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PERFORMANCE ASSESSMENT OF ROTAVATOR UNDER VERTISOLS FIELD CONDITIONS IN JABALPUR, MADHYA PRADESH INDIA

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ABSTRACT

The rotavator is a tractor-drawn implement designed for efficient seed bed preparation in one or two passes. It is effective in clearing and blending residues from crops such as maize, wheat, sugarcane, and more. This process contributes to enhancing soil health while simultaneously saving on fuel, costs, time, and energy. This study aimed to evaluate the performance of power operated rotavators on vertisols field conditions. All experiments were carried out in the research field affiliated with the College of Agricultural Engineering, JNKVV Jabalpur (Madhya Pradesh). The performance parameters of the rotavator were evaluated through five replications of dependent variables, namely, a lambda ratio (peripheral speed of rotor/forward speed) 6.33, and a depth of operation 15 cm, conducted on a 30x40 square meter test plot. Following the prescribed methodology outlined in Indian standards, the obtained results were as follows: The theoretical field capacity, calculated at a speed of 2.5 km/h, was 0.45 ha/h. Following a single pass, the recorded actual field capacity was 0.35 ha/h, which increased to 0.36 ha/h after a double pass of the machine. Field efficiency demonstrated a rise from 77.60% for the single pass to 80.44% during the double pass. In terms of fuel consumption, the average was 6.01 l/h for a single pass and 5.51 l/h for a double pass. The rotary power was 260.25 Nm during a single pass on ploughed land, and for a double pass on previously tilled soil, the necessary torque was 216.11 Nm at a u/v ratio of 6.33.

***Keywords* :** Rotavator, Vertisols, Field efficiency, Torque, and Fuel consumption**.**

Introduction

Jabalpur stands as a grassroots institution strategically positioned in Madhya Pradesh situated amidst the Kymore Plateau and Satpura Hills Agro Climatic Zone (Zone-VII) (Kumar *et al.*, 2023a and Kumar *et al.*, 2018b). The district encompasses 1393 villages, covering an expansive geographical area of 5,19,757 hectares (Nahatkar *et al.*, 2021; Kumar *et al.*, 2023a and Kumar *et al.*, 2018a). The climate here provides an ideal environment for the successful cultivation of oilseeds, pulses, cereals, and horticultural crops, with an annual rainfall of 1358 mm (Kumar *et al.*, 2023a and Kumar *et al.*, 2018a). May witnesses the highest temperatures ranging from 40-43°C, while January records the lowest temperatures at 8-10°C.The district predominantly engages in the cultivation of crops such as Paddy, Pigeon pea, Soybean, Maize, and Sesame during the kharif season and Wheat, Gram, Pea, and Mustard during the rabi season. Notably, 28% of the total area is under irrigation, with only 18% being double-cropped in this district (Nahatkar *et al.*, 2021 and Kumar *et al.*, 2023b).

Scientific and technological advancements form the foundation for fostering agricultural development (Sagar and Manish, 2018; Hendrick, and Gill, 1971a; and Kumar *et al.*, 2018b). A key factor contributing to consistent growth is the adoption of mechanized farm equipment, resulting in a steady rise in farmers' yield output (Bashir *et al.*, 2015; Hendrick, and Gill, 1971a; and Du *et al.*, 2021). Efficient mechanization plays a crucial role in enhancing production through two primary mechanisms. The first involves timely operations, while the second focuses on achieving high-quality work. Among the various agricultural operations, tillage stands out as the most critical unit operation. Its primary purpose is to loosen the top layer of soil, facilitate the incorporation of fertilizers, and eliminate weeds. This process enhances the water-air, thermal, and nutrient conditions of the soil, thereby promoting optimal conditions for the growth and development of crops (Hendrick and Gill, 1971a; Hendrick and Gill, 1971b; Du *et al.*, 2021).

Tillage stands out as a crucial operation in agriculture (Anonymous, 2016; Bashir *et al.*, 2015; Sagar and Manish, 2018; Namdev *et al.*, 2019; and Farzaneh *et al.*, 2012). In contemporary times, most of Indian farmers employ tractor-drawn advanced agricultural implements and machinery for various field operations. For primary tillage, implements such as the MB plough, Disc plough, and Rotary ploughs are commonly utilized. In contrast, secondary tillage operations involve the use of implements like offset disc harrow, cultivators, blade harrows, and rotavators (Kepner *et al.*, 1978; Cheng *et al.*, 2021; Bashir *et al.*, 2015; Namdev *et al.*, 2019; Farzaneh *et al.*, 2012).

The initial introduction of the rotavator in the United States dates back to the 1930s by a Swiss manufacturer (Kankal *et al.*, 2016). The rotavator's operation entails the direct utilization of tractor engine power through a specially designed rotor and blades for soil preparation, creating optimal growth conditions for seedlings and seeds (Sagar and Manish, 2018; Du *et al.*, 2021; Kumar and Singh, 2016). In recent times, the rotavator has gained popularity among farmers for land preparation in areas where two or more crops are cultivated within a year. The rotavator can play a significant role in double or multiple cropping systems, especially in situations where there is limited time available for land preparation (Hendrick and Gill, 1971a; and Kepner *et al.*, 1978). The rotavator efficiently creates an ideal seedbed with fewer passes (Anonymous, 2016; Yadav *et al.*, 2017; Du *et al.*, 2021; Bashir *et al.*, 2015; Aman *et al.*, 2020; and Kumar and Singh. 2016). It proves to be the perfect implement for farmers requiring swift burial and incorporation of crop residues between crops. Tillage tools channel energy into the soil to achieve specific effects such as cutting, breaking, inversion, or soil movement (Anonymous, 2016; Kepner *et al.*, 1978; Cheng *et al.*, 2021; Kumar and Singh, 2016; Farzaneh *et al.*, 2012; Hendrick and Gill, 1971b; and Kankal *et al.*, 2016). This process transforms the soil from its initial state to a different condition. The rotavator, a mechanical gardening tool equipped with power blades on a rotating surface, effectively plows the soil, ensuring optimal tillage.

Rotavators are gaining popularity in agricultural settings due to their uncomplicated design and superior efficiency (Aman *et al.*, 2020; Kumar and Singh. 2016; Yadav *et al.*, 2017; Sagar and Manish. 2018; and Kankal *et al.*, 2016). With the use of these rotavators, both primary and secondary tillage operations can be integrated into a single stage. Despite their relatively high energy consumption, rotary tillers exhibit the capability to perform a diverse array of tillage tasks in a singular step, resulting in an overall minimal power requirement for these machines. Rotavator works fine in sandy soil or other light soils as a primary or secondary tillage operation, but in vertisols field conditions, it is difficult to perform the tillage machinery in primary or secondary tillage operation because of the heterogeneous conditions of the soils (Kepner *et al.*, 1978; Kumar *et al.*, 2023a; Kumar *et al.*, 2023b; Kankal *et al.*, 2016; and Du *et al.*, 2021). After analyzing many kinds of literature of reviewers, decided to evaluate the performance of the rotavator under vertisols field conditions at a selected experimental site (Jabalpur).

Material and Methods

Selection of site for experiments

This study was carried out at the research farm of the College of Agricultural Engineering, JNKVV, located in Jabalpur, Madhya Pradesh (Kumar *et al.*, 2023a; and Kumar *et al.*, 2023b). The farm is positioned at approximately 23.90° N latitude and 79.58° E longitude, with an elevation of 411.78 m above mean sea level (Nahatkar *et al.*, 2021; and Kumar *et al.*, 2018b). Jabalpur features a humid subtropical climate typical of north-central India, covering parts of Madhya Pradesh and southern Uttar Pradesh (Kumar *et al.*, 2018a; and Aman *et al.*, 2020). The soil in Jabalpur falls under the vertisol classification according to the US soil classification system (Salokhe and Quang. 1995; Dudal. 1963). It displays a dark black colour, varying from mild to deep (Kumar *et al.*, 2018b; Mandal *et al.*, 2012; Kumar *et al.*, 2023a; Gupta and Sharma. 2015; and Dudal.1963). During the summer months, the clay-rich soil develops extensive cracks due to increased dryness. The soil's performance is suboptimal, regardless of whether conditions are excessively dry or wet. The soil in the test field was identified as vertisols, characterized by a composition of 13.6% sand, 32.8% silt, and 53.6% clay

(Cheng *et al.*, 202; Salokhe and Quang. 1995; Nahatkar *et al.*, 2021; Dudal, 1963; Mandal *et al.*, 2012; and Kumar *et al.*, 2023b).

Soil parameters

Moisture content of the soil

Before performing each test for the treatments, moisture content was measured using both a rapid soil moisture meter and the oven dry method depicted in Plate 1. The moisture meter was calibrated by comparing its readings with the results obtained from the oven drying method, with samples collected from the same measurement spot (Farzaneh *et al.*, 2012; Aman *et al.*, 2020; Bashir *et al.*, 2015; Pal *et al.*, 2016; Kumar *et al.*, 2012; and Kumar *et al.*, 2023a). The moisture content of the soil samples was calculated by using the following Equation 1.

$$Mc(\%)=\frac{m_1-m_2}{m_2}\times 100 \qquad (1)$$

Where;

Mc = Moisture content (%);
m_1 = Mass of soil sample before drying (g); and
m_2 = Mass of soil sample after drying (g).

Plate 1: Methods for measurement of moisture content on actual field condition

Cone index

A soil strength test, specifically measuring the cone index (CI), was carried out to assess soil compactness (Aman *et al.*, 2020; Farzaneh *et al.*, 2012; Pal *et al.*, 2016 and Kumar *et al.*, 2012). This evaluation was performed prior to each operation of the rotavator at five randomly selected locations along the diagonal of the test field plot. A calibrated digital cone penetrometer and analog cone penetrometer were used to measure the cone index at various depths (0, 2.5, 5, 7.5, 10, 12.5, 15, 17.5 and 20 cm) within the soil during these tests shown in Plate 2. The observed value was calculated by use of following Equation 2 (Kumar *et al.*, 2023a; and Kulaya and Singh. 2019).

$$CI = 0.098\frac{F}{A} \qquad (2)$$

Where,

CI = Cone index (kPa);
F = Force measured by cone penetrometer (kgf); and
A = Cone base (cm^2).

Plate 2: Measurement of cone index on field before test

Mean weight diameter of the soil particles

The soil bed's quality for crop sowing is reflected in the finer particle sizes, contributing to the formation of a well-finished soil bed. The particle size of the tilled soil was measured after completing the test. The mean weight diameter (MWD) was determined using a mechanical sieve analyzer. Soil samples were extracted diagonally from all experimental fields at the operating depth and subsequently dried for 24 hours at 105 °C in a hot air oven dryer. A set of sieves on a sieve shaker was arranged in descending order of size (4.75mm, 2.36mm, 1.18mm, 600, 300, 150, 75, and pan). Following this, 800 g of soil from the dried sample was placed in the top sieve, as illustrated in Plate 3. Equation 3 (Kemper and Rosenau, 1986; Aman *et al.*, 2020; Bashir *et al.*, 2015; Kulaya and Singh. 2019 and Farzaneh *et al.*, 2012) was employed to calculate the mean weight diameter (MWD).

$$\mathrm{MWD} = \sum_{i=1}^{n} \overline{X}_{1} W_{i} \qquad (3)$$

Where,

$\overline{X}_i$ = The mean dia. of the sieves at which soil retained on the preceding sieve, mm;

W_i = Fraction of the weight of soil collected from the retained sieve to the total weight of the sample, g.

Plate 3: Measurement of mean weight diameter of soil particles

Bulk density of the soil

The soil's bulk density was determined by calculating the ratio of its mass to volume. The core cutter method, as illustrated in Plate 4, was employed to obtain the soil's bulk density (Bashir *et al.*, 2015; Kulaya and Singh. 2019; Aman *et al.*, 2020 and Kumar *et al.*, 2012). Soil samples were extracted along the length at five different locations within each test strip using the core cutter method. These soil samples from the test field were then subjected to a 24-hour drying period at 105°C in an oven dryer. The bulk density was computed using Equation 4, where the ratio of the weight of oven-dried soil samples to the volume of the core cutter was utilized (Farzaneh *et al.*, 2012; Kulaya and Singh. 2019 and Kumar *et al.*, 2023a).

$$\rho = \frac{M}{V} \qquad (4)$$

Where,

ρ = Bulk density of soil, g/cm^3
M = Mass of soil contained in the core, gm
V = Volume of the core cutter, cm^3.

Plate 4: Measurement of bulk density of the soil

Machine parameters

Theoretical field capacity

The theoretical field capacity of the machine can be defined as the area covered by the machine, as calculated from (Equation 5), under the assumption that the machine operates 100% of the time at its rated forward speed and consistently covers 100% of its rated width (Kumar *et al.*, 2023a; Aman *et al.*, 2020; Bashir *et al.*, 2015; Kepner *et al.*, 1978 and Yadav *et al.*, 2017).

$$\text{Theoretical field capacity}\left(\frac{\text{ha}}{\text{h}}\right)=\frac{W\times S}{10} \qquad (5)$$

Where,

S = Forward speed of operation km/h; and

W = Rated width of implement, m.

Actual field capacity

This represents the effective field capacity, characterized as the true average coverage rate achieved by the machine, derived from Equation 6. The overall time needed to execute the function was assessed, and the effective field capacity was documented accordingly. This measurement encompasses the total time spent on functional operations, incorporating periods lost during field turns, idle travel, operator skill, and other factors (Kumar *et al.*, 2023a; Kepner *et al.*, 1978; Yadav *et al.*, 2017).

$$\text{Actual field capacity}\left(\frac{\text{ha}}{\text{h}}\right)=\frac{A}{T} \qquad (6)$$

Where,

A = Actual field area covered by the machine, ha; and

T = Effective time consumed, h.

Field efficiency

Field efficiency was calculated as the percentage ratio of effective field capacity to theoretical field capacity, as outlined in Equation 7 (Kumar *et al.*, 2023a; and Bashir *et al.*, 2015).

$$\text{Field efficiency}\,(\%)=\frac{\text{Effective field capacity (EFC)}}{\text{Theoretical field capacity (TFC)}} \qquad (7)$$

Fuel consumption

The tank was initially filled with fuel before the test, and the machine operated within a specific area (Aman *et al.*, 2020 and Kumar *et al.*, 2023a). Upon completing the operation, the remaining fuel was measured using the filling method. Fuel consumption was recorded five times and computed as either fuel consumed per unit area (l/ha) or the time taken to cover that area (l/h), as expressed in Equation 8.

$$\text{Fuel consumption}=\frac{\text{Fuel consumed in (ml)}\times 10}{\text{Area covered in }(\text{m}^2)} \qquad (8)$$

Measurement of torque

The torque needed to rotate the rotary spiral blade was gauged using a slip ring torque transducer (Aman *et al.*, 2020; Bashir *et al.*, 2015 and Kumar and Singh. 2016). One side of the transducer was linked to the PTO shaft, while the other was connected to the side of the machine via the universal coupling, as illustrated in Plate 5. The sensor was rotated for one minute to stabilize the reading. Subsequently, the machine was set in motion to interact with the soil, and the readings were observed and recorded by the data logger system.

Plate 5: Measurement of torque with torque sensor

Results and Discussions

This section provides a comprehensive examination of the performance assessment of a power-operated rotavator under vertisols field conditions. The subsequent outcomes and discussions encompass an in-depth analysis of various parameters associated with the rotavator.

Moisture content

Soil moisture levels were assessed at five distinct locations within the test plot using a calibrated digital moisture meter or rapid soil moisture meter. The field's soil moisture ranged between 14% and 16% (dry basis) across various soil depths. Table 1 illustrates the average moisture content recorded at different soil depths, based on observations collected from the test field prior to conducting the test.

Table 1: Moisture content of the soil at different depth of soil

Sr. No.	Depth of sample (cm)	Moisture % (db)
1	5	14.95
2	10	15.62
3	15	15.13
4	20	14.34
Average Mc % (db)		**15.01**

Cone index

A test was conducted to assess soil strength, measured in terms of cone index (CI), utilizing the SC 900 electronic cone penetrometer. Measurements were taken both before and after each pass of the rotavator with observations. Prior to the initial pass, the maximum CI value was determined to be 550±30 KPa. After two passes of the rotavator on the tilled soil bed, the highest cone index value was recorded as 325±30 KPa. Upon completion of all passes of the rotavator, the average CI values for the soil bed at different depths are presented in Table 2 and Figure 1.

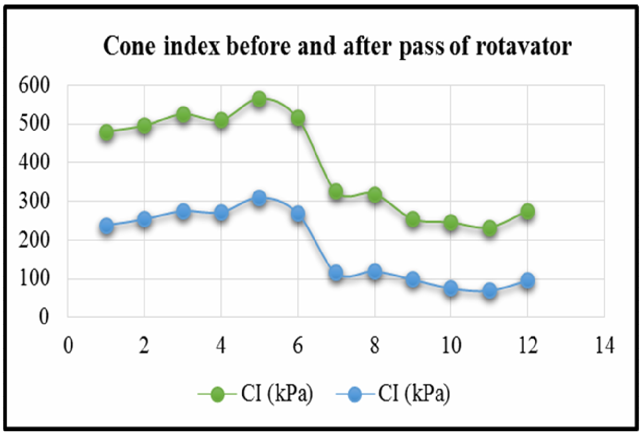

Fig. 1: Cone index of the soil bed before and after passing the rotavator

Soil bulk density

The soil bulk density in the test field was assessed both before and after the machine test, following the procedures outlined in the materials and methods section. The machine underwent five replications in the field, with data collected from five randomly selected locations before and after each pass. The average soil bulk density before the single-pass test was determined to be 1.762 g/cm^3, while before the double pass of the machine, the average value was 1.594 g/cm^3, illustrated in Figure 2. Subsequent to completing both the single and double passes of the rotavator, the average soil bulk densities for the soil bed were measured at 1.564 g/cm^3 and 1.176 g/cm^3, respectively shown in Table 2.

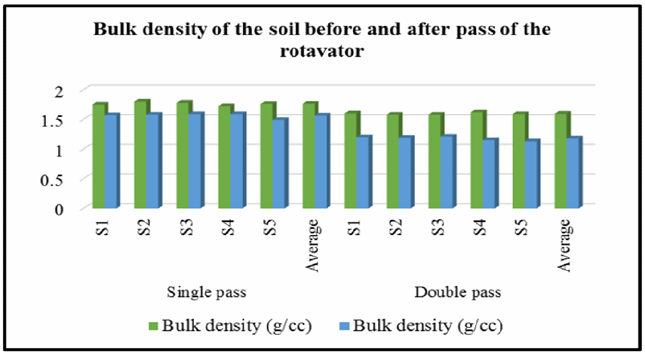

Fig. 2: Results of bulk density of the soil before and after pass the rotavator

Mean weight diameter of the soil

To calculate the mean weight diameter (MWD) the Equation (3) was used (Kemper and Rosenau, 1986). The soil sample was collected from the test field after operating the rotavator and soil MWD was determined. The average mean weight diameter of the bed soil after passing single or double pass by the rotavator was found 8.42 mm, and 4.48 mm shown in table 2.

Table 2: Results of the changes in soil properties during field test of rotavator

Pass	Replications	CI (kPa)		Bulk density (g/cc)		MWD (mm)
		Before	After	Before	After	
Single pass	S1	480	237	1.75	1.57	8.5
	S2	495	254	1.8	1.58	7.9
	S3	525	275	1.78	1.59	8.3
	S4	510	272	1.72	1.59	8.5
	S5	565	310	1.76	1.49	8.9
	Average	**515**	**269.6**	**1.762**	**1.564**	**8.42**
Double pass	S1	325	115	1.6	1.2	5.5
	S2	319	119	1.58	1.19	4.3
	S3	254	98	1.58	1.21	4.5
	S4	245	75	1.62	1.15	3.9
	S5	232	69	1.59	1.13	4.2
	Average	**275**	**95.2**	**1.594**	**1.176**	**4.48**

Theoretical field capacity (ha/h)

The effective working width of the machine determined either during its single or double pass, measured 180 cm. The computed theoretical field capacity, at a forward speed of 2.5 km/h, was established as 0.45 ha/h, as depicted in Table 3.

Actual/effective field capacity (ha/h)

Referencing Table 3, the average field capacity of the rotavator during test was noted at a forward speed of 2.5 km/h and a depth of operation 15 cm. Following the single pass of the rotavator, the observed average actual field capacity was 0.35 ha/h, and after the double pass of the machine, the actual field capacity increased to 0.36 ha/h.

Field efficiency (%)

After conducting the treatment five times and obtaining the averages, the field efficiency of the rotavator was determined. The calculated field efficiency was 77.60% for the single pass and increased to 80.44% during the double pass, all under vertisols field conditions shown in Table 3.

Fuel consumption (l/h)

The fuel consumption of a 55 hp tractor, measured in litters per hour (l/h), was recorded under various test conditions. The average fuel consumption for the machine was determined using a fuel measurement method. After conducting five replications with selected variables of 15 cm depth of operation and 6.33 lambda ratio, the average fuel consumption during a single pass and double pass of the machine was observed to be 6.01 l/h and 5.51 l/h, respectively (as shown in Table 3).

Torque (Nm)

To maintain a consistent u/v (lambda) ratio across different forward speeds, the power needed to operate the rotary blade of the machine was measured using a torque sensor during its operation. The average calculated rotary power, as shown in table 3, was found to be 260.25 Nm during the single pass on ploughed land. When operating as a double pass on previously tilled soil using the rotavator, the required torque was 216.11 Nm at a u/v ratio of 6.33.

Table 3: Results of machine parameters during field test

Pass	Replications	Field capacity		Field efficiency (%)	Fuel consumption (l/h)	Torque (Nm)
		Theoretical	Actual			
Single pass	S1	0.45	0.36	80.67	5.8	258.5
	S2	0.45	0.34	76.00	6.3	256.25
	S3	0.45	0.35	78.00	6.2	265
	S4	0.45	0.34	75.56	5.9	263.3
	S5	0.45	0.35	77.78	5.85	258.24
	Average	**0.45**	**0.35**	**77.60**	**6.01**	**260.25**
Double pass	S1	0.45	0.37	82.89	5.34	215.25
	S2	0.45	0.36	80.44	5.54	210.4
	S3	0.45	0.35	78.00	5.6	218.5
	S4	0.45	0.36	80.67	5.65	221.5
	S5	0.45	0.36	80.22	5.45	214.9
	Average	**0.45**	**0.36**	**80.44**	**5.51**	**216.11**

Conclusion

The calculated theoretical field capacity at 2.5 km/h was 0.45 ha/h. After a single pass, the observed actual field capacity was 0.35 ha/h, increasing to 0.36 ha/h after a double pass. The field efficiency was 77.60% for the single pass and rose to 80.44% during the double pass. Fuel consumption during five replications with selected variables resulted in an average of 6.01 l/h for a single pass and 5.51 l/h for a double pass. The calculated rotary power was 260.25 Nm during a single pass on ploughed land, and for a double pass on previously tilled soil, the required torque was 216.11 Nm at a u/v ratio of 6.33.

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References

Aman, J.R., Shambhu, S. and Suryakant, S. (2020). Performance evaluation of tractor drawn rotavator for dry and wet land preparation. *Journal of Pharmacognosy and Phytochemistry,* **9**(6), 529-531.

Anonymous (2016). Tillage.www.agritech.tnau.ac.in/ agriculture/ agri_tillage_types_of_ tillage. html.

Bashir, M.A., Dawelbeit, M.I., Eltom, M.O. and Tanakamaru, H. (2015). Performance of different tillage implements and their effects on sorghum and maize grown in Gezira vertisols, Sudan. *International Journal of Scientific and Technology Research*, **4**(4), 237-242.

Cheng, J., Kan, Z., Junfang, X., Guoyang, L., Liu, J. and Dong, L. (2021). Analysis of adhesion between wet clay soil and rotary tillage part in paddy field based on discrete element method. *Processes,* **9**(845),1-16.

Du, J., Yifan, H., Kan, Z., Wenliang, Z., Jumin, Z. and Junfang, X. (2021). Evaluation of the performance of a combined tillage implement with plough and rotary tiller by experiment and DEM simulation. *Processes,* **9**(1174),1-13.

Dudal, R. (1963). Dark clay soils of tropical and sub-tropical regions. *Soil Science* **4**(95), 264-270.

Farzaneh, B., Morteza, A., Morteza, S. and Saeid, M. (2012). Assessment of soil compaction bulk density indices and cone index in different moistures and depths for application in precise tillage. *World Applied Sciences Journal*, **20**(12),1704-1712.

Gupta, C. and Sharma, R.K. (2015). Study of black cotton soil and local clay soil for sub-grade characteristic. 50th Indian Geotechnical Conference 1-10.

Hendrick, J.G. and Gill, W.R. (1971a). Rotary – Tiller design parameters – Direction of rotation. Transactions of ASAE. 669-674.

Hendrick, J.G. and Gill, W.R. (1971b). Rotary – Tiller Design parameters – Depth of Tillage. Transactions of ASAE. 675-683.

Kankal, U.S., Karale, D.S., Thakare, S.H. and Khamballkar, V.P. (2016). Performance evaluation of tractor operated rotavator in dry land and wet land field condition. *International Journal of Agricultural Science and Research,* **6**(1),137-146.

Kemper, W.D. and Rosenau, R.C. (1986). Aggregate stability and size distribution. Snake River Conservation Research Center Agricultural Research Service, USDA Kimberly, *Idaho,* **17**(1),425-442.

Kepner, R.A., Bainer, R. and Barger, E.L. (1978). Book chapter, soil tillage and dynamics. *Principles of Farm Machinery,* **3**, 112-135.

Kulaya, P.W. and Singh, M.U. (2019). Interaction effect of operating parameters of rotary tiller blade on tillage quality under soil bin condition. *International Research Journal of Engineering and Technology,* **6**(4),3680-3684.

Kumar, A., Patel, A., Shrivastava, A.K., Pandey, M.K. and Khandelwal, N.K. (2018a). Change in Scenario of Sugarcane Production in Narsinghpur, India, during 2013 to 2016. *Current Journal of Applied Science and Technology,* **28**(6),1-12.

Kumar, A., Shrivastav, A.K. and Patel, A. (2018b). Energy analysis for cultivation of sugarcane, a case study in Narsinghpur (M.P.), India. *Current Journal of Applied Science and Technology,* **28**(2),1-10.

Kumar, A., Shrivastava, A.K., Nandini, Y. and Namdeo, R. (2023a). Performance evaluation of trailed type disc harrow on vertisols field condition. *International Journal of Statistics and Applied Mathematics*, **8**(6), 329-333.

Kumar, A., Shrivastava, A.K., Nandini, Y. and Namdeo, R. (2023b). Development of profile meter for measuring displacement and disturbance of soil by ridger. *Biological Forum – An International Journal,* **15**(10),706-710.

Kumar, S. and Singh, T.P. (2016). Assessment of power energy and torque of powered disc through soilbin study. *Journal of Agricultural Engineering,* **53**(3),1-9.

Kumar, A., Chen, Y., Sadek, A. and Rahman, S. (2012). Soil cone index in relation to soil texture, moisture content, and bulk density for no-tillage and conventional tillage. *Agricultural Engineering International CIGR Journal,* **14**(1),1-16.

Mandal, C., Mandal, D.K., Prasad, J., Sarkar, D., Chandran, P., Tiwary, P., Patil, N.G., Obi Reddy, G.P., Lokhande, M.A., Wadhai, K.N., Dongare, V.T., Sidhu, G.S., Sahoo, A.K., Nair, K.M., Singh, R.S., Pal, D.K., Ray, S.K. and Bhattacharyya, T. (2012). Revision of black soil map of India for sustainable crop production. KSRSAC Charting Karnataka's Future-Through Geospatial Governance 43-55.

Nahatkar, S.B., Pahalwan, D., Vani, G.K., Sharma, H.O., Rathi, D. and Khare, D. (2021). Agriculture atlas of the State of Madhya Pradesh. Publication office of the Dean Faculty of Agriculture, JNKVV, Jabalpur 19-96.

Namdev, S.K., Pateriya, R. and Manikrao, J. (2019). Comparative performance evaluation of various intercultural implements for their adoptability and suitability to farmers. *Pantnagar Journal of Research*, **17**(3), 242-245.

Pal, R., Chaudhary, S., Mishra, R., Bhatia, S. and Bist, A.S. (2016). Performance evaluation of rotavator based on different soil moisture content. *International Journal of Engineering Sciences and Research Technology,* **5**(8),808-816.

Sagar, G.K. and Manish, R.D. (2018). Effect of rotavator based tillage systems on soil physical properties in vertisols of centralindia. *Multilogic in Science,* **7**, 218-223.

Salokhe, V.M. and Quang, N.B. (1995). Dynamics of a powered disk in clay soil. *Journal of Terramechanics*, **32**(5),231-244.

Yadav, R.K., Singh, P. and Singh, S.K. (2017). Performance analysis of rotavator and other tillage implement driven by the tractor. *International Journal of Agricultural Engineering,* **10**(2),590-594.