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Effect of Operational Parameter on the Bulk Density of the Rotary Blades (L and J- Shape Blade)

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ABSTRACT: A research investigation aimed to determine the optimal combination of commercially available L and J-shaped rotary blades concerning blade speed (75, 100, and 125 rpm), operating depth (3, 6, 9 cm), and forward motion speed (1, 1.5, 2 km/h) in vertisol soil. Following the rotary blades' pass, the various treatment combinations were assessed. It is so difficult to find out the soil parameters in laboratory condition, due to the factor affect on the blades while in operational condition. All the tests were carried out as per the Indian standard and after following the correct methodology to obtained the findings. Results indicated that J-shaped blades resulted in lower bulk density compared to L-shaped blades at a rotary speed of 110 rpm, forward speed of 1.5 km/h, and an operating depth of 8.25 cm for the J-shaped blade. The predicted mean bulk density for J-shaped blades was 1.441 g/cm³. In contrast, L-shaped blades exhibited higher bulk density than J-shaped blades. Overall, the J-shaped blade proved more effective for pulverization operations compared to the L-shaped blades.

Keywords: L shape blade, J shape blade, Rotary rpm, Forward speed, Bulk density.

INTRODUCTION

Weeding operations play a crucial role in intercultural tillage, serving to control unwanted plants between rows that tend to deplete fertilizers and diminish crop yields. Weed management poses a significant challenge for farmers, particularly during the early stages of field crops, where timely intervention is essential to prevent losses in crop growth. In India, traditional hand tools have conventionally been employed for this task, with single-hand weeding demanding labor inputs ranging from 300 to 1200 man-hours per hectare.

Manual weeding, conducted in an upright bending posture using traditional hand tools such as the Khurpi, is labor-intensive, time-consuming, and often financially burdensome. The inefficiency of hand weeding becomes evident as it often results in incomplete uprooting of weeds, leaving the root portions intact, leading to weed regrowth shortly after the operation (Rangasamy *et al*., 1993). Studies indicate that weed-related yield reductions can range from 30% to 60%, depending on the crop and location, with losses due to weeds constituting a significant portion of cultivation expenses. In India, an annual expenditure of about 4.2 billion rupees is allocated for weed control in major crop production. Farmers and researchers are collaboratively addressing this weed removal challenge, recognizing the need for effective mechanical weeders to enhance productivity and alleviate poverty (De *et al.,* 1974).

In the current scenario, the traditional use of bullock-operated hoes for weeding is becoming less feasible due to the decreasing bullock population. Manual labor, which is time-consuming and labor-intensive, remains the primary method for weeding. To address these challenges, the development of self-propelled and autonomously operated weeders emerges as a viable solution, offering medium cost, small size, and improved maneuverability, particularly in smaller land holdings. While various aspects of agriculture in India are partially mechanized, the intercultivation operation for field crops remains largely manual due to the absence of suitable weeders. Recognizing the need for autonomous weeders, this paper explores the optimization of L and J-shaped rotary blades in an indoor soil bin filled with vertisol (Chen *et al.,* 1993). The goal is to enhance the performance of the developed remote-operated weeder, especially in heavy soil conditions, and provide a mechanized solution to the challenges associated with manual weeding.

MATERIAL AND METHODS

To optimize the kinematic parameters of the L-shaped soil cutting blade, the responses chosen was Bulk density. After tilling the soil, these performance parameters were measured at three levels of forward speeds of operation (1, 1.5, 2 km/h), three levels of rotational speeds of the blades (75, 100, 125 rpm), and three levels of depths (3, 6, 9 cm) under controlled soil bin conditions at the Department of Farm Machinery and Power Engineering, College of Agricultural Engineering, JNKVV, Jabalpur. The soil bin was filled with black cotton soil (Vertisol), and the Cone Index (600±30 KPa) and soil moisture content (14-16%) were kept constant for all experimental runs. The Box Behnken Design (BBD) in Response Surface Methodology (RSM) was employed to optimize the effects of forward speed of operation (km/h), blade speed (rpm), and depth of operation (cm) on dependent variables such as MWD and bulk density under indoor soil bin conditions. Both L and J-shaped blades had 2 flanges on the rotor, with 6 blades mounted on each flange. Details of the different blades used are provided in plate 1 and figure 1. Soil samples were collected after the passage of the test trolley with rotary blades to measure bulk density (Sakai, 1978).

Plate 1. L and J-shaped rotary blade during test under soil bin

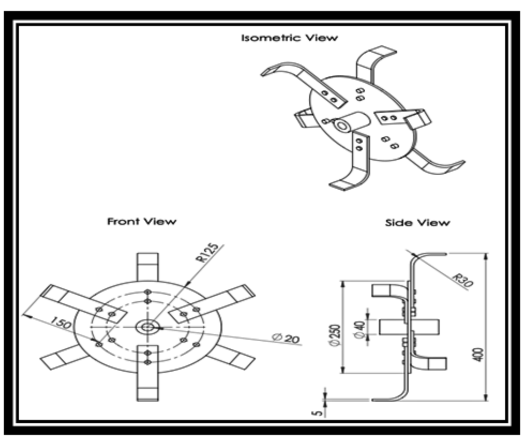

Fig. 1. Rotary flange with J-type blades.

Bulk density. The soil's bulk density, expressing the ratio of its mass to volume, was determined using the core cutter method (Zareiforoush *et al.,* 2010). A standard procedure was followed to ascertain the soil's bulk density by applying equation 1, where the bulk density is the quotient of the weight of oven-dried soil samples to the volume of the core cutter (Shrivastava and Datta 2006).

The process for measuring the bulk density of the soil involved the following steps:

- Soil samples were extracted from five different locations along the length and at the center of the soil bin, utilizing the core cutter.
- The collected soil samples were then placed in an oven dryer set at a temperature of 105°C for 24 hours to facilitate sample drying.
- The dimensional specifications of the core cutter, with a diameter of 100mm and a length of 170mm, were taken into account.
- The volume of the core cutter (V) was determined, as illustrated in Plate 2, showcasing the oven dryer utilized for bulk density measurement.
- Equation 1 was applied to calculate the bulk density, considering the weight of the oven-dried soil samples in relation to the volume of the core cutter.

$$\rho = \frac{M}{V} \qquad \ldots(1)$$

Where,

ρ = Bulk density of soil, g/cm^3

M = Mass of soil contained in the core, gm; and

V = Volume of the core cutter, cubic cm.

Plate 2: Procedure for measuring bulk density of the soil for the experiment.

RESULTS AND DISCUSSION

A. Effect of operational parameter on the bulk density of the rotary blades (L and J shape blade)

As we observed, it was noted that the L-shaped blade yielded the highest soil bulk density after its pass, reaching 1.64 g/cm^3, while the lowest was recorded at 1.53 g/cm^3. In contrast, the J-shaped blade exhibited a maximum bulk density of 1.51 g/cm^3 and a minimum of 1.41 g/cm^3. The subsequent discussion delves into the examination of the impact of independent variables, such as forward speed of operation, rotary speed, and depth of operation, on soil bulk density as a response.

B. Effect of forward speed and rotary speed on the bulk density

Within a consistent context of a 6 cm depth of operation, Fig. 2a and b shed light on the influence of rotary speed, forward speed of operation, and their interplay on bulk density. The peak bulk density recorded for L-shaped and J-shaped rotary blades was

1.6 g/cm^3 and 1.478 g/cm^3, respectively, occurring at a forward speed of 1 km/h and a rotary speed of 125 rpm. Conversely, the lowest bulk density, 1.56 g/cm^3 and 1.441 g/cm^3, for L-shaped and J-shaped rotary blades, was observed at a forward speed of 2 km/h and a rotary speed of 75 rpm.

Specifically, at a 6 cm depth of operation and a forward speed of 2 km/h, an increase in rotary speed from 75 to 125 rpm resulted in a bulk density increase from 1.56 g/cm^3 to 1.58 g/cm^3 (Shiva *et al.,* 2017) and 1.441 g/cm^3 to 1.459 g/cm^3. This can be attributed to the efficacy of well-designed and operated rotary blades in breaking up clods and compacting the soil. Notably, with an increase in forward speed from 1 to 2 km/h for all rotary RPM, there was a significant decrease in soil bulk density ($P<0.05$). For instance, at 125 rpm rotary speed, raising the speed from 1 to 2 km/h resulted in a decrease in bulk density from 1.6 to 1.58 g/cm^3 and 1.478 to 1.459 g/cm^3. The higher machine speed led to reduced interaction time with the soil, resulting in less comprehensive mixing, clod breakage, and compaction, ultimately causing lower bulk density. Additionally, the interaction effect (AB) of forward speed and rotary RPM on soil bulk density was found to be significant ($p<0.05$).

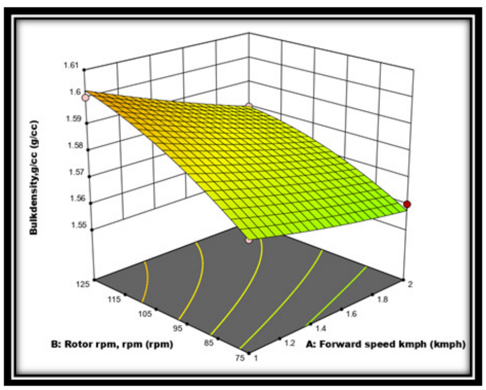

Fig. 2a. Effect of forward speed and rotary speed on the bulk density for L- shape blade.

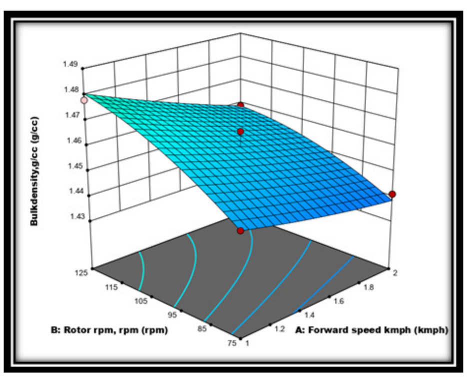

Fig. 2b. Effect of forward speed and rotary speed on the bulk density for J- shape blade.

C. Effect of forward speed and depth of operation on the bulk density

In a consistent setting with a rotary speed of 100 rpm for the blades, Fig. 3a and 3b depict the influence of forward speed of operation, depth of operation, and their interaction on bulk density. The highest bulk density recorded for L-shaped and J-shaped rotary blades was 1.64 g/cm^3 and 1.515 g/cm^3, respectively, observed at a forward speed of 1 km/h and a depth of operation of 3 cm. Conversely, the lowest bulk density, measuring 1.54 g/cm^3 and 1.422 g/cm^3, was noted at a forward speed of 2 km/h and a depth of operation of 9 cm.

Maintaining a constant rotary speed of 100 rpm and a forward speed of 2 km/h, an increase in the depth of operation from 3 to 9 cm resulted in a decrease in soil bulk density from 1.62 g/cm^3 to 1.54 g/cm^3 and 1.49 g/cm^3 to 1.42 g/cm^3 (Shiva *et al.,* 2017). Furthermore, for all depths of operation, raising the forward speed from 1 to 2 km/h led to a significant ($P<0.05$) reduction in soil bulk density. For example, at a 9 cm depth of operation, escalating the speed from 1 to 2 km/h resulted in a decrease in bulk density from 1.56 to 1.54 g/cm^3 and 1.44 to 1.42 g/cm^3 for L and J-shaped blades. This reduction is attributed to the diminished soil interaction time due to the higher machine speed, resulting in less comprehensive mixing, clod breakage, and compaction, ultimately leading to lower bulk density. Notably, the interaction effect (AC) of forward speed and depth of operation on soil bulk density was found to be not significant ($p>0.05$).

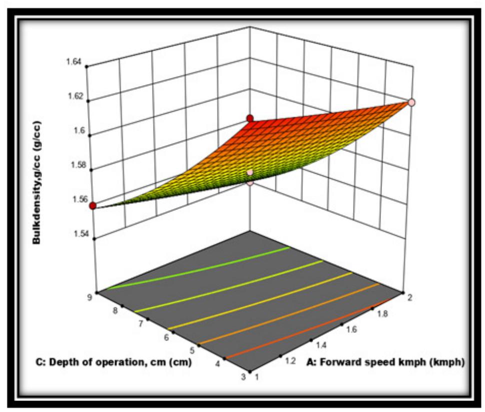

Fig. 3a. Effect of forward speed and depth of operation on the bulk density for L- shape blade.

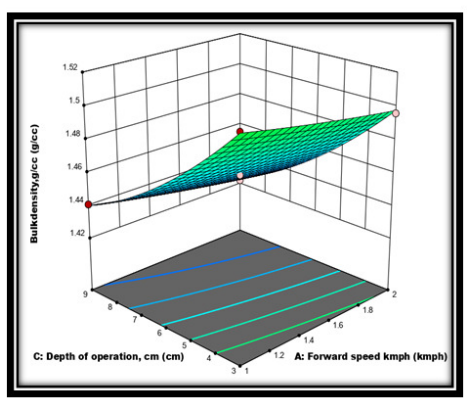

Fig. 3b. Effect of forward speed and depth of operation on the bulk density for J- shape blade.

D. Effect of depth of operation and rotary blade on the bulk density

In a consistent scenario with a fixed forward speed of operation at 1.5 km/h, Fig. 4a and 4b offer insights into the impact of depth of operation, rotary speed, and their interaction on bulk density. The highest bulk density recorded for L-shaped and J-shaped rotary blades was 1.64 g/cm^3 and 1.51 g/cm^3, respectively, achieved at a rotary speed of 125 rpm and a depth of operation of 3 cm. Conversely, the lowest bulk density, 1.53 g/cm^3 and 1.41 g/cm^3, was registered at a rotary speed of 75 rpm and a depth of operation of 9 cm.

Specifically, with a consistent forward speed of 1.5 km/h, increasing the depth of operation from 3 to 9 cm at a rotary speed of 125 rpm resulted in a decrease in soil bulk density from 1.64 g/cm^3 to 1.56 g/cm^3 and 1.51 g/cm^3 to 1.44 g/cm^3 (Shiva *et al*., 2017). However, for all depths of operation, increasing the rotary speed from 75 to 125 rpm significantly ($P<0.05$) increased soil bulk density. For example, at a 9 cm depth of operation, elevating the rotary speed from 75 to 125 rpm led to an increase in bulk density from 1.53 to 1.56 g/cm^3 and 1.41 to 1.44 g/cm^3 for L-shaped and J-shaped blades. It's noteworthy that the interaction effect (BC) of forward speed and depth of operation on soil bulk density was found to be not significant ($p>0.05$).

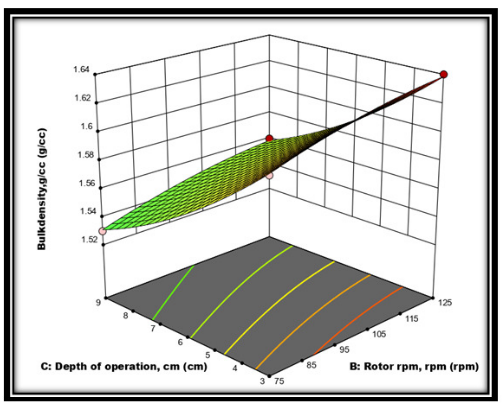

Fig. 4a. Effect of depth of operation and rotary blade on the bulk density for L- shape blade.

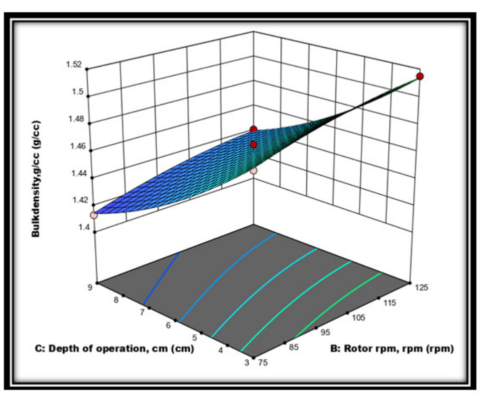

Fig. 4b. Effect of depth of operation and rotary blade on the bulk density for J- shape blade.

E. ANOVA for Response Surface Quadratic Model of bulk density

The Model F-value, which stands at 2497.51, underscores the significance of the model. There is only a 0.01% probability that an F-value of this magnitude could arise from random variation. P-values below 0.0500 indicate the statistical significance of model terms. In this case, terms A, B, C, D, AB, CD, B^2, and C^2 are all deemed statistically significant. Conversely, values exceeding 0.1000 suggest that certain model terms lack statistical significance. The presence of numerous insignificant model terms (excluding those essential for hierarchy) may impact overall model quality.

The Lack of Fit F-value, measured at 0.93, indicates that the Lack of Fit is not statistically significant when compared to pure error. A non-significant Lack of Fit is advantageous for model fitting. The Predicted R^2, standing at 0.9981, demonstrates reasonable agreement with the adjusted R^2 of 0.9990, with a difference of less than 0.2. Adeq Precision evaluates the signal-to-noise ratio, and a ratio greater than 4 is considered desirable. With a ratio of 161.375, the model exhibits an adequate signal. Therefore, equation 2 from this model can be reliably employed for predicting bulk density.

Bulk density, g/cm^3 $= +1.52-0.0085A+0.0133\ B-0.0385\ C-0.0603\ D-0.0025\ AB+0.0000\ AC+0.0002\ AD+0.0000\ BC-0.0005\ BD+0.0015\ CD+0.0009\ A^2-0.0039\ B^2+0.0081\ C^2$ …(2)

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

Numerical optimization of the performance parameter of L and J-shaped rotary blade. To enhance the performance parameters of both L-shaped and J-shaped rotary blades, we established constraints aligned with the desired functionality of these blades, as detailed in Table 2. The goal and relative importance were defined by inputting data into the Design Expert software. Once the criteria were set, we utilized the Design Expert software to identify an optimized solution, presented in Table 3. The numerical values of the optimized independent variables, generated by the Design Expert software, were determined as follows: For the J-shaped rotary blade, a rotary speed of 110 rpm, a forward speed of 1.5 km/h, and a depth of operation of 8.25 cm. These values correspond to the predicted response: bulk density of 1.441 g/cm^3. The individual desirability of these parameters is depicted in Fig. 5 and 6.

Table 1: ANOVA for response surface quadratic model for the response as bulk density, g/cm^3.

Source	Sum of quares	df	Mean Square	F-value	p-value	
Model	0.1520	13	0.0117	2497.51	< 0.0001	significant
A-Forward speed kmph	0.0012	1	0.0012	246.85	< 0.0001	*
B-Rotor rpm, rpm	0.0028	1	0.0028	599.84	< 0.0001	*
C-Depth of operation, cm	0.0237	1	0.0237	5064.34	< 0.0001	*
D-Type of blade	0.1236	1	0.1236	26394.30	< 0.0001	*
AB	0.0000	1	0.0000	10.68	0.0039	*
AC	0.0000	1	0.0000	0.0000	1.0000	ns
AD	1.000E-06	1	1.000E-06	0.2135	0.6490	ns
BC	0.0000	1	0.0000	0.0000	1.0000	ns
BD	4.000E-06	1	4.000E-06	0.8542	0.3664	ns
CD	0.0000	1	0.0000	7.69	0.0117	*
A^2	6.821E-06	1	6.821E-06	1.46	0.2416	ns
B^2	0.0001	1	0.0001	26.65	< 0.0001	*
C^2	0.0006	1	0.0006	119.44	< 0.0001	*
Residual	0.0001	20	4.683E-06			
Lack of Fit	0.0001	12	4.538E-06	0.9262	0.5635	not significant
Pure Error	0.0000	8	4.900E-06			
Cor Total	0.1521	33				
Std. Dev.		0.0022	R^2		0.9994	
Mean		1.52	Adjusted R^2		0.9990	
C.V. %		0.1421	Predicted R^2		0.9981	
			Adeq Precision		161.3746	

*significant, ns non-significant

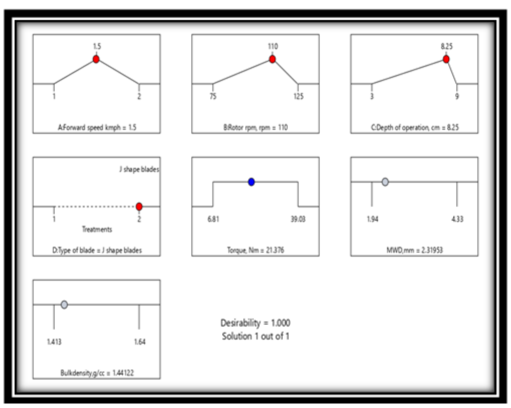

Fig. 5. Ramp bar for optimizing the performance parameters.

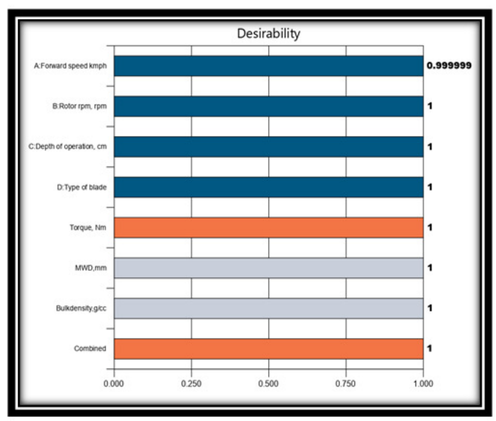

Fig. 6. Desirability graph for different parameters after analysis.

Table 2: Constraints decided for numerical optimization.

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Forward speed km/h	is in range	1	2	1	1	3
B:Rotary speed, rpm	Is in range	75	125	1	1	3
C:Depth of operation, cm	Is in range	3	9	1	1	3
D:Type of blade	is equal to	L-shape blades	J- shape blades	1	1	3
Bulk density, g/cm^3	none	1.413	1.64	1	1	3

Table 3: Optimized Solutions provided through analysis by software.

Sr. No.	Forward Speed km/h	Rotary speed rpm	Depth of operation cm	Type of blade	Bulk density g/cm^3	Desirability	
1.	**1.500**	**110.00**	**8.250**	**J- shape**	**1.441**	**1.000**	**Selected**
2.	1.500	107.18	8.147	J- shape	1.441	1.000	
3.	1.500	105.77	8.435	J- shape	1.438	1.000	
4.	1.500	106.24	8.041	J- shape	1.441	1.000	
5.	1.500	109.54	8.453	J- shape	1.439	1.000	
6.	1.500	109.43	8.250	J- shape	1.441	0.995	

Post analysis of the optimization. Point predictions were derived by entering the desired operational conditions into the software, and the predicted responses were determined with a 95% confidence interval. The model yielded predictions based on the optimized independent parameters. Following this, an experiment was conducted to validate the predicted response values under the optimal operational conditions. These results served to confirm the accuracy of the optimized parameters for the rotary blades. The predicted mean values for the observed bulk density of the J-shaped blade were 1.441 g/cm^3, respectively. Notably, these values fell within the range defined by the 95% confidence interval, as depicted in Table 4.

Table 4: Point prediction confirmation of the optimized result given by model.

Response	Predicted Mean	Predicted Median	Std Dev	SE Mean	95% CI low for Mean	95% CI high for Mean
Bulk density, g/cm^3	1.44122	1.44122	0.002	0.00096	1.439	1.443

CONCLUSIONS

Bulk density exhibits a decrease with an increase in the depth of operation and forward speed of motion, while it increases with an increase in rotor speed. This decline is attributed to the diminished soil interaction time resulting from higher machine speed, leading to less thorough mixing, clod breakage, and compaction, ultimately yielding lower bulk density. Optimal weeding and tillage were observed at 110 rotor rpm, 1.5 km/h forward speed, and a depth of operation of 8.25 cm, specifically with the J-shaped blade. The predicted mean bulk density, determined after analysis, was 1.441 g/cc. In comparison, the L-shaped blade resulted in higher bulk density than the J-shaped blades. Notably, the J-shaped blade demonstrated higher effectiveness, particularly in pulverization operations.

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Conflict of Interest. None.

REFERENCES

Chen, J., Dai, J. H., Pan, C. G. and Gao, L. (1993). Studies on the downcut energy saving rotary blades. *Trans Chinese Soc Agrc Machinery, 24* (1), 37-42.

De, D. S. K., Aragon, K. L. and Malabuge, J. A. (1974). Vertical differences in and practices for upland rice, Seminar proceeding, Rice breeding and vertical environment west Africa rice development association, Monrovia, Liberia, 35-73.

Rangasamy, K., Balasubramanian, M. and Swaminathan, K. R. (1993). Evaluation of power weeder performance. AMA, *24*(4), 20-23.

Sakai (1978). Design process and theories of rotary blade for better rotary tillage. Part I. *JARQ 12* (2), 86-93.

Shiva, B., Manes, G. S., Apoorv, P. and Anoop, D. (2017). Effect of blade shape and rotor speed of rotavator on pulverization and mixing quality in sandy loam soil. *Agricultural Research Journal, 54* (3), 394-397.

Shrivastava, A. K. and Datta, R. K. (2006). Effect of different size and orientation of rectangularrotary blades on quality of puddling. *Journal of Terramechanics, 43*(2), 191-203.

Zareiforoush, H., Komarizadeh, M. H. and Alizadeh, M. R. (2010). Rotary tiller design proportional to a power tiller using specific work method (SWM). *Nature and Science, 8*(9), 39-45.

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