Full Length Research Article

Research Journal of Agricultural Sciences
Volume 15; Issue 05 (Sept–Oct 2024); pp 1175–1179

ISSN: 0976-1675 (P)
ISSN: 2249-4538 (E)

Design, Development and Field Evaluation of Modified Six Row Vertical Axis Rotary Tiller

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Received: 20 Aug 2024; Revised accepted: 30 Sep 2024

Abstract

In this research, a single row vertical axis rotavator mounted on the loading car was developed for measuring the torque requirement in the soil bin by varying the forward speed (2.0, 2.5, 3.0 and 3.5 km h^{-1}), rotary speed (2.3, 2.8 and 3.2 ms^{-1}), depth of operation (100, 150 and 200 mm) and rake angle (0°, 5°, 10° and 15°). The minimum and maximum torque requirement of 33.3 Nm and 48.7 Nm were observed for the optimized levels. The modified six-row vertical axis rotavator resulted in 17.5 mm of soil mean weight diameter, 2220.7 kPa of cone index, 0.3 ha h^{-1} of theoretical field capacity, 0.267 ha h^{-1}, 89 per cent of field efficiency, -2 per cent of wheel slip, 5.3 cm of bite length and 4.2 l h^{-1} of fuel consumption.

***Key words*:** Tillage, Rotary tiller, Vertical, Torque, Rake angle, Rotavator, Cone index

A rotary tiller or rotavator is indeed a specialized agricultural tool designed to prepare the soil by mechanically churning it up using rotating blades. Its main purpose is to break up compacted soil, making it easier to plant seeds or grow crops. It is particularly effective for preparing seedbeds, as it helps to aerate the soil and ensure it is free from weeds or debris that could hinder crop growth. Rotary tillers are popular for use in both commercial agriculture and smaller-scale gardens or lawns. Their ability to break up soil and blend organic matter (such as compost or manure) into the earth makes them essential for modern agricultural practices [1].

The increased use of rotary tillers in modern agriculture is largely due to their simple design and high efficiency. These machines have become essential tools because they combine primary and secondary tillage operations into a single step. This reduces the time, labor, and fuel required for land preparation. With rotary tillers, the soil is not only loosened (primary tillage) but also finely pulverized (secondary tillage), creating an ideal seedbed in one pass. This dual functionality is particularly beneficial in large-scale farming operations, where time and resource efficiency are critical. The ability to work across various soil types and conditions adds to the popularity of rotary tillers, making them a versatile tool in both small and large agricultural settings [2]. Despite of their high-energy consumption, since rotary tillers have the ability of making several types of tillage applications in one stage, the total power needed for this equipment is low [3]. Energy requirement is the issue of concern in agricultural machinery management in crop production systems. The design characteristics of rotary blades are the biggest determinants of power consumption.

The main reasons for the popularity of rotavator among the farmers are [4]:

i. Present-day tractors develop more power than they can transmit efficiently to a draft implement through the tyres:

ii. The soil break-up created and the easy combination with other machines (e.g. sowing machines) allows a reduced number of passages.

However, improper use of rotary tillers can indeed lead to adverse effects on the soil and, consequently, crop production. When the machine's forward speed and rotor angular velocity are not correctly matched to the soil conditions, it can over-pulverize the soil. This leads to soil compaction and crust formation, especially after rainfall, which creates a dense, hard surface layer [5-6]. These crusts can restrict water infiltration, reduce aeration, and inhibit the emergence of seedlings, thereby negatively affecting seed germination. Over-pulverized soil can also lead to increased erosion risk, as fine soil particles are more easily washed away by wind or water. To avoid these issues, it is important to adjust the tiller's speed and rotor velocity according to the specific soil type and moisture content. Proper calibration can ensure that the soil is tilled adequately without being overworked, thus maintaining its structure and promoting better crop growth [7-8].

In India, some farm equipment manufacturers have introduced vertical axis rotary tiller in recent years. Farmers claim difference between horizontal and vertical axis rotary action but there is no scientific work compare them. Some research has been done on comparison between rotavator and

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Citation: Ganapathi, Suthakar, Pandian KA. 2024. Design, development and field evaluation of modified six row vertical axis rotary tiller. *Res. Jr. Agril. Sci*. 15(5): 1175-1179.

conventional tillage implements. In this, research single row vertical axis rotavator has been developed and evaluated. Therefore, the mean weight diameter, cone index of soil and torque requirement were investigated.

MATERIALS AND METHODS

1. *Soil pulverization characteristics*

This study deals with assessing the soil pulverization characteristics such as soil mean weight diameter and cone index by varying the forward speed rotary speed and depth of operation. Horizontal axis rotary tiller was used for the laboratory study. Rotavator consisted of 16 blades and developed a single row vertical axis rotary unit consisted of mainframe, rotary blade and power transmission system (Fig 1a-b).

The experiments were planned to conduct in clay soil, a typical extreme soil condition. The soil in the bin was prepared by tilling three times with a tractor operated rotavator at a depth of 100 mm and the tilled soil was levelled with leveler attached with the bottom of the holding car. Soil moisture content and compaction level were maintained at desired level by the soil treatments. Forward speed and time were recorded using digital stopwatch to cover 20 m length of the soil bin by the tractor. The travel length was measured with the help of measuring tape. There after speed was calculated in kmph. The same procedure was followed for all the treatments with three replications and readings were noted down.

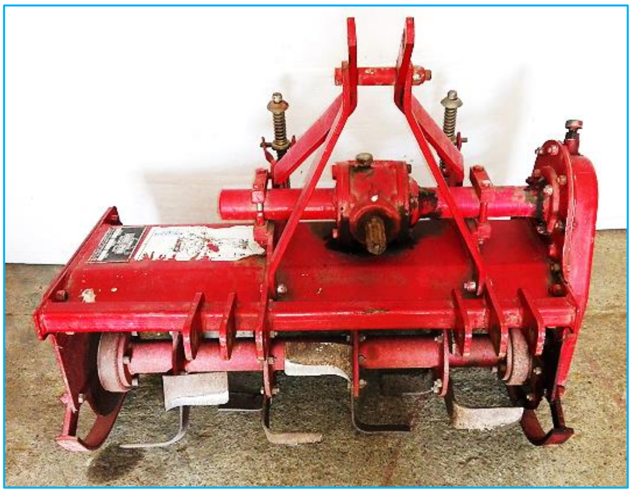

Fig 1a Horizontal axis rotavator

Fig 1b View of single row vertical axis rotavator

2. *Torque measurement*

To assess the torque required to operate the single row vertical rotary tiller experiments were conducted in the rectangular soil bin. An experimental set up was developed in the Agricultural Machinery Research Centre, Tamil Nadu Agricultural University, Coimbatore to measure the torque required during the operation (Fig 2). Soil preparation for the evaluation of single row vertical axis rotavator on torque requirement was measured as explained in section 3.2.4. The selected speeds viz., 2.0, 2.5, 3.0 and 3.5 km h^{-1} were attained by selecting the proper gear and regulating the electric motor speed of the power drive through variable frequency speed drive. Forward speed and time were recorded using digital stopwatch to cover 20 m length of the soil bin by the tractor. The travel length was measured with the help of measuring tape. There after speed was calculated in km h^{-1}. The same procedure was followed for all the treatments with three replications and readings were noted.

Fig 2 Experimental set up for measurement of torque for single row vertical axis rotary tiller

3. *Measurement of operational parameter*

Soil parameters and machine parameters were measured for the modified six row vertical axis rotary tiller to measure the soil mean weight diameter, cone index, operating speed, theoretical field capacity, effective field capacity, field efficiency, wheel slip, bite length, fuel consumption and cost economics of the modified six row vertical axis rotavator as shown in (Fig 3).

Fig 3 Ideal view of the modified six row vertical axis rotavator

RESULTS AND DISCUSSION

1. *Soil pulverization characteristics*

A total of 108 randomly replicated experiments were conducted in the rectangular soil bin with selected levels of variables. The soil mean weight diameter and cone index were measured for both horizontal axis rotavator and vertical axis rotavator for all the treatments.

It is observed that the soil mean weight diameter and cone index for horizontal axis rotavator is less than that of vertical axis rotavator. Comparing the soil mean weight diameter and cone index for the horizontal axis rotavator and vertical axis rotavator, as a representative case the values of soil mean weight diameter and cone index for rotary speed of 3.2 ms^{-1} (S_3) at the depth of operation of 50 mm (D_1) at the 2.0 km h^{-1} (F_1) forward speed of both horizontal axis rotavator and vertical axis rotavator [9-10].

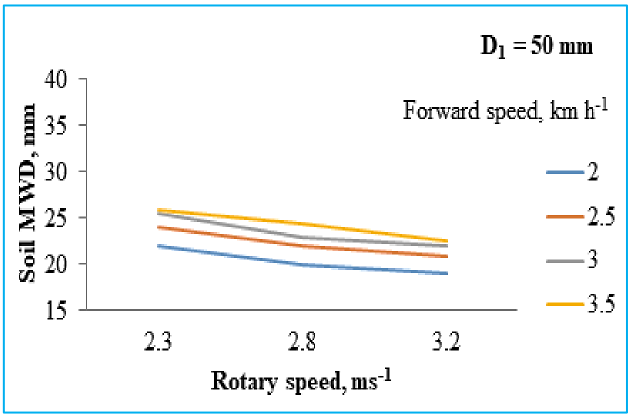

Fig 4 Effect of rotary speed on soil mean weight diameter for horizontal axis rotavator

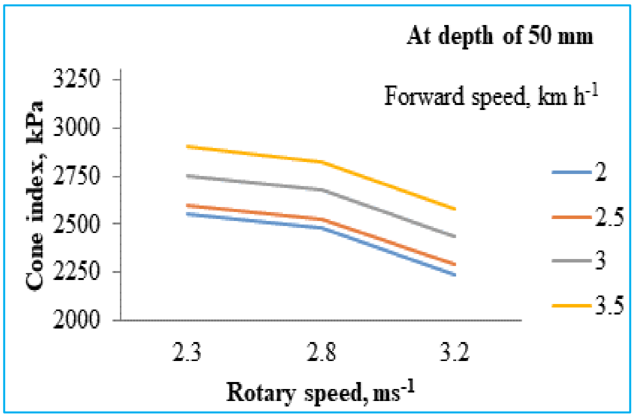

Fig 5 Effect of rotary speed on soil cone index for horizontal axis rotavator

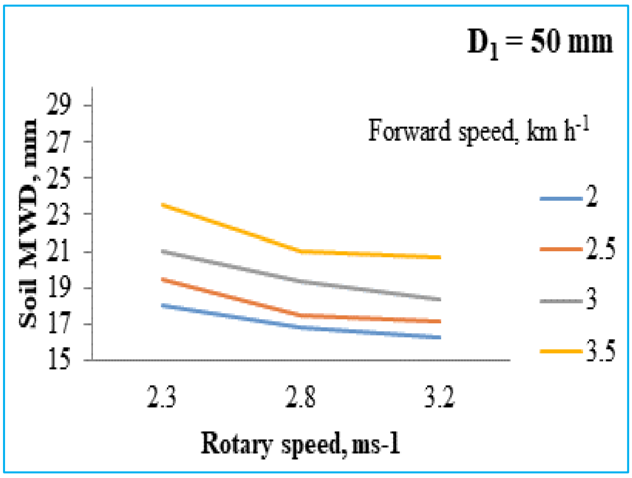

Fig 6 Effect of rotary speed on soil mean weight diameter for vertical axis rotavator

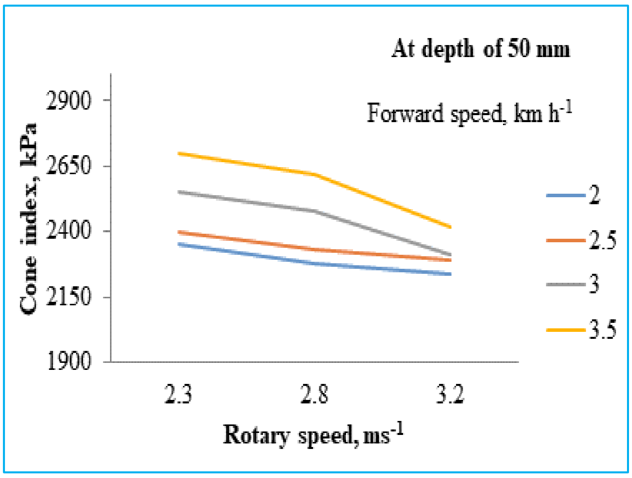

Fig 7 Effect of rotary speed on soil cone index for vertical axis rotavator

2. *Torque measurement*

A total of 432 randomly replicated experiments were conducted using the single row vertical axis rotavator in soil bin with selected levels of variables. The torque requirement was recorded for all the treatments under investigation. In order to confirm the results obtained statistical analysis of the data was performed to assess the significance of the variables viz. forward speed (F), rotary speed (S), depth of operation (D) and rake angle (B) on torque. These findings confirm that the optimal combination of these variables is critical to achieving efficient rotavator performance while minimizing energy consumption [11].

Table 1 ANOVA for vertical axis rotavator on torque requirement

S. No.	SV	df	SS	MS	F	P- value
1.	Forward Speed (F)	3	395.9197	172.9732	3129.70**	0.2675
2.	Error (a)	8	1271.7904	158.9738		
3.	Rotary speed (S)	2	1203.7443	601.8722	13893.07**	0.0000

4.	F × S	6	41.5150	6.9192	159.72**	0.0000
5.	Error (b)	16	0.9352	0.0584		
6.	Depth (D)	2	484.8043	242.4022	4147.24**	0.0000
7.	F × D	6	14.4033	2.4005	41.07**	0.0000
8.	D × S	4	19.3151	4.8288	111.46**	0.0000
9.	F × S × D	12	16.7695	1.3975	32.26**	0.0000
10.	Error (c)	48	2.0794	0.0433		
11.	Rake angle (B)	3	935.9197	311.9732	34119.60**	0.0000
12.	F × B	9	8.8148	0.9794	107.12**	0.0000
13.	D × B	6	56.1872	9.3645	1024.17**	0.0000
14.	S × B	6	5.8811	0.9802	107.20**	0.0000
15.	F × D × B	18	15.8363	0.8798	96.22**	0.0000
16.	F × S × B	18	13.8597	0.7700	84.21**	0.0000
17.	D × S × B	12	4.7623	0.3969	43.40**	0.0000
18.	F × S × D × B	36	37.8664	1.0518	115.04**	0.0000
19.	Error (d)	216	1.9750	0.0091		
	Total	431	4892.4798			

CV (F) = 29.98%, CV (S) = 0.5749%, CV (D) = 0.4950%, CV (B) = 0.2274%
** = significant at 1 % level

3. *Measurement of operational parameter*

The field evaluation of the modified six-row vertical axis rotavator with optimized variables has been conducted. The performance of modified six row vertical axis rotavator is given in the following (Table 2).

Table 2 Field evaluations results of modified six row vertical axis rotavator

S. No.	Particulars	Value
1.	Soil mean weight diameter, mm	17.50
2.	Soil cone index, kPa	2220.70
3.	Operating speed, km h^{-1}	2.00
4.	Theoretical field capacity, ha h^{-1}	0.30
5.	Effective field capacity, ha h^{-1}	0.270
6.	Field efficiency, %	89.00
7.	Wheel slip, %	-2.00
8.	Bite length, cm	5.30
9.	Fuel consumption, l h^{-1}	4.20

The results in (Table 2) reflect the performance and efficiency of the modified six-row vertical axis rotavator in field conditions. The combination of low soil mean weight diameter and cone index indicates effective soil pulverization, while the high field efficiency suggests optimal operational performance [12]. Additionally, the negative wheel slip and reasonable fuel consumption rates highlight the practicality of using this modified rotavator for agricultural tasks, ensuring effective soil preparation and crop establishment [13-14].

CONCLUSION

The study comprehensively evaluated the performance of horizontal and vertical axis rotavators under various operational conditions. Key findings are summarized as follows: A total of 108 replicated experiments conducted in a rectangular soil bin demonstrated that the horizontal axis rotavator exhibited better soil pulverization characteristics compared to the vertical axis rotavator. Both the soil mean weight diameter and cone index were consistently lower for the horizontal axis rotavator, indicating finer soil breakup and reduced soil resistance. In a representative case, with a forward speed of 2.0 km/h, rotary speed of 3.2 m/s, and a depth of operation of 50 mm, the horizontal axis rotavator outperformed the vertical axis rotavator in soil pulverization efficiency. A series of 432 replicated experiments were conducted to analyze the torque requirements for the single-row vertical axis rotavator. Statistical analysis revealed that forward speed (F), rotary speed (S), depth of operation (D), and rake angle (B) significantly influenced the torque requirement. Optimal combinations of these variables resulted in improved rotavator performance while minimizing energy consumption. The interaction effects between these variables, as shown in the ANOVA results, underscore the importance of fine-tuning the operational parameters to achieve efficient and cost-effective operation. Field trials of the modified six-row vertical axis rotavator with optimized variables showed favorable performance metrics. The rotavator achieved a field efficiency of 89%, an effective field capacity of 0.270 ha/h, and low wheel slip of -2%, suggesting excellent traction and minimal soil disturbance. The fuel consumption was recorded at 4.20 l/h, indicating good energy efficiency for the field operations. Overall, the study confirms that while horizontal axis rotavators deliver superior soil pulverization, vertical axis rotavators with optimized variables can achieve high field efficiency and energy savings, making them suitable for specific field conditions. The optimization of forward speed, rotary speed, depth of operation, and rake angle plays a crucial role in enhancing the overall performance of vertical axis rotavators.

Conflicts of interest

The authors declare that they have no conflict of interest.

Data availability

The datasets used and analyzed during the current study are available from the corresponding author on request.

Funding

Funding was provided by Agricultural Machinery Research Centre, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India to carry out this project.

LITERATURE CITED

1. Hendrick JG, Gill WR. 1971. Rotary tiller design parameters: Part I - Direction of rotation. *Transactions of the ASAE* 14(4): 669-674.

2. Jahn BR, Humburg DS. 2002. A tractor-mounted device for measurement of in-situ soil strength properties. *American Society of Agricultural Engineers* 2: 308.
3. Culpin C. 1981. *Farm Machinery*. 10th Edition Granada Technical Books Press, Spain.
4. Destain MF, Houmy K. 1990. Effects of design and kinematic parameters of rotary cultivators on soil structure. *Soil and Tillage Research* 17: 291-301.
5. Yuan Y, Wang J, Zhang X, Zhao S. 2023. Effect of rotary speed on soil and straw throwing process by stubble-crushing blade for strip tillage using DEM-CFD. *Agriculture* 13(4): 877.
6. Chen Y, Cavers C, Tessier S, Monero F, Lobb D. 2005. Short-term tillage effects on soil cone index and plant development in a poorly drained, heavy clay soil. *Soil Tillage Research* 82: 161-171.
7. Jakasania RG, Vadher AL, Kathiria RK. 2017. Performance evaluation of vertical rotary plough. *Journal of Scientific Research and Reports* 13(6): 1-7.
8. Jacobs CO, Harrol WR. 1983. *Agricultural Power and Machinery*. Mc-Graw Hill Press, New York.
9. Maheshwari TK, Singh UV. 2018. Tractor drawn rotavator - A comparative study. *Int. Jr. Curr. Microbiology and Applied Science* 7(4): 2373-2380.
10. Mandal SK, Bhattacharyya B, Mukherjee S, Karmakar S. 2014. Soil-blade interaction of a rotary tiller: Soil bin evaluation. *International Journal of Sustainable Agricultural Research* 1(3): 58-69.
11. Kumar SP, Tewari VK, Chandel AK, Mehta CR, Pareek CM, Chethan CR, Nare B. 2023. Modelling specific energy requirement for a power-operated vertical axis rotor type intra-row weeding tool using artificial neural network. *Applied Sciences* 13(18): 10084.
12. Kasirajan S, Parthipan T, Elamathy S, Kumar GS, Rajavel M, Veeramani P. 2024. Dynamics of soil penetration resistance, moisture depletion pattern and crop productivity determined by mechanized cultivation and lifesaving irrigation in zero till blackgram. *Heliyon* 10(7): e28625. doi: 10.1016/j.heliyon.2024.e28625.
13. Badgujar C, Das S, Figueroa DM, Flippo D. 2023. Application of computational intelligence methods in agricultural soil–machine interaction: A review. *Agriculture* 13(2): 357.
14. Al-Dosary NMN, Alnajjar FM, Aboukarima AEWM. 2023. Estimation of wheel slip in 2WD mode for an agricultural tractor during plowing operation using an artificial neural network. *Sci Reporter* 13(1): 5975.