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Selection of dibble radius in automatic dibble type vegetable transplanter based on zero velocity condition in planting

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Abstract
Mechanization in vegetable transplanting is the current need due to increase in the cultivable area of vegetables and subsequent non availability of agricultural labor. A mini tractor mounted automatic dibble type vegetable transplanter was designed for a plant to plant spacing of 60 cm. Transplanter consists of conveying, dibbling wheel and seedling ejection units. Dibbling wheel consist of four dibble cups, selected based on the ground clearance of under complete lift position of tractor. Size of dibble wheel (radius of swing) was selected based onnumber of dibble cupsand zero-velocity condition of dibble wheel. With four dibble cups and rear wheel diameter of 80 cm, the gear ratio selected between the rear wheel of tractor and dibble wheel was 0.95. Zero velocity condition of dibble was obtained for value $\lambda \geq 1$. The shape of displacement plots depends on parametric function value λ. At all forward speeds of 0.72, 1.08, 1.44, 1.8 and 2.16 kmh^{-1} for dibble wheel radius of 10, 20 and 30 cm, the value of λ was less than 1. Increase in the radius beyond 38.5 cm, the value of λ was greater than equal to 1. The displacement plots observed trough shape for diameter less than 38.5 cm, while there observed a closed trochoid for the radius greater than 38.5 cm. Selection of radius above 38.5 cm of dibble wheel would have zero velocity condition of dibbling. At this radius of swing, dibbling would be vertical and plant would be less inclined after transplanting.

Keywords: Automatic, vegetable transplanter and dibbling

1. Introduction
The diverse climate in India ensures availability of all varieties of fresh fruits and vegetables. India ranks second in vegetables production in the world, after China. Vegetables occupied an area of 10.26 million hectares during 2017-18, having an average production and productivity of 184.39 million metric tons and 18 tonnes per hectare respectively. The area under cultivation of fruits stood at 6.3 million hectares while vegetables were cultivated in 10.1 million hectares (Anonymous, 2015). Developing countries are contributing about 72% of the total vegetable production in the world. Manual transplanting is time consuming, expensive in terms of labour and may results in non-uniformity of plant spacing. Manual planting of chilli bare root seedlings involved 321 $man\text{-}hha^{-1}$ and recorded higher mortality (Dihingia *et al.*, 2017) [4]. Field capacities of hand operated machines were low with less than 0.014 hah^{-1}. Non uniformity of spacing between plants increases the nutrient uptake competition between plants (Heege, 1993) [5]. More labour involvement and lower efficiency of hand operation is difficult for large scale production.

2. Review of Literature
Nandade and Raheman (2016) developed a tractor drawn 3 row multi-stack vegetable transplanter for planting vegetable seedlings raised in paper pots. Planting unit consists of metering wheels, fixed slotted plate, furrow wheels and soil covering devices. Seedlings placed in circular array over the metering wheels rotates with the machine forward speed and coincides with the slots on the fixed plate and drops in to the furrow through metering tube by gravity.
Sivakumar (2014) [12] developed a working model of an automatic transplanting machine for vegetable crops which eject the seedling from portray and plant the seedlings on dropping them by gravity. Seedlings were grown in trapezoidal portray cells, instead of drawing the seedlings from top and was made to drop through bottom. Plating tray was under axial

movement by walking beam mechanism. A 12 V DC motors with finger wheel actuates the seedling segment. A single slider crank mechanism, operated by 12 V, 100 rpm DC motor was provided with a 6 mm rod was used to eject the seedlings.

Kumar and Raheman (2011) [8] developed a automatic feeding of slat type horizontal chain conveying mechanism for feeding and a horizontal pusher type chain conveyor for metering the paper pot seedlings of tomato and eggplant. Conveying and feeding mechanisms were powered form the ground wheel of power tiller. Seedlings on the conveyor was placed at a spacing of 76.2 cm. Pusher type chain conveyor receives the pot seedlings arranged in rows and delivers them to the seedling tube

Nambu and Tanimura (1992) [10] developed a fully automatic vegetable transplanter which can plant chain pot type paper pot grown vegetable seedlings. Chain type pots were formed by connecting the paper pot (two layers of sheet) and jointed together by a piece of thick paper were made of perforated sections. Planting mechanism consists of a cam operated planting fingers which draws the bandolier paper pot seedlings from the conveyor, separates the chain seedlings in to singulars and plant them in to the soil.

Huang and Splinter (1968) [6] developed a single and two row automatic transplanter for tobacco transplants. Transplanter consists of a grid cartridge for holding the peat pots provided with seedlings arranged in continuous grid and intermittent grid, drop tube, furrow openers, press wheels and shifting mechanism. At the bottom of grid cartridge there was a fixed plate having holes drilled at equal spacings for dropping the pot from cartridge to furrow.

Chen *et al.* (2011) [2] simulated and analyzed the planting motion of dibble transplanter. Planting and structural parameters were analyzed. Mathematical model was developed for planting motion. Relations between characteristic parameters such as number of dibble cups, speed of dibble wheel, transmission ratio were developed. Model equations revealed the relation between the plant spacing and transmission ratio. A machine parameter 'λ' was developed to know the variations in planting velocity. Kinematic model was developed to know the planting trajectories at various machine forward speed and planting speeds.

Chen *at al.* (2012) [3] simulated the dibble planting motion and equations of planting movement were established. The characteristic parameter 'λ' was explained and its effect on planting was modeled through kinematic simulation. Computer simulation was developed to know the effect of 'λ'. Out of the kinematic trajectory analysis parametric conditions such as $\lambda < 1$, $\lambda = 1$ and $\lambda > 1$, the condition $\lambda \geq 1$ was suited ideal for normal working conditions for zero velocity of seedling planting

3. Material and Methods

3.1 Working principle of dibble type vegetable transplanter

Dibble type vegetable transplanter as shown in Fig. 1, consists of plant conveying unit (20), dibbling unit (21) and plant ejecting unit (16). Plant conveying unit carries the pot seedlings and convey the seedlings on plant carriers. A dibble unit was provided to carry the seedling ejecting out of plant carrier by plant ejecting unit, where the seedlings drop by gravity from conveying unit to dibble cups. As the machine moves forward, dibble cups were constrained to pass through the confiner (19) where the cup penetrates, opens and drops the seedling into the soil. The drive to dibble unit was obtained from rear wheel of tractor to dibble shaft (11) through counter shaft (12). Appropriate radius of swing of dibble cups was selected for verticalness in planting of seedlings. Horizontal and vertical displacement plots of dibble cups were analyzed for different dibble radius by plotting the displacement values in Microsoft Excel 2010. Theoretical selection of dibble radius was made based on the zero-velocity condition of dibble cups

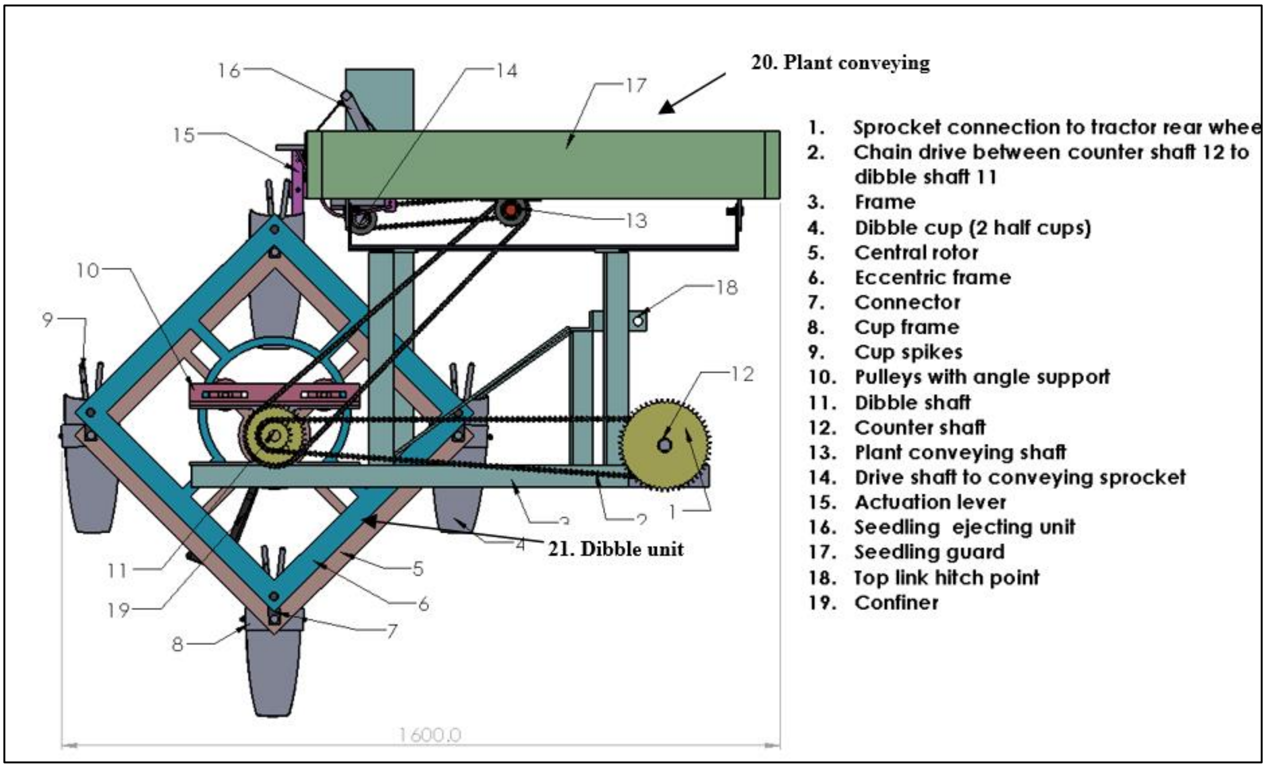

Fig 1: Dibble type vegetable transplanter

3.2 Zero velocity condition of dibble wheel

The motion of the dibble wheel, which act as the planting device combines the forward movement of transplanter and the rotational movement of dibble cups. Considering the centre of the shaft of rotation as the coordinate origin, the dibble wheel motion schematic can be depicted as shown in Fig.2 and the displacement equations of the dibble cup can be obtained by following equations.

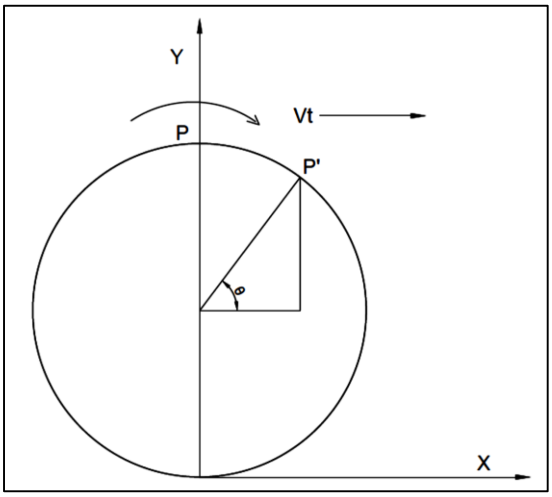

Fig 2: Graphical analysis of combined motion of dibble wheel

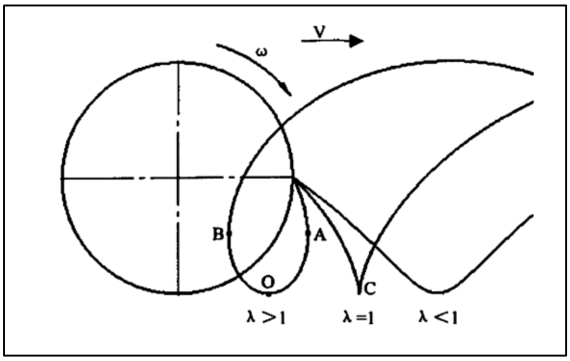

Fig 3: Graphical trajectory for dibble cups based on λ (Chen *et al*, 2011) [2].

The 'ω' is the dibble wheel angular velocity and 'V' forward velocity of machine. Let P be the point on the wheel and it assumes a new position P' after moving with forward velocity of V_x. The displacement trajectory equation of dibble cup is given by

Along x direction, $X = R_2 \cos(\omega_2 t) + Vt$ ----------- (i)
Along y direction, $Y = - R_2 \sin(\omega_2 t)$ ---------- (ii)
Were, R_1 and R_2 are the radius of rear wheel and dibble wheel respectively.
ω_1 and ω_2 are the angular velocities of rear wheel and dibble wheel respectively.
V is the forward velocity of the machine
t is the travel time
Velocity component along the x and y directions are obtained by derivation of equations I & ii with respective to time.
Velocity along x direction, $V_x = V - \omega_2 R_2 \sin(\omega_2 t)$ -------- (iii)
Velocity along y direction, $V_y = - \omega_2 R_2 \cos(\omega_2 t)$ --------- (iv)
The motion path of dibble cup forms a closed trochoid, when forward velocity of the machine, $V_x < 0$ or $\lambda \geq 1$. The diameter of rear wheel (D_1) was 80 cm.
The main idea of considering the parametric equation was to choose the correct diameter of the dibble wheel which could get the zero-velocity trajectory for dibble cups. Motion path of the dibble is to form a closed ring of trochoid when there is a possible $V_x<0$ or $\lambda \geq 1$. The dibble has an opposite motion relative to the ground, which ensures the zero-velocity planting.

Forward velocity of the machine (V) is expressed as $V = S \times f = R_1 \times \omega_1$ -------- (v)
Angular velocity of dibble wheel (ω_2) = ω_1 / G -------(vi)
Ratio between driver and driven (G) = $n S / \pi D_1$-----(vii)
ω_1= Angular velocity of rear wheel = V / R_1 -------- (viii)

S = Plant spacing, cm
f = frequency of planting, plants/ min
n = number of dibble cups = 4
R_1& R_2 = Radius of rear wheel and dibble wheel respectively.
The value of λ (parametric function) was expressed as,

$$\lambda = \frac{R_2\,\omega_2}{V}$$
$$= \frac{R_2\,\omega_1}{V\,G} \quad \text{(from eq.vi)}$$
$$= \frac{R_2\,V}{R_1\,V\,G} \quad \text{(from eq.v)}$$
$$= \frac{R_2}{R_1\,G} \quad \text{---------- (ix)}$$

4. Results and Discussions

4.1 Speed ratio between dibble wheel and rear wheel of tractor

Selected tractor had rear wheel tire specification of 8 x 18. Rear wheel diameter was calculated from the rolling radius of the tractor rear wheel. Rolling radius of wheel (R_1) was calculated as

$$R_1 = \frac{\text{Distance travelled by rear wheel in 1 revloution}}{2\pi}$$

$$= \frac{250\,cm}{2 \times 3.14} = 39.814 \text{ cm}$$

∴ Wheel diameter D_1 = 39.814 x 2 = 79.628 ≅80 cm

$$\text{Gear ratio} = \frac{N_1}{N_2} = \frac{T_2}{T_1} = \frac{n \times s}{\pi\, D1} = \frac{4 \times 60}{3.14 \times 80} = \frac{0.95}{1}$$

T_1 and T_2 represents teeth on rear wheel and dibble wheel sprockets respectively.
Based on number of dibble cups (4), diameter of rear wheel (80 cm), plant to plant spacing of 60 cm, calculated speed ratio was 0.95. It was evident that, a speed ratio of 0.95:1 was to be maintained between the dibble shaft and rear wheel of tractor for a plant spacing of 60 cm.

4.2 Zero velocity condition of dibble wheel

From equation. ix, the parametric value λ is proportional to radius of dibble wheel (R_2), inversely proportional to radius of driving wheel (R1) and gear ratio (G) between dibble wheel and driving wheel. When the machine moves at forward speed of 0.72 kmh^{-1} the planting frequency would be 20 plants/min, as shown in Table.1. At particular forward speed of 0.72 kmh^{-1} and planting frequency of 20 plants/min, the calculated values of λ at different radii of dibble wheel and driving wheel diameter of 40 cm (R_1) and gear ratio 0.95 (G) were shown in Table.2. The values in the Tables 1 and 2 were calculated from the equations v to viii.

Table 1: Planting frequency and machine forward speed

Planting frequency (f), plants/ min	20	30	40	50	60
Forward velocity of machine (V), kmh^{-1}	0.72	1.08	1.44	1.8	2.16

Table 2: λ values of different dibble wheel diameters at f = 20 plants/ min (0.72 kmh^{-1})

R_2, cm	10	20	30	38.5	40
V, cm/sec	20	20	20	20	20
ω_1, rad/sec	0.50	0.50	0.50	0.50	0.50
ω_2, rad/sec	0.53	0.53	0.53	0.53	0.53
λ	0.26	0.52	0.78	1.0	1.06

Zero velocity condition of dibbling would obtain when the value $\lambda \geq 1$, as shown in Fig 3. The author Jiang-Tao *et al*, 2013 [7], conducted kinematic analysis of up-film planting devices and selected optimum driving wheel diameter, dibble diameter, number of dibbles and plant spacing for low leakage rate of plantation for uprightness of seedling and minimum damage of mulch film.

Similar analysis was conducted for uprightness of seedlings, where drive wheel radius (R_1) was made fixed, speed ratio was selected and made fixed (G), and number of dibbles (4) was selected based on the ground clearance of dibble wheel under complete lift position of tractor hydraulic. Horizontal and vertical displacements of dibble cups were plotted.

From the equation ix, four different radius of dibble wheel R_2 (10, 20, 30 and 38.5 cm) was checked for zero velocity condition at different machine forward speeds (V).

By considering the values in Table. 3, displacement plot is drawn in Microsoft Excel 2010, using parametric equations i and ii for different radii of dibble (R_2) and planting frequency of 20 plants/min (0.72 kmh^{-1}) is shown in Fig. 4.Similar plots were drawn for forward speeds of 1.08 (Fig.5) 1.44 (Fig.6), 1.8 (Fig.7) and 2.16 (Fig. 8) kmh^{-1}. X and Y axis in plots represents the horizontal and vertical displacements of dibble cups respectively.

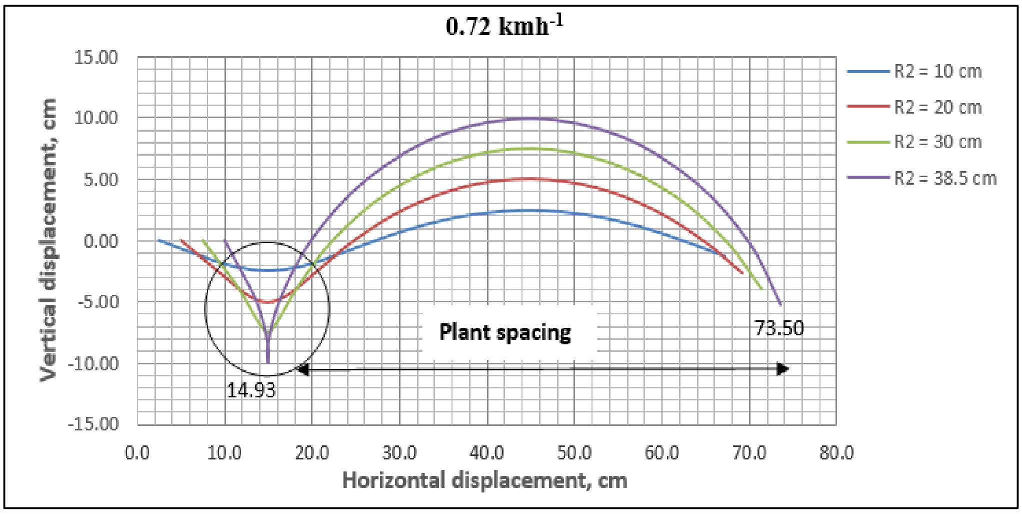

Fig 4: Displacement of dibble cups with different diameters and f= 20 plants/min

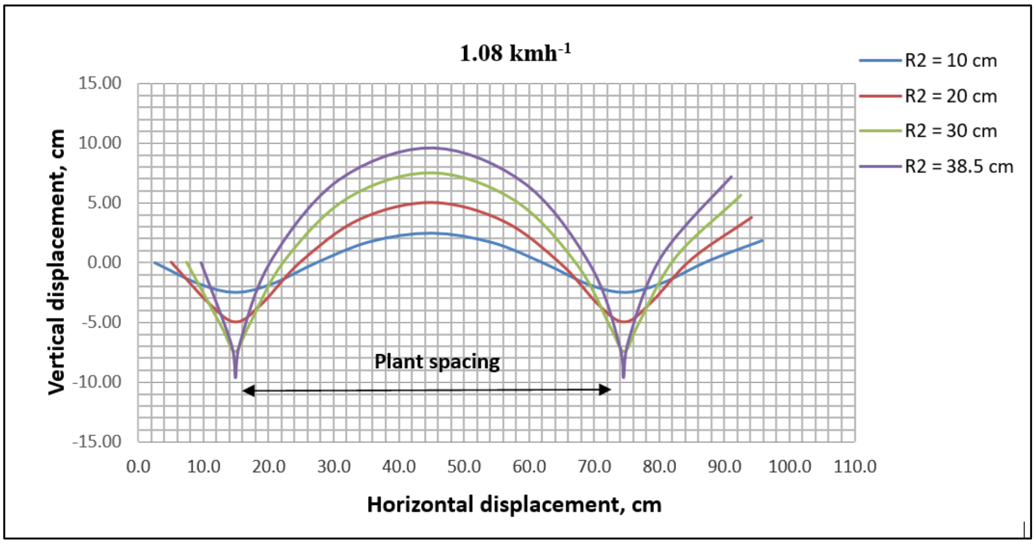

Fig 5: Displacement of dibble cups with different diameters and f= 30 plants/min

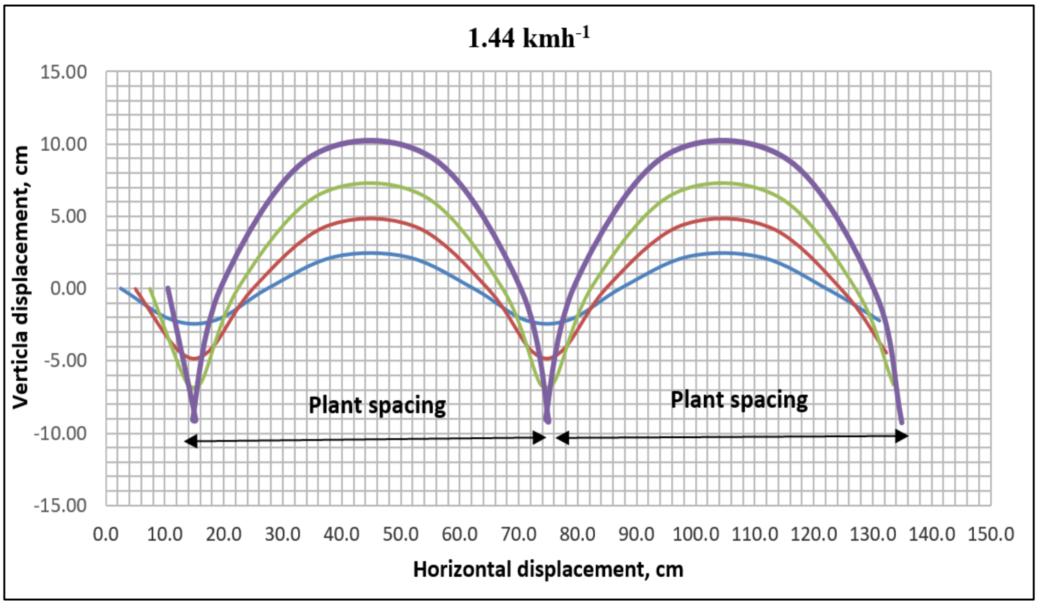

Fig 6: Displacement of dibble cups with different diameters and f= 40 plants/min

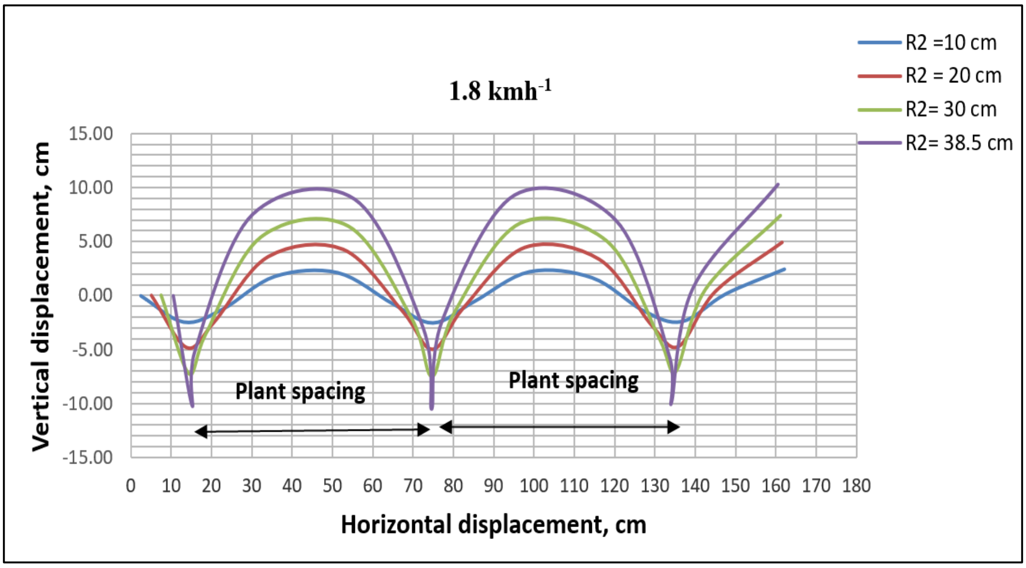

Fig 7: Displacement of dibble cups with different diameters and f= 50 plants/min

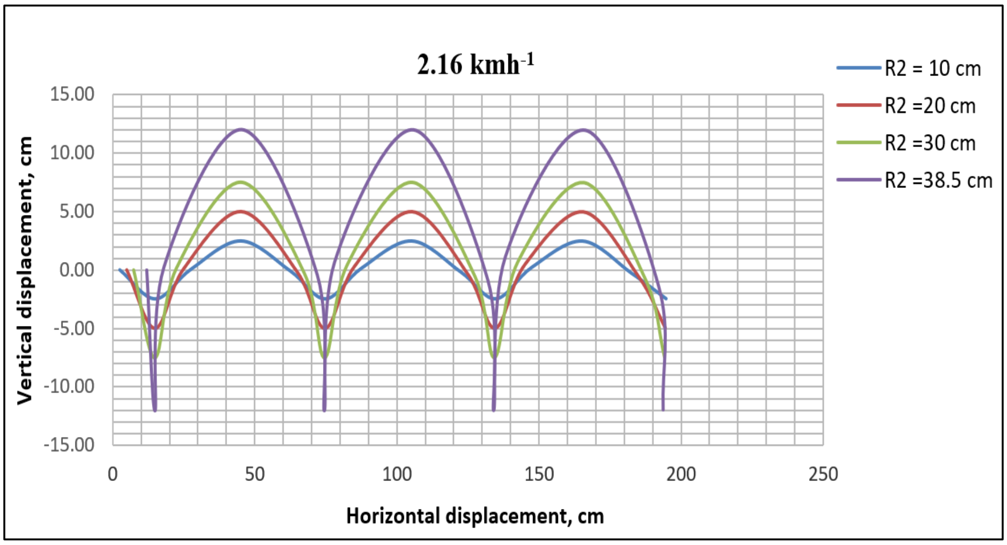

Fig 8: Displacement of dibble cups with different diameters at f= 60 plants/min

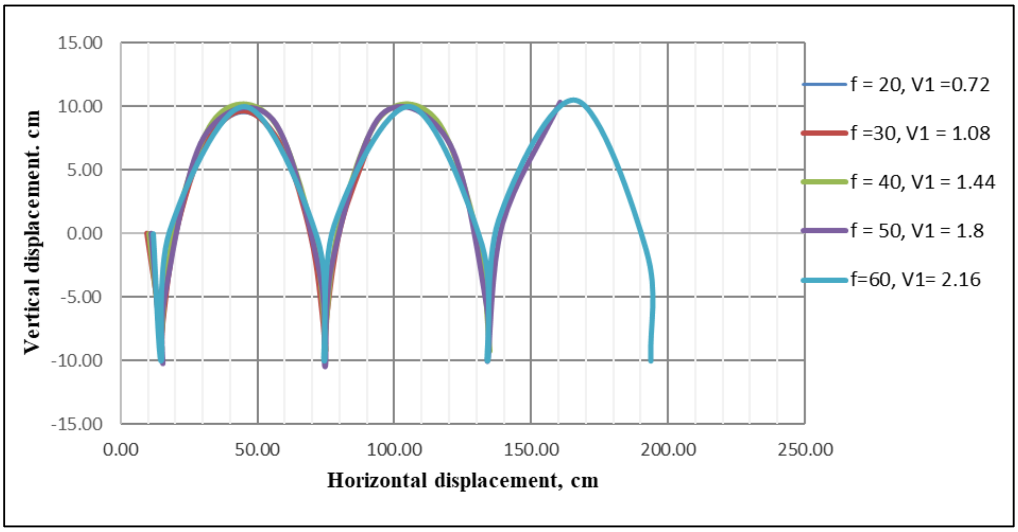

Fig 9: Displacement of dibble cups at different forward speed with 38 cm dibble radius

Fig. 4 represents the horizontal and vertical movement of dibble cups at different radii of dibble wheel at forward velocity of 0.72 kmh^{-1} (20 plants /min). Circled portion in the Fig. 4 represents the penetration of dibble cup in to the soil. During the dibbling operation, if the displacement curve forms closed trochoid, then the dibble cup would have a positive plant stand at zero velocity of dibble cup. When the radius of dibble cup was increased from 10 cm to 30 cm, the displacement curves were of open trough shaped (circled portion). This is due to the increased speed of dibble due to reduced diameters as compared to the driving wheel radius (40 cm). The λ values corresponding to the dibble diameters of 10, 20 and 30 cm were 0.26, 0.52 and 0.78. When the dibble diameter was 38.5 cm, the displacement curve forms a closed trochoid at the lower portion and corresponding λ value was 1.0 shown in Table 2. Chen *et al*., 2011 [2], simulated the planting movement of dibble- type transplanter and devised a condition $\lambda \geq 1$ for better planting of seedlings. The displacement curve obtained at the diameter of 38.5 in the present study was similar to λ =1 in Fig.3.

Similarly, displacement curves at all the forward speeds of 1.08, 1.44, 1.8 and 2.16 kmh^{-1}(Fig. 5, 6, 7and 8) with radius of 10, 20 and 30 cm, formed an open trough shape, whereas the dibble wheel of radius 38.5 cm had close trochoid.

From Fig. 4, the distance between the two formed dibbles would be (73.5 -14.93 = 58.57 cm) 60 cm, but at 0. 72 kmh^{-1}only one dibble cup was in contact (t = 13 sec). Whereas, at 1.08, 1.44, 1.8 and 2.16 kmh^{-1} number of dibbles coming in contact with ground surface was 2, 3, 3 and 4, respectively for all the diameters. This was evident from the plots that, as the forward speed (V) increases, number of dibbles coming in contact with ground would also increase at fixed gear ratio (G), radius of driver (R_1) and plant spacing (S).

At higher forward speed of travel i.e., 2.6kmh^{-1}as shown in Fig. 9, the dibble radius of 38 cm observed closed trochoid which indicating λ =1. It is further observed that forward speed of travel speed has no effect on the zero-velocity condition, when the driver and driven members were coupled with gear ratio satisfying the condition of parametric function λ.

5. Conclusions

- Gear ratio of 0.95 was selected between rear wheel of mini-tractor to dibble wheel based on plant spacing (60 cm), number of dibble cups (4) and diameter of rear wheel of tractor (80 cm).
- The machine could able to plant 20, 30, 40, 50 and 60 plants/min with verticalness of seedlings at forward speeds of 0.72, 1.08, 1.44, 1.8 and 2.16 kmh^{-1} with a dibble swing radius of 38 cm because the forward speed had no effect on the zero-velocity condition of dibble.
- At all the forward speeds, the displacement plots showed open trough shape for the dibble radii of 10, 20 and 30 cm with parametric function value λ <1, which indicates that dibble radii was not suitable for zero velocity condition at gear ratio of 0.95.
- Dibble radius greater than 38.5 cm shown a closed trochoid for all the speeds with parametric function value λ = 1, indicating that all radii greater than 38.5 cm would achieve zero velocity condition for verticalness in planting of seedlings.

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