Comparative performance of rotavators with varying length in combine harvested rice field and assessing the matching power source

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ABSTRACT : Rotavators are becoming popular for tillage operation both in dry and wet land conditions mainly due to better quality work and less time requirement. However, selection of an appropriate size of rotavator for a given power source is difficult due to lack of data. In this study performance of four rotavators with different rotor lengths was evaluated in combine harvested rice field for seedbed preparation. Based on the result obtained, rotavator C and D performed better than other two rotavators, however, size of rotavator D with 195 cm rotor length was found appropriate for 37.3 kW tractor used in the experiment on the basis of specific work. The power consumption for these rotavators was found as 27.34 and 29.17 kW/meter rotor length respectively. The specific fuel consumption and specific tillage energy for these rotavators were found as 9.72, 9.82 l/m3 and 132.75, 96.24 MJ/m3 respectively. Both the rotavators saved 51.94 and 65.16 percent of energy over the smallest size (rotor length 1150 mm) of rotavator. On the basis of specific work and performable work of tractor, a matching tractor size of 29, 34, 44 and 50 hp was predicted for rotavators A, B, C and D respectively.

Key words: Fuel power, performance index, rotavator size, specific energy, specific fuel consumption, specific work, tillage

Rice-wheat are the two major crops of Indo-Gangetic Plains covering around 10 million hectare area and contributing about 40% of the country's total food grain production. During 2014-15, these two crops together contributed more than 76% to the total food grain production of the country (Anonymous 2016). Seedbed preparation, referred as tillage, is one of the important operations which consume more time and energy. It is greatly influenced by the parameters like type of soil, moisture content, type of previous crop grown, amount of crop residue present in the field etc. Preparing seedbed for wheat crop in combine harvested rice field with large amount of residue is a bigger problem. Because of less turn-a-round time available between rice harvest and wheat sowing, it is a great challenge for the farmers to complete this operation timely. Disc harrow is one of the popular tillage implement that is being used since long by majority of the farmers for seedbed preparation in such condition with medium to heavy textured soil. The number of passes depends on various parameters mentioned above. This passive implement, due to its inherent characteristics, requires more time and energy resulting into both higher cost of tillage and crop production.

Horizontal axis down-cut rotavators, over the recent years, are becoming quite popular due to its promotion by Indian government through subsidy schemes under sub-mission on agriculture mechanization. Goyle (2013) reported the sale of 103775 rotavators in the year 2013 as against 60,000 during 2006 recording a growth of 72.96% in its sale during these seven years. These rotavators have been reported to produce smaller clod size, better residue incorporation ability, energy efficient and cost effective tool for seedbed preparation (Singh *et al.* 2006; Prasad 1996) as compared to disc harrow and other passive tillage tools. It also produces acceptable tilth quality in fewer passes (Destan and Houmy 1990) and hence number of tractor passes reduces significantly leading to lesser wear and tear of tractor. Makange and Tiwari (2015) reported better economy, lower fuel consumption and less energy requirement for horizontal axis rotavators. The optimum tilling depth and operating speed were found as 10 cm and 2.71 km/h. A large number of manufacturers are selling rotavators of various sizes to the users, however, data on its appropriate size to match a particular size of tractor is lacking for the soils of *Tarai* region of Uttarakhand. Keeping this point in consideration, the work of evaluating four different sizes of rotavators and assessment of their matching size of power source was undertaken.

MATERIALS AND METHODS

The experiment was conducted at university farm of Pantnagar in combine harvested rice field having average of 31hills/m^2. The average number of tillers per hill was observed 12 where as the mean plant population was found to be 372 plants/m^2. The height of anchored rice residue present in the field ranged from 32.4 to 39.4 cm with mean value of 36.19 cm. The total residue load left after combine harvesting, at mentioned height of cut, ranged from 5.80 to 6.40 t/ha with an average of 6.03 t/ha. The soil of the experimental field is silty-clay-loam. Four common sizes of horizontal axis down-cut rotavators viz. A, B, C and D (rotor lengths 1150, 1480, 1720 and 1950 mm and rotor radius 19.50, 19.50, 20.50 and 18.75 cm respectively) with L-type blades and weighing 394, 416, 445 and 448 kg respectively were selected for the study. Soil moisture content and bulk density was determined before commencing the experiment. After the completion of tillage operation soil aggregate size, residue incorporation and fuel consumption was determined by standard procedure as prescribed in RNAM (1995).

The experiment was planned in Completely Randomized Design (CRD) with three replications each having total twelve experimental plots of size 60 m x 10 m. Rotavators were operated twice (two operations) for preparing seedbed by using same tractor [50 hp (37.29 kW) maintaining same forward gear and throttle position to minimize the experimental error. Fuel power and tillage performance index (TPI) was determined in terms of quantity (volume of soil handled) and quality (degree of pulverization) by the following equation (Padhee *et al.,* 2012).

Fuel power=Fuel consumption, l/h × calorific value, MJ/l (1)
T.P.I. = (Quantity × Quality) ÷ Power requirement (2)

Energy consumption in tillage operation i.e. human, machine and fuel energy was determined using energy equivalences for these energy sources. The energy equivalents for human and fuel was considered as 1.96 MJ/h and 56.31 MJ/l where as for machinery it was taken as 13.06 MJ/h (Ozkan *et al.,* 2004). The following equations were used to determine human, machinery and fuel energy as suggested by Singh *et al*., 2006.

Human Energy (MJ/ha) = Number of labor × energy coefficient × time (h) (3)
Machinery Energy (MJ/ha)=[wt (kg)×coefficient×time (h)] ÷ [life(y) × annual use (h)] (4)
Fuel energy (MJ/ha) = Fuel consumption, l/ha × coefficient ×time (h) (5)

Specific work of rotavators (A) and maximum performable work by tractor (Ac) was also determined to assess the matching size of rotavator with the tractor used for experiment. The following equations as suggested by Bernacki *et al*., 1972 were used to determine these parameters.

Specific work (A) = $A_0 + A_B$ (6)
$A_0 = 0.1\ C_0K_0$ (7)
$A_B = 0.001\ a_v\ v^2$ (8)
$Ac = 7.5\ N_c\ \eta_c\ \eta_z/vab$ (9)
$a_v = a_u\lambda^2$ (10)

Where,
A_0 and A_B - Static and dynamic specific work of rotavators, Kg-m/dm^3
C_0 - Coefficient based on soil type, adopted 2.5 for light textured soil
K_0 - Specific soil strength, adopted 40 kg/dm^3 for light textured soil
a_v and a_u - Dynamic coefficients, adopting a_u as 400 kg.s^2/m^4
v - Forward speed of operation, m/s
u - Tangential velocity of rotavator blade, m/s
λ - Ratio of peripheral velocity to forward velocity of tractor
Nc - Tractor power, hp
η_c - Traction efficiency, adopted as 0.9 for rotavators in forward rotation
η_z - Coefficient of tractor power reservation, adopted as 0.8
a - Depth of operation of rotavator, dm
b - Actual width of rotavator, dm

RESULTS AND DISCUSSION

Soil moisture and bulk density

Soil moisture content was determined before and after tillage operation and is presented in Table 1. The data indicated initial soil moisture content in the range of 24.7 to 25.8% which finally reduced between 15.1 to 17.3%. This is due to the reason that between first and second operation of the rotavators, two days gap was provided for soil moisture depletion to obtain better pulverization effect as the same is greatly affected by soil moisture content. However, no definite trend could be established for final soil moisture content with respect to size of rotavator. Table 1 also showed initial mean value of bulk density as 1.38 g/cc that finally reduced in the range of 1.13 to1.14 g/cc after tilling the soil twice by the rotavators. Data revealed that the rotavators C and D performed better in comparison to rotavators A and B resulting into lower values of bulk density.

Aggregate size and residue incorporation

The results of clod size are presented in Table 1 which revealed minimum clod mean-weight-diameter (CMWD) of 14.9 mm for rotavator A followed by 15.8, 16.7 and 17.2 mm for rotavators D, C and B respectively. The result showed that in all the four rotavators, the clod size obtained after two operations is quite close to the acceptable range of 16 mm for wheat sowing (Singh *et al.,* 2006). The degree of pulverization showed a higher value for rotavator C and D indicating better aggregate size reduction compared to rotavator A and B. This could be due to better cutting and pulverizing action of rotavator C and D in comparison to other two rotavators. However, clod size was found to vary significantly from each other at 5% level of significance.

Table 1 also revealed maximum residue incorporation of 87.56% for rotavator A followed by 87.40, 86.40 and 85.74% for rotavators D, B and C respectively. Probably due to smaller bite length, as evident from smaller CMWD, the rotavator A and D was able to cut, slice and mix the residue in a better manner as compared to other rotavators resulting into higher residue incorporation. The percentage residue incorporation in all the treatments was found to vary significantly from each other at 5% significance level.

Machine operating parameters

Table 2 represents machine parameters results determined during field test. The actual speed of operation ranged between 1.15 to 1.21 m/s with standard deviation of 0.026 for all the rotavators. The tractor's throttle position was kept at fixed position, for all the rotavators, to minimize the experimental variations. However, minor variation in speed of operation could be due to variation in field condition and load on the tractor. Depth of operation was observed between 77 to 82.5 mm with a standard deviation of 2.4 mm. The observed value was found to vary significantly from each other ($p<0.05$) and closer to the desired depth of tilling of 100 mm. The “L” type rotavator blades have been reported more suitable for shallow tilling (Butterworth 1972). Also shallow tilling depth (depth<rotor radius) has been reported to consume 10 to15% less energy in forward rotation (Matyashin 1968).

The volume of soil worked by each rotavators showed least for rotavator A as 358.6 m^3/h. The same was observed 15.95, 51.70 and 81.76 % higher for rotavators B, C and D respectively. The volume of soil worked was observed to vary significantly for each rotavator. This was due to higher field capacities of these rotavators with almost similar tilling depths. Similarly, tillage performance index (TPI) was also observed significantly higher for larger size of rotavator A and vice-versa.

Table 1: Soil parameters and residue incorporation

Rotavator	Bulk density, g/cc		Soil MC, %		Mean mass diameter, mm	Degree of pulverization, decimal	Rice residue incorporated, %
	Initial	Final	Initial	Final			
A	1.37	1.14	25.3	17.3	14.9a	0.17^{a}	87.56^{a}
B	1.38	1.14	25.8	15.1	17.2b	0.23^{b}	86.40^{b}
C	1.38	1.13	25.1	15.8	16.7c	0.50^{c}	85.74^{c}
D	1.37	1.13	24.7	16.4	15.8d	0.56^{d}	87.40^{d}

Letters a, b, c, d show significance, same letters indicates non-significant at 5%

Table 2: Mean values of machine parameters for various rotavators

Rotavator	Forward travel speed, m/s	Effective tilling depth, mm	Volume of soil worked, m^3/h	Tillage perform ance index	Actual field capacity, ha/h	Field efficiency %	Time required in tillage, h/ha	Fuel consump tion, l/h	Fuel power, MJ/h	Power consumed, kW/m rotor length
A	1.21	81.5^{a}	358.6^{a}	0.301	0.44	83.91	4.53^{a}	5.63^{a}	180.2	43.52
B	1.15	77.0^{b}	415.8^{b}	0.457	0.54	83.92	3.71^{b}	5.82^{b}	186.2	34.95
C	1.18	80.0^{c}	544.0^{c}	1.602	0.68	86.51	2.96^{c}	5.29^{c}	169.3	27.34
D	1.20	82.5^{d}	651.8^{d}	1.417	0.79	86.92	2.52^{d}	6.40^{d}	204.8	29.17

Field capacity and field efficiency

Field capacity was determined which was observed minimum as 0.44 ha/h for rotavator A and maximum as 0.79 ha/h for rotavator D (Table 2). In general, the field capacity was found to increase with increase in rotavator size. This is due to the fact that area coverage has positive correlation with size of implements. Similarly the field efficiency was also found higher for larger size of rotavators C and D compared to rotavators A and B. This was due to large size of rectangular field selected for experiment leading to minimum turning time losses. Table 2 also indicated total time required for seedbed preparation which was found minimum (2.52 h/ha) for rotavator D where as it was maximum (4.53 h/ha) for rotavator A having smallest rotor size. The time requirement varied significantly ($p<0.05$) for each rotavator which was due to variation in field capacities with the size of rotavators.

Fuel consumption

Fuel consumed by tractor after tilling operation by each rotavators was measured which showed minimum consumption of 5.29 l/h for rotavator C and maximum 6.40 l/h for rotavator D having largest rotor size (Table 2). In general, the fuel consumption increased significantly with the increase in size of rotavators which is due to increased volume of soil being worked per unit time. However, minimum fuel consumption for rotavator C could be due to better match with the tractor being used to operate it. Fig. 1 revealed fuel requirement on area basis which again was observed higher for rotavator A and lower for rotavator C. Rotavator D consumed marginally higher (3.40%) fuel where as rotavators A and B required significantly higher, 38.53 and 63.08%, fuel respectively in comparison to rotavator C. Polynomial relationship of second order was found between the total fuel consumption and size of rotavators (R^2 = 0.942). Similar trend (R^2 = 0.911) was also observed between rotavator size and specific fuel consumption (SFC). The lowest SFC was observed for rotavator C followed by rotavators D, B and A respectively. The specific fuel consumption for rotavator D was observed 1.03% higher than rotavator C. The reason for lower SFC for rotavator C and D could be explained due to lower fuel consumption, higher volume of soil tilled and better match with power source in comparison to rotavators A and B. Raheman and Sahu (2006) also reported that for a given tractor power and ratio of tangential velocity of blade to forward speed (u/v ratio), the peripheral force available decreased with increase in forward velocity of the machine. This also might be one of the reasons of lesser SFC for rotavator C and D.

Result of fuel power consumption (Table 2) indicated minimum power consumption of 169.3 MJ/h for rotavator C. Rotavators A, B and D consumed 6.44, 9.98 and 20.97% higher fuel power in comparison to rotavator C. This is due to higher fuel consumption per unit time by these rotavators in relation to rotavator C. The power consumption per meter rotor length showed minimum for rotavator C followed by rotavators D, B and A respectively. On the basis of SFC, the power requirement per inch rotor length was determined which ranged from 0.93 to 1.48 hp (0.68 to1.09 kW), minimum being for rotavator C. Rotavator A, B and D consumed 59.18, 27.86 and 6.71% higher power as compared to Rotavator C. Polynomial relationship of second order (R^2 = 0.978) was observed between rotavator size and power consumption per unit length of rotor. The value obtained for all the rotavators, except A, was observed well within the power requirement of 0.83-1.25 hp/inch as reported by Smith and Wilkes (1988).

Energy analysis

Tillage energy analysis for seedbed preparation was determined for all the rotavators (Table 3) which indicated minimum tillage energy consumption of 62.73 GJ/ha for rotavator D followed by rotavators C, B and A respectively. The specific energy requirement was also observed minimum (96.24 MJ/m^3) for rotavator D. Rotavators C, B and A required 37.94, 112.89 and 186.99% higher tillage energy which was found significant ($p<0.05$) in comparison to rotavator D. This indicated rotavator D as most energy efficient rotavator size among all other rotavators included for the study. This may be due to less time and fuel requirement in tilling the soil. Furlong (1956) and Hendrick and Gill (1971) also reported that for shallow tillage depths (depth < rotor radius), an increase in the depth

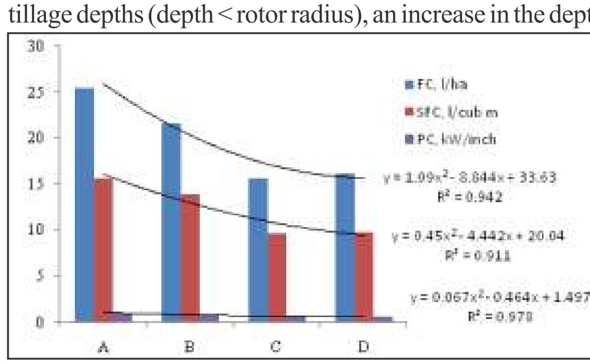

Fig.1: Fuel and power consumption for various sizes of rotavators

Table 3: Total tillage input energy for various sizes of rotavators

Rotavator	Human energy tillage, MJ/ha	*Machine energy, GJ/ha	Fuel energy, MJ/ha	Total tillage energy, GJ/ha	Specific tillage energy requirement, MJ/m^3	Energy saving over rotavator A, %
A	8.88	97.60	1432.53	99.05	276.20[a]	-
B	7.27	83.97	1216.86	85.19	204.89[b]	25.82
C	5.80	71.33	878.44	72.22	132.75[c]	51.94
D	4.94	61.81	908.28	62.73	96.24[d]	65.16

* Tractor energy neglected being common for all

Table 4: Specific work of rotavators and performable work of tractor

Rotavator	Linear speed of rotor, m/s	λ-ratio	$a_v = a_u \lambda^2$	A_B	Ao	A	Ac	Ac-A	Predicted size of power source, hp
A	3.68	3.04	3691.14	4.466	10	14.47	25.35	10.88	29
B	3.68	3.20	4086.35	4.699	10	14.70	21.94	7.24	34
C	3.86	3.27	4289.49	5.062	10	15.06	17.23	2.17	44
D	3.53	2.95	3469.78	4.164	10	14.16	14.43	0.27	50

of operation of a rotary cultivator increased the power requirement but decreased the specific power requirement when other operating conditions were constant. This could probably be the reason that rotavator D showed lowest specific energy requirement as compared to other rotavators. The energy saving in rotavating by rotavators B, C and D over rotavator A was found as 25.82, 51.94 and 65.16% respectively.

Table 4 indicates the *specific work* performed by the rotavators and maximum *performable work* by the tractor. The same was determined for assessing the matching power source for these rotavators. The λ-ratio for all the rotavators was observed in the range of 2.95 - 3.27 at an average rotor speed of 180 rpm. The specific work performed by the rotavators was observed little higher for rotavator C as compared to other rotavators. Similarly, in light of the observed operating parameters, the performable work by the tractor was found lower for larger size of rotavator D and the same increased with decrease in rotavator size. This is because the tractor power is inversely proportional to size of rotavator. The difference between maximum performable work of tractor and specific work performed by the rotavator is least for rotavator D and maximum for rotavator A. This indicates that rotavator D is comparatively a better match for 50 hp tractor being used for the experiment. Predicted size of power (Table 4) indicated that rotavator A, B and C would require 29, 34 and 44 hp tractor respectively in place of 50 hp tractor used in experiment, thus would save 42, 32 and 12% of power. Modification in category of hitch would also be required for these rotavators depending upon the predicated size of tractor.

CONCLUSIONS

Based on the result obtained, it is concluded that rotavator C and D (rotor length 172 and 195 cm) were found to perform better in comparison to other two sizes of the rotavators in terms of higher field capacity, field efficiency and lesser time required in tilling the field. Rotavator C was found superior to rotavator D in terms of higher tillage performance index, lower fuel power, power consumption per unit length and also lower SFC. However, in terms of specific tillage energy rotavator D required less energy and saved energy higher (13.22%) than rotavator C. Based on specific work and performable work of tractor, rotavator D was found a better match for 50 hp tractor used for the experiment. In similar field and operating conditions, matching power source for rotavator A, B and C was predicted as 29, 34 and 44 hp (21.63, 25.35 and 32.81 kW) respectively.

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Received: January 26, 2017
Accepted: March 30, 2017