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Design and Development of a Manually Operated Pull-Type Three-Row Dibble Wheel for Efficient Agricultural Planting

M. Lokesh [a++] and M. Anusha [a++*]

[a] *VFSTR University, Vadlamudi Guntur, Andhra Pradesh, 522213, India.*

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

This research introduces a novel pull-type three-row dibble wheel designed to improve agricultural planting efficiency. The dibble wheel's primary purpose is to create evenly spaced holes in the soil for precise seed placement, reducing the labor-intensive manual hole digging process. Ergonomic features are incorporated to reduce operator fatigue. Performance evaluation involved key metrics, including effective field capacity (EFC), field efficiency (FE), cost of operation (COP), and cost savings (SC), compared to the traditional planting method (TM). Three dibble methods were assessed: single-row seated dibbling (SE), single-row standing dibbling (ST), and the three-row dibble wheel (DW). Results demonstrated significant improvements in EFC, FE, COP, and SC for SE, ST, and DW compared to TM. Specific measurements for dibble diameter, depth, and intra-dibble spacing were consistent. Statistical analysis revealed significant differences in intra-dibble spacing, effective field capacity, and field efficiency among dibbling methods at p=0.01, while no

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[++] *Assistant Professor;*
**Corresponding author: E-mail: maddalianusha33@gmail.com;*

distinctions were found in hole diameter and depth. In conclusion, the three-row manually operated dibble wheel significantly reduces planting time and labor, ensuring precise seed placement. It offers advantages in field capacity, field efficiency, cost-effectiveness, and cost savings, making it suitable for small and marginal farmers as an improvement over traditional methods.

Keywords: Dibble wheel; dibbler; transplanter; seedlings.

1. INTRODUCTION

Vegetables are highly beneficial for their dietary fiber, vitamins, minerals, antioxidants, and phytochemicals, playing a crucial role in ensuring food and nutritional security in the country. As stated by Sahoo et al. [1] and Korla et al. [2]. India is a major producer of vegetables, with significant growth in production and productivity in recent years. Kumar et al. [3] highlights that India ranks second globally in terms of farm output. However, a large portion of Indian farmers, approximately 65 percent, are small-scale or marginal landholders, making it challenging for them to afford expensive agricultural machinery and equipment. Anusha et al. [4] emphasize the necessity for affordable and easily accessible farm machinery to alleviate the physical strain on farmers and reduce product damage.

Seeds of various crops such as cowpea (Vigna unguiculata), okra (Abelmoschus esculentus), and carrot (Daucus carota) are typically either drilled or directly planted. However, when it comes to vegetable crops like tomato (Solanum lycopersicum), onion (Allium cepa), chilli (Capsicum annuum), brinjal (Solanum melongena), cauliflower (Brassica oleracea var. botrytis), and cabbage (Brassica oleracea var. capitata), transplanting is the preferred method. Although significant advancements have been made in transplanting vegetable seedlings in Indian agriculture, farmers with marginal and fragmented land holdings, due to their socio-economic status, are unable to adopt higher forms of non-renewable power sources, as noted by Vignesh et al. [5]. Consequently, these farmers rely on traditional manual methods for vegetable transplanting. However, this traditional method of manually creating holes for transplanting seedlings is a laborious and time-consuming task. It requires a significant amount of labor, which may not always be readily available. The unavailability of labor can lead to delays in the transplanting process, directly impacting crop production and the economic condition of the farmer, as highlighted by Nandede et al. [6]. Therefore, an investigation was conducted to develop and assess the performance of a manually operated three-row dibble wheel. The aim of this development was to reduce the physical strain and operational costs associated with the manual dibble method.

2. MATERIALS AND METHODS

The objective of the proposed prototype was to create holes for various vegetable crops, ensuring proper seedling spacing both between rows and within a row. Additionally, the prototype needed to be lightweight, cost-effective, easy to use, and constructed using locally available materials.

2.1 Development of Manually Operated 3-Row Dibble Wheels

The manually operated pull type three-row dibble wheels were constructed using locally available materials. The design included a frame made of mild steel (MS) square box (1), a shaft made of MS (2), a handle made of MS pipe (3), MS flat for additional components (4), MS pipes for the dibble wheels (5), and an MS sheet for providing weight. The prototype was designed to be pulled by one or two individuals. As the machine was pulled across a well-prepared seed bed, the dibble wheels would rotate and create holes at the desired seedling and row spacing for the transplanting of vegetable seedlings. Fig. 1 illustrates the manually operated pull type three-row dibble wheels.

1.Frame; 2. Shaft; 3. For loads; 4. Dibble wheels with lugs; 5. Handle

The components of the three-row dibble wheels include:

1. Frame: The frame is made of a strong MS square box with dimensions of (25x25x3) and a length of 153 cm. It provides support and balance to the machine during operation, distributing the load symmetrically.

2. Shaft: The shaft is made of MS rod with a diameter of 16mm and a length of 110cm. It is

supported by two bearings and connects the frame to the dibble wheels.

3. Plug tray holder: Two plug tray holders, made of MS sheet with a thickness of 1mm and an area of 2307.5 cm^2 each, are used to arrange the trays. They are positioned on top of the frame using MS rods with a diameter of 6 mm. Additional weights can be placed on the holders for better penetration if needed.

4. Dibble wheels: The dibble wheels are responsible for creating holes for transplanting seedlings. They are fabricated from MS flat bars, MS rods, and MS pipes. Each dibble wheel has a diameter of 500 mm and is equipped with 5 inner spokes and 7 outer lugs for punching holes and reducing slippage. The lugs on the outer periphery of the wheel can be adjusted using a nut and bolt arrangement to achieve the desired intra-row spacing.

5. Adjustable Handle: The handle is made of three mild steel pipes with a diameter of 20 mm and a total length of 3630 mm. It can be adjusted in height to accommodate the operator's height, ensuring smooth and comfortable operation of the machine.

2.2 Field Performance

The field trials for the developed dibble wheels were carried out at the ICAR-Central Institute of Agricultural Engineering in Bhopal. The selected plot size for the trial was 60m x 3m, which corresponds to an area of 180 m^2 or 0.018 hectares. The row-to-row spacing was maintained at 45 cm.

Fig. 1. Developed manually operated pull type three row dibble wheels

Table 1. Technical specifications of the manually operated three-row dibble wheels

Parameters of implement	Details
Length of the machine, mm	1500
Width of the machine, mm	1100
Diameter of the shaft, mm	16
Length of the shaft, mm	1100
Diameter of the dibble wheel, mm	500
Number of wheels	3
Height of handle from ground, mm	1000
Diameter of handle, mm	20
Adjustment of row to row, mm	400-500
Overall weight, kg	24.2
Cost, ₹	2000.00

During the trials, the dibble wheels were tested extensively under actual field conditions. Evaluation of the dibble wheels included various performance parameters such as theoretical field capacity, effective field capacity, field efficiency, labor requirement, cost of operation, as well as parameters related to the holes created by the dibble wheels, such as the depth of the hole, hole-to-hole distance, and hole diameter.

The theoretical field capacity refers to the maximum area covered by the machine per unit time. The effective field capacity takes into account various factors such as turns, overlaps, and delays, providing a more realistic measure of the actual work accomplished in the field. The field efficiency represents the percentage of the effective field capacity achieved in relation to the theoretical field capacity.

The labor requirement and cost of operation are assessed to determine the human effort and financial implications of using the dibble wheels for transplanting seedlings. These factors contribute to determining the economic feasibility and practicality of the machine. Additionally, parameters related to the holes created by the dibble wheels, such as the depth of the hole, hole-to-hole distance, and hole diameter, are evaluated to ensure that they meet the desired specifications for proper seedling transplanting. Through rigorous testing and evaluation in the field, the performance of the developed dibble wheels can be assessed and its suitability for practical application can be determined.

2.3 Soil Moisture Content (SMC)

To determine the moisture content of the soil samples collected from the test plot, the following procedure was followed:

1. Random sample collection: Five soil samples were collected randomly from a depth of 5 cm within the test plot area. It is important to ensure that the samples represent the overall soil conditions in the field.

2. Preparing samples for drying: The collected soil samples were placed in separate containers or bags, clearly labelled for identification. Each sample was properly sealed to prevent moisture loss or gain during transportation and storage.

3. Drying process: The soil samples were taken to the laboratory and placed in an oven set at a temperature of 105°C. The samples were left in the oven for a period of 24 hours to ensure complete evaporation of moisture. This specific temperature and time are commonly used for soil drying in accordance with standard methods.

4. Weighing the samples: After the drying period, the soil samples were carefully removed from the oven and allowed to cool in a desiccator to avoid moisture absorption from the atmosphere. Once the samples reached room temperature, their dry weight was determined using a sensitive balance or scale.

5. Calculation of moisture content: By following this oven drying method, the moisture content of the soil samples can be accurately determined, allowing for further analysis and interpretation of soil characteristics related to moisture availability and management. Moisture content (d.b) % $= W_1 - W_2 / W_2$

Where,

W_1 = Initial weight of sample, gm.
W_2 = Oven dry weight, gm.

6. Recording and analysis: The moisture content values for each soil sample were recorded. These values provide insights into the soil's water content, which is essential for understanding its physical properties and suitability for various agricultural practices.

2.3.1 Bulk density

The bulk density was determined by dividing the weight of sample by volume it occupied and calculated by using the formula.

Bulk density (g/cm^3) = M_d / V

Where,

M_d = Mass of dry sample, g
V = Soil volume, cm^3

2.3.2 Speed of operation and losses

The forward speed of the machine and losses time required were determined by obtaining distance and time required for losses (in seconds) with the help of stopwatch.

Speed (km/h) = distance covered /time require to cover above distance (s) * 3.6

2.3.3 Field capacities and field efficiency

Theoretical field capacity, effective field capacity and field efficiency were calculated by using formulae

Theoretical field capacity (ha/hr) = avg. speed (km/h) * width of implement (m)/10

Effective field capacity (ha/hr) = forward speed (km/h) * width of implement (m)/10
Field efficiency =EFC (ha/h) / TFC (ha/h)

2.3.4 Hole to hole distance, depth of hole, hole diameter

The hole to hole distance, depth of hole, hole diameter sown by the dibble wheels was measured randomly at thirty locations in each replication at the time of operation (Fig. 2).

2.3.5 Labour required

The labour requirement of making hole operation was calculated in terms of man-hour required per hectare.

2.3.6 Cost of operation

The labour charges were considered as Rs. 37.5 /hr. Hence the labour cost required (Rs.) for one-hectare dibbling was calculated by multiplying man hours required for dibbling in one hectare area with Rs. 37.5.

2.3.7 Time saving over traditional method

The time saving over traditional method in terms of percentage was calculated by using following formula.

TS_{TM} = (man-hours required by traditional method - man-hours required by using developed dibble wheels) / man-hours required by traditional method × 100

Where,

TS_{TM} = time saving over traditional method

2.3.8 Comparative Evaluation

Developed three-row dibble wheels were compared with manual traditional methods of sitting and standing posters as shown in Fig. 3.


a) Hole to hole distance b) Hole depth c) Hole diameter

Fig. 2. Evaluation of field performance parameters

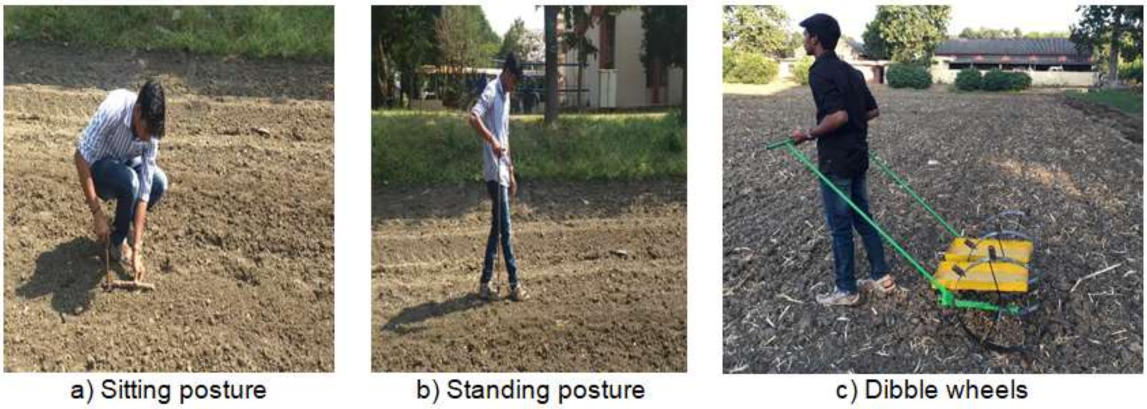
a) Sitting posture b) Standing posture c) Dibble wheels

Fig. 3. Comparative evaluation of dibbling methods

2.4 Statistical Analysis

Five replications were carried out for each treatment. Completely Randomized Design (CRD) was used analysis to find the significance of the parameters over dibbling methods using SAS 9.3.

3. RESULTS AND DISCUSSION

The results obtained from the field test of the dibble wheels, following standard procedures, are summarized in Table 2. The soil had an average moisture content of 12%, while the average bulk density was measured at 1.17 g/cm^3. The dibble wheels exhibited an average speed of 2.4 km/h, with an average time loss of 0.45 minutes due to turning and other factors. Theoretical field capacity, effective field capacity, and field efficiency for the 3-row dibble wheels were calculated to be 0.33 ha/h, 0.28 ha/h, and 86%, respectively. The labour requirement for the operation was determined to be 3.52 m-h/ha, and the associated cost was calculated as ₹136. Furthermore, the average depth of the holes created by the dibble wheels was found to be 3.85 cm, with a hole diameter of 7.2 cm. The distance between each hole was measured to be an average of 37.3 cm. These parameters are crucial for ensuring the proper transplanting of seedlings.

3.1 Statistical Analysis

ANOVA for effect of dibbling methods on hole diameter is as given in Table 3. The model was found non-significant hence we can conclude that hole diameters were almost same with each treatment.

ANOVA for effect of dibbling methods on hole to hole distance is as given in Table 4. The model was found significant at 1% level of significance with a coefficient of determination (R^2) and coefficient of variance (CV). It can be seen that the effect of replication was non-significant but dibbling methods were highly significant. It shows that hole to hole distance varied as dibbling method varies.

Table 2. Performance results of manual drawn dibble wheels (DW) and traditional methods of sitting & standing posters

Particulars	Performance values			
	SITTING	**STANDING**	**DW**	
moisture content, (d.b) %	12	12	12	
Bulk density, g/cm^3	1.17	1.17	1.17	
average forward speed, km/h	0.5	0.6	2.10	
Average time loss, min	1.16	0.88	0.45	
TFC, ha/h	0.038	0.05	0.33	
EFC, ha/h	0.02	0.03	0.28	
FE, %	54	55	86	
Avg. hole diameter, cm	7.4	6.5	7.2	
avg. hole depth, cm	3.65	3.0	3.85	
Avg. hole to hole distance, cm	34.6	33.3	37.3	
Labour required, m-h/ha	47.84	37.04	3.52	
Cost of operation, ₹/ha	1794	1388	132	
Cost saving %	--	22.58	92.64	90.49
Time saving %	--	22.58	92.64	90.49

Table 3. ANOVA for effect of dibbling methods on hole diameter

Source	DF	Sum of Squares	Mean Square	F Value
Model	6	176.8	29.46	2.21^{NS}
Error	8	106.8	13.35	
Corrected Total	14	283.6		
R^2=0.623, CV=5.175, RMSE=3.653, mean=70.6				
Replication (R)	4	15.6	3.9	0.29^{NS}
Dibbling	2	161.2	80.6	6.04^{NS}

R^2=coefficient of determination, CV=coefficient of variance, RMSE= root mean square error, ^{NS}=non significant.

Table 4. ANOVA for effect of dibbling methods on hole to hole distance

Source	DF	Sum of Squares	Mean Square	F Value
Model	6	3280.4	546.7	29.32**
Error	8	149.	18.65	
Corrected Total	14	3429.6		
R^2=0.956, CV=1.23, RMSE=4.318, mean=349.6				
Replication (R)	4	17.6	4.4	0.24^{NS}
Dibbling	2	3262.8	1631.4	87.47**

*R^2=coefficient of determination, CV=coefficient of variance, RMSE= root mean square error, **=significant at 1% level of significance, ^{NS}=non significant.*

ANOVA for effect of dibbling methods on depth of hole is as given in Table 5. The model was found non-significant. Hence, hole depth achieved using dibble wheels was at par with other methods.

The effective field capacity was also found to be affected significantly at 1% of significance by all dibbling methods Table 6. The R^2 (0.998) and CV (5.76) shows the good uniformity in data. It can be seen that the effect of replication was non-significant [7-11].

Field capacity was also found to be affected significantly at 1% of significance by all dibbling methods Table 7. The R^2 (0.998) and CV (1.41) shows the good uniformity in data. It can be seen that the effect of replication was non-significant.

Table 5. ANOVA for effect of dibbling methods on depth of hole

Source	DF	Sum of Squares	Mean Square	F Value
Model	6	110.13	18.35	2.28^{NS}
Error	8	64.26	8.03	
Corrected Total	14	174.4		
R^2=0.631, CV=7.7, RMSE=2.83, mean=36.8				
Replication (R)	4	25.73	6.43	0.80^{NS}
Dibbling	2	84.4	42.2	5.25^{NS}

*R^2=coefficient of determination, CV=coefficient of variance, RMSE= root mean square error, **=significant at 1% level of significance, ^{NS}=non significant.*

Table 6. ANOVA for effect of dibbling methods on effective field capacity

Source	DF	Sum of Squares	Mean Square	F Value
Model	6	0.22	0.04	950.38**
Error	8	0.00	0.00	
Corrected Total	14	0.22		
R^2=0.998, CV=5.76, RMSE=0.0061, mean=0.107				
Replication (R)	4	0.00	0.00	0.61^{NS}
Dibbling	2	0.22	0.11	2849.91**

*R^2=coefficient of determination, CV=coefficient of variance, RMSE= root mean square error, **=significant at 1% level of significance, ^{NS}=non significant.*

Table 7. ANOVA for effect of dibbling methods on the field efficiency

Source	DF	Sum of Squares	Mean Square	F Value
Model	6	3527.93	587.98	696.21**
Error	8	6.75	0.844	
Corrected Total	14	3534.69		
R^2=0.99, CV=1.41, RMSE=0.91, mean=64.73				
Replication (R)	4	8.88	2.221	2.63^{NS}
Dibbling	2	3519.04	1759.5	2083.35**

*R^2=coefficient of determination, CV=coefficient of variance, RMSE= root mean square error, **=significant at 1% level of significance, ^{NS}=non significant.*

4. CONCLUSIONS

Based on the findings, it can be concluded that using a three-row dibble wheels, as compared to traditional sitting and standing postures, resulted in a lower field capacity of 0.28 ha/h and a higher field efficiency of 86%. Additionally, the cost of using the dibble wheels was found to be significantly lower, at ₹132/ha. Statistical analysis revealed that the distance between holes, effective field capacity, and field efficiency varied significantly among different dibbling methods. However, there was no significant difference observed in terms of hole diameter and depth. The developed three-row manually drawn dibble wheels were found to be more suitable for small and marginal farmers, particularly in black cotton soils. Overall, the performance of the machine was deemed satisfactory.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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