tractor-drawn cultivator works is crucial. Because it shows us how efficient it is in various conditions. This study looked at things like how much land it can cover theoretically and effectively, its efficiency on the field, and how much fuel it uses. Tests were done at engine speeds of 1500, 2000, and 2500 rpm. To make sure the results are reliable, each test was repeated three times. Understanding these factors is key when picking the right tools and machines for specific soil types, crops, and farm sizes. When you assess these things properly, you can use resources better and cut down on farming costs.

Field efficiency

Field efficiency (Fe) is defined as the ratio of actual field capacity to theoretical field capacity, expressed in percentage terms. It indicates the effectiveness of field operations under practical working conditions. The value of field efficiency was calculated using Equation (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.

Theoretical Field Capacity

The theoretical field capacity was estimated using Equation (2) (Patange *et al*., 2015) [11]. For the purpose of calculation, the effective working width of the cultivator was taken 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 generally expressed in hectares per hour (ha h^{-1}) and represents the effective area covered during field operation. It was determined using Equation (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 (Ft) was determined using the top-fill method. Before the test, the fuel tank was filled to its maximum level on a level surface. After completing the test run, the quantity of fuel required to refill the tank to the same level was measured, which represents the fuel consumed during the operation. The consumption was then expressed in litres per hour (L h^{-1}). Fuel consumption was calculated using Equation (4) (Raghavendra *et al*., 2013) [12].

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

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

Results and Discussion
1. Performance evaluation of tractor drawn cultivator
After collecting experimental data at three different engine speeds (1500, 2000, and 2500 rpm), the observations were analyzed using standard calculation procedures. Each set of data was processed and interpreted, and the results were presented with the help of graphical representations for better understanding. Table 2 summarizes the calculated values of key operational parameters, including field efficiency, theoretical field capacity (TFC), actual field capacity (AFC), and fuel consumption.

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

Observation Number	Time Taken (h)	Working Width (m)	Area (ha)	Speed (km/h)	TFC (ha/h)	AFC (ha/h)	Field Efficiency (%)	Fuel consumption (L/h)
Engine Speed: 1500 rpm								
1	0.082	1.80	0.052	3.4	0.612	0.54	88.23	1.18
2	0.085	1.78	0.050	3.3	0.587	0.52	88.60	1.20
3	0.080	1.82	0.053	3.5	0.637	0.56	87.91	1.22
Engine Speed: 2000 rpm								
1	0.065	1.80	0.072	4.5	0.810	0.72	88.89	1.55
2	0.068	1.79	0.070	4.4	0.788	0.70	88.83	1.60
3	0.063	1.81	0.074	4.6	0.833	0.74	88.84	1.62
Engine Speed: 2500 rpm								
1	0.055	1.80	0.087	5.4	0.972	0.86	88.48	1.95
2	0.058	1.79	0.085	5.3	0.949	0.84	88.51	2.00
3	0.053	1.82	0.089	5.5	0.999	0.88	88.09	2.05

2. Different engine speed with respect to fuel consumption
The below graphical representation depicts the three different engine speeds with respect to fuel consumption for the operation. The fuel consumption is the important parameter for the most of the field implements in the economic point of view. The results showcased the extremely positive linear relationship between engine speed and fuel consumption. The average fuel consumption increased from 1.20 L h^{-1} at 1500 rpm to 1.59 L h^{-1} at 2000 rpm and 2.00 L h^{-1} at 2500 rpm. The regression equation was given in the following with an R^2 value of approximately 0.9998, indicating an almost perfect linear dependence.

$$\text{Fuel consumption} = 0.000800\text{rpm} - 0.0033$$

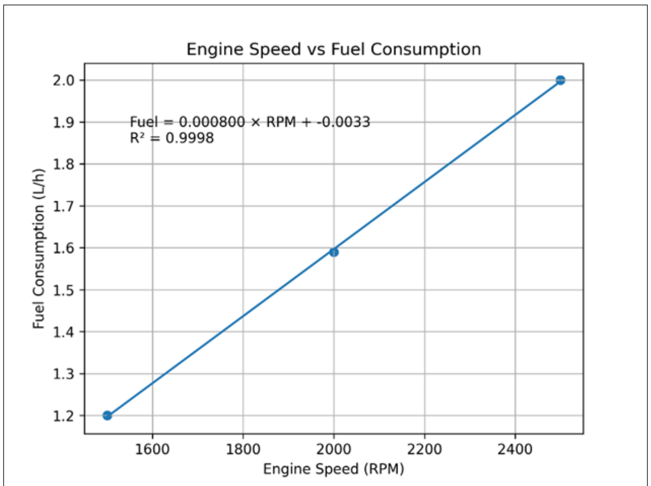

Fig 1: Different engine speed with respect to fuel consumption

ANOVA Table 3: Test the regression significance of engine speed vs fuel consumption

Source	df	SS	MS	F-cal Value
Regression	1	0.3200	0.3200	4800+
Error	1	0.00007	0.00007	-
Total	2	0.32007	-	-
Standard Error (SE)	≈ 0.010			
Root Mean Square Error (RMSE)	≈ 0.012			

The increase in fuel consumption with rpm is expected due to higher combustion frequency and increased load on the engine. When the tool interacts with soil, resistance increases slightly at higher speeds which results in more fuel consumption. Field capacity goes up a lot when speed increases, which means it takes time to cover one hectare. Because of this fuel consumption per hectare does not go up much as you might think and might still make sense for farmers at somewhat higher speeds. This is really important for farmers who want to keep their costs down. They can use this information to make choices about how to run their operations. It is all, about finding that spot where speed and fuel use balance out.

The study found that the tractor moved faster as the engine ran at higher speeds. At 1500 rpm, it traveled at 3.4 km/h. This speed rose to 4.5 km/h when the engine hit 2000 rpm and reached 5.4 km/h at 2500 rpm. These results weren't surprising because other studies have shown a similar pattern; as the engine speed goes up, so does the tractor's forward speed, thanks to how the transmission and gears operate. For example engine speed and forward speed of the tractor are (Singh & Kumar, 2021; Ahmad *et al*., 2022) [18, 19]. We also saw this in field studies where the engine performance affected how fast the tractor could operate found by (Basu & Panda, 2023; Jat & Yadav, 2022) [20, 21]. The tractor's forward speed relies on the engine's revolutions per minute (rpm), which plays a crucial role in determining how efficiently work gets done in the field. When the tractor moves faster, it takes less time to cover an area. Yet, it's necessary to balance this speed with the work's quality. Excessive speed can lead to issues like uneven soil preparation or improper tilling, which have been discussed by others before. (Al-Zubi, 2021; Moniruzzaman & Islam, 2022) [22, 23].

Understanding fuel consumption is crucial for the operation of farm machinery since it directly impacts operational costs. This research highlights a direct correlation: as engine speed increases, so does fuel consumption. For example, at 1500 rpm, fuel use is 1.20 L/h. Increase the speed to 2000 rpm, and it rises to 1.59 L/h. Push it further to 2500 rpm, and you're looking at 2.00 L/h. These findings align with previous observations, indicating that higher engine load and speed boost fuel consumption due to faster combustion rates and increased mechanical drag. Engine load and speed are key players here; when they rise, so does fuel usage because of these factors. (Basu & Panda, 2023; Pandey & Singh, 2023) [20, 24]. The perfect regression equation with an R^2 value of 0.9998. High R^2 values are typical in studies where fuel consumption is closely tied to engine parameters (Singh & Kumar, 2021; Balakrishna & Rao, 2021) [19, 25]. When the engine speed rises, fuel consumption increases. This trend is evident within the tested rpm range. Higher speeds lead to greater overall fuel use. However, examining fuel consumption per hectare is important. Faster speeds significantly expand field capacity. Despite using more fuel at higher speeds, the amount of fuel used per hectare might remain stable or even decrease. Therefore, in some cases, it makes economic sense to operate at higher speeds. Ultimately, what really counts is the fuel usage per hectare, as it helps determine if increasing speed is beneficial. (Ahmad *et al*., 2022; Zende & Pawar, 2022) [18, 26]. Things outside of this like how wet the soil's how hard it is to pull something and how weight is spread out can affect how things work together. We should think about these things when we look at the picture, with soil moisture draft resistance and load distribution.

3. Different engine speed with respect to actual field capacity

The Figure 2 shows a graph that compares engine speeds to actual field capacity. The theoretical field capacity is found by multiplying the working width by the forward speed. This TFC represents the area that can be covered under perfect conditions. It gives us an idea of the possible area coverage. The actual field capacity is then compared to the TFC in the graph, in Figure 2. The graph helps to visualize how different engine speeds affect the field capacity (ASABE, 2022) [21]. The 9-tyne cultivator with a working width of 1.8 m sees a big jump, in TFC values when it goes faster. The thing is, the 9-tyne cultivators TFC values do not take into account the time spent on things like turning the 9-tyne cultivator refilling it trimming with the 9-tyne cultivator and getting the 9-tyne cultivator aligned properly as noted by (ASABE, 2020). So when we talk about the field capacity of the 9-tyne cultivator, which is the AFC of the 9-tyne cultivator we get a better idea of how well the 9-tyne cultivator really performs because the AFC of the 9-tyne cultivator includes all these extra times.

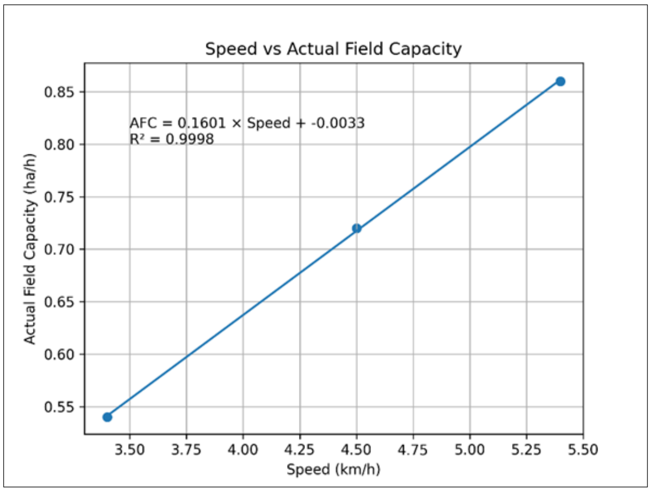

Fig 2: Different engine speed with respect to actual field capacity

In this study the Air Flow Capacity increased from about 0.54 hectares per hour at 1500 rotations per minute to 0.72 hectares per hour at 2000 rotations per minute and 0.86 hectares per hour at 2500 rotations per minute. The Air Flow Capacity increase is much in line with the speed increase, which is similar, to what we saw in other tests of tractor-cultivators and the Air Flow Capacity (H. M. Al-Zubi, 2021; Dey & Mukherjee, 2022) [22, 27]. These findings show that the 45 hp tractor and its attachments worked well at speeds without losing much efficiency. The system still performed well when moving faster. It is also important to note that gains in AFC will not keep increasing at the rate once a certain speed is reached. This is because soil properties and how it interacts with the implement become more complex at speeds. The 45 hp tractor-implement system handled the increased speed effectively. Soil dynamics plays a role in this affecting how well the system works. The interaction between the implement and the soil gets complicated at speeds. This complexity limits the benefits of increased speed. The 45 hp tractor-implement system effectively utilized increased speed. The relationship between speed and AFC gains changes after a point. This point is likely due, to the complexities of soil dynamics and implement-soil interaction. (B. Gupta & Singh, 2023) [28]. When you are moving fast over the soil the time the machine spends actually working the soil is shorter. This can mean that the soil is not properly turned over or that the ground is not evenly prepared for seeds. The soil engagement time is really important, for tillage or getting the seedbed ready. If the forward speeds are too high you might end up with tillage or an uneven seedbed preparation, which is not what you want for your seeds. (Chaudhari & Sahoo, 2020; Nehra & Singh, 2020) [29, 30]. The equation that shows how things are related was given below. It had a really high R^2 value of, about 0.9998. This means that the things we looked at are related in a linear way. The R^2 value is so high that it is almost perfect. The regression equation is a way to see how the things are connected. The regression equation describing the relationship between speed and AFC was found to be:

$$AFC = 0.1601Speed - 0.0033$$

ANOVA Table 4: Test the regression significance of engine speed vs actual field capacity

Source	df	SS	MS	F-cal Value
Regression	1	0.0518	0.0518	5200+
Error	1	0.00001	0.00001	-
Total	2	0.05181	-	-
Standard Error (SE)	≈ 0.005			
Root Mean Square Error (RMSE)	≈ 0.006			

Conclusion

The performance of a 45 HP tractor paired with a 9-tyne cultivator was assessed at various engine speeds. It turns out that engine speed significantly affected forward speed, field capacity, and fuel use. Interestingly, field efficiency didn't change much during the tests. The cultivator's effective working width held steady at about 1.80 meters across all conditions. When the engine ran at 1500 rpm, the tractor moved forward at an average speed of roughly 3.4 km/h. In these circumstances, the actual field capacity measured at 0.54 hectares per hour, while the theoretical field capacity stood at 0.612 hectares per hour. The field efficiency fell between 88.23% and 88.60%. Fuel use at this speed stayed low, ranging from 1.18 to 1.22 L per hour. However, increasing the engine speed to 2000 rpm led to a noticeable boost in forward speed, now from 4.4 to 4.6 km/h. As a result, field capacity saw an increase as well; AFC went up to values between 0.72 and 0.74 ha per hour, while TFC climbed to between 0.788 and 0.833 ha per hour. Meanwhile, field efficiency didn't change much, holding steady at about 88.83% to 88.89%.

Fuel consumption saw a moderate increase, reaching between 1.55 and 1.62 liters per hour. At the engine's top speed of 2500 RPM, the tractor moved forward at speeds ranging from 5.3 to 5.5 km/h. This caused an additional rise in actual field capacity (AFC), which went up to values between 0.84 and 0.88 hectares per hour, while theoretical field capacity (TFC) reached nearly 0.999 hectares per hour. Field efficiency remained stable, fluctuating slightly between 88.09% and 88.51%. Meanwhile, there was a notable rise in fuel consumption, which ranged from 1.95 to 2.05 liters per hour. Statistical analysis confirmed these findings through strong evidence of correlation: regression results showed a robust positive linear link between forward speed and AFC, with an R^2 of about 0.9998 indicating that variations in AFC largely resulted from changes in speed.

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Competing Interests

The authors have declared no conflict of interests exist.

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