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Development of an Auger Conveyor Type Metering Device for Transplanting of Vegetable Seedlings Raised in Paper Pots

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ABSTRACT: *An auger type metering mechanism which consisted of an auger type metering device, a seedling delivery tube, a furrow opener, a furrow closer, a power transmission system and a frame was developed for metering of paper pot seedlings for transplanting. The setup was evaluated in simulated field conditions (soil bin) in order to select the operating parameters of the metering device. Evaluation was carried out with pot seedlings of 10-15 cm height at five forward speeds i.e. 1.6, 1.8, 2.0, 2.2 and 2.4 km/h. Data on intra row spacing, angle of inclination of seedling, soil coverage and conveying efficiency (CE), feeding efficiency (FE), transplanting efficiency (TE) and overall efficiency (OE) were determined. The CE, FE, TE and OE were found to be higher than 90% for forward speeds up to 1.6 to 2.0 km/h. Further, the increase in forward speed above 2.0 km/h resulted the FE higher than 90%, however, the TE and OE reduced below 55%. Moreover, increase in the seedling tilting greater than 15% (angle of inclination of seedling >30º from vertical plane) was observed beyond the forward speed of 2.0 km/h. The developed auger type metering mechanism was found to be suitable for metering of vegetable pot seedlings up to the forward speed of 1.6 to 2.0 km/h effectively at a planting rate of 53 to 65 seedlings/min.*

Keywords: *Auger, metering, seedlings, vegetable transplanter*

INTRODUCTION

In India, the 25-year temporal vegetable cultivation from the year of 1991-92 to 2014-15 shows, increased trend of production (from 58.532 to 168.3 t) of about 187% over 70% increased cultivable area (from 5.593 mha to 9.541 mha) (Anon, 2016). Farmers allocate a small proportion of land to vegetable cultivation (Kumar and Raheman, 2008). The estimated demand of vegetable by the year of 2020 is 220 t (Anon, 2016). Non-availability of labour during peak season and increased labour cost in last decade are bottlenecks in increasing area under vegetable cultivation (Pandey and Singh, 2004). The vegetable transplanting mainly accomplished manually (260 to 320 man-h/ha) using bare-root seedlings and is a time consuming and costly operation. Therefore, mechanical transplanters have been developed to overcome the problems in manual transplanting. These transplanters include devices for feeding, conveying and metering of a variety of vegetable seedlings. Initially, semi-automatic transplanters were reported as successful for transplanting of vegetable seedlings, but they require significantly high number of labourers to feed the seedlings to the transplanter. To overcome the limitations of semi-automatic transplanter, automatic vegetable transplanters with suitable mechanisms to feed the seedlings to a metering device without any human intervention have been developed for plug and pot type seedlings (Suggs *et al.,* 1987; Choi *et al.,* 2002; Ueno *et al.,* 2002). Although these automatic and robotic transplanters performed well, their structural complexity and requirement of skilled operator made these machines unable to reach the Indian farmers. In addition to that these transplanters are not economically viable for Indian conditions because of their high manufacturing costs and unavailability of maintenance facility (Choi *et al.*, 2002). Therefore, there is a need to develop an automatic transplanter which is structurally simple, functionally accurate, and economically feasible and low-cost in maintenance.

The metering mechanism/device of transplanter directly affects the performance of the transplanter (transplanting efficiency). The metering mechanisms and type of seedlings used in various semi-automatic and automatic vegetable transplanters around the globe are summarized in Table 1.

Table 1. Different types of metering mechanisms with their suitability for semi-automatic and fully-automatic transplanters for bare-root, plug and pot type seedlings

Metering mechanism	Seedling type	Author and Year
Semiautomatic vegetable transplanter		
Pocket type (finger/picker wheel type)	Bare root	Rotty, (1960); Chaudhuri *et al.,* (2003); Singh, (2008); Satpathy and Garg, (2008); Kumar and Tripathi, (2016)
Conveyer type	Bare root Pot Plug	Margolin *et al.,* (1986); Harrison *et al.,* (1990); TNAU, (2006); Mahapatra, (2010); Dihingia *et al.,* (2016)
Revolving magazine or rotary cup type	Plug	Choon, (1999); Craciun and Balan, (2005); Anon, (2006);
	Pot	Gaikwad, (2010); Ganapathi and Kumar (2015)**
Multi-stage metering type	Paper pot	Nandede and Raheman (2016)
Automatic vegetable transplanter		
Vertical descending cup	Plug grown	Munilla and Shaw (1987)***
Rotary planting fingers	Chain of pots	Nambu and Tanimura (1992)
Seedling pick–up device	Plug	Brewer (1994); Tsuga (2000); Kim *et al.* (2001); Choi *et al,* (2002); Park *et al.,* (2005)*
Push-plug type (pneumatic ejector)	Plug	Shaw (1997)
Conveyor type	Paper pot	Feng *et al.* (2000);
Combined lateral and longitudinal conveyor		Kumar and Raheman (2011)

**pick-up linkage with elliptical path (hole-pin type and latch type)*
***metering mechanism developed for conical paper-pot type rice seedlings*
****A high-speed dibbling transplanter under mulched condition*

The developed vegetable transplanters require either bare-root, plug or pot type seedlings. Feeding of seedlings consisted of singulation, selection, alignment and transfer of seedlings to the planting device, which are difficult to accomplish with bare-root seedlings (Suggs *et* *al*., 1987). Therefore, either tray grown plug seedlings or seedlings grown in bio-degradable pots with a provision to place the seedlings in the soil without removal of pots during transplanting are used for automatic feeding of seedlings to the metering device. The initial investment on trays for raising plug seedlings being expensive; seedlings raised in paper pots seems to be a better option due to their ability to degrade, lower cost and easiness in preparation (Ueno *et al.,* 2002).

Developed robotic and fully-automatic vegetable transplanters are much suitable for either plug seedlings or pot seedlings due to ease in picking by discriminating individual seedlings by metering mechanism (Luhua, 2015; Jiang *et al.,* 2015). These robotic and fully-automatic transplanters have structural complexity in metering mechanism (especially with plug seedlings). They are expensive and sensitive to seedling type and uniformity, they require skilled labours. Whereas, semi-automatic transplanters are simple but have limited by speed of operation (by manual feed rate 30 to 40 plants/min). Therefore, there is necessity to develop simple affordable metering unit for fully-automatic transplanters to achieve high planting rate.

MATERIALS AND METHODS

Metering device and its components

The isometric exploded view of the auger type metering unit is shown in Figure 1. The developed laboratory setup consisted of a right-hand auger of 50 mm (±1.5 mm) pitch and diameter of 100 mm fabricated using 2 mm Mild Steel (MS) sheet mounted on a 16 mm diameter shaft (8, 9). A trough opens at top side *i.e.* fabricated from MS sheet of 1.6 mm thickness (7). End plates fabricated from MS sheet of 3 mm thickness was used to fix the auger shaft at both ends (5). A rectangular cut was made at one end of the trough to deliver the seedlings to delivery tube (6). A rectangular socket (11) was fixed at the power transmission shaft. At one end of the auger shaft after end caps, a plug pin was welded (10) to transmit the power to the auger and easy removal of the auger metering unit. A support bar (4) was fabricated to hold the power transmission assembly to auger metering unit. Main shaft fabricated from MS rod of 20 mm diameter (1) and to transmit the power to auger metering unit in 90°, two bevel gears were used (2) along with linking shaft (3). Auger was placed inside the open top rectangular box and closed with end caps. The end plates were bored twice with marginal pitch of 10 mm and 40 mm apart to mount box with nut and bolts. The centre hole is provided to hold the shaft (auger blade mounted) and auger shaft is free to rotate about its axis and locked for movement with split pins on both side to form a metering unit assembly. The overall dimensions of individual detachable auger metering unit were 1125 mm length, 107 mm height and 120 mm width.

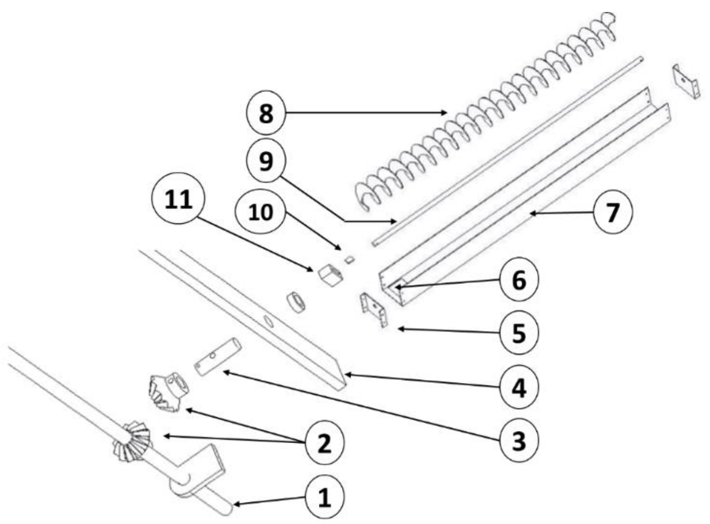


Figure 1. The isometric exploded view of the auger type metering unit

1. Idler shaft; 2. Bevel gear; 3. Linking shaft; 4. Support bar; 5. End plate; 6. Opening for seedling drop; 7. Opened top rectangular box; 8. Right hand auger; 9. Shaft; 10. Plug pin to receive the drive; 11. Rectangular socket

The pitch of auger was decided based on the pot diameter calculated for 82 cc pot volume (Ueno *et al.,* 2002; Nandede *et al.,* 2014). The mitre type bevel gear (12 teeth) is used for perpendicular power transmission form idler (intermediate) shaft to auger metering units with rectangular socket as drive outlet. This was driven by ground wheel. The tests conducted for rigorous evaluation in the soil bin unit (simulated field condition).

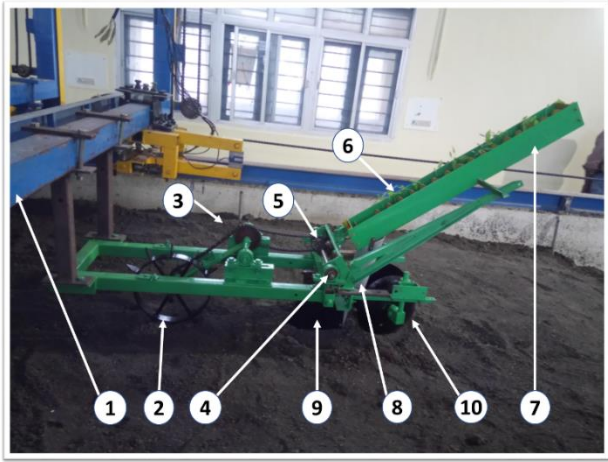
While operation, the seedlings were placed at one side of the auger and allowed to conveyed in upright position towards the discharge point where a seedling delivery tube was provided. Side wall of the trough guided the seedlings towards the seedling delivery tube (Figure 2). The seedling was then dropped into the furrow opened by the furrow opener. The dropped seedlings were further covered with soil by the furrow closer attached to the shank of the furrow opener. The rotational speed required for the metering mechanism corresponding to different forward speeds (1.6, 1.8, 2.0, 2.2 and 2.4 km/h) for transplanting seedlings to obtain plant spacing's of 50 cm was calibrated. It was set accordingly while evaluating the metering mechanism under controlled soil bin conditions.

Pot seedlings configuration

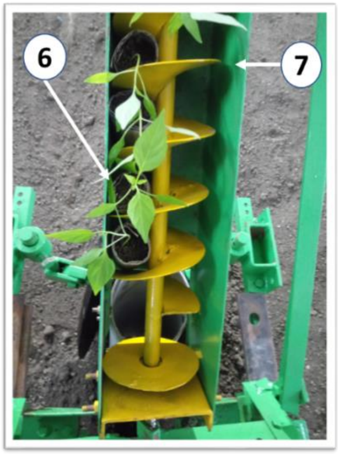
The seedlings raised in cylindrical shaped paper pots (50 gsm recycled newspaper) were used for conducting the experiments. Soil based potting mix of Farm Yard Manure (FYM): Soil: Sand used in 4:1:1 on volume basis and pot size of 82 cc were used, as it was found to be suitable for raising good quality seedlings of all the three vegetables (Nandede *et al.,* 2014). The mean dimensions of the pots used in experiments were of diameter 50±1 mm, height 40±1.5 mm, maximum diagonal length 64±1 mm and weight 65±1.5 g. The moisture content of the potting mix was maintained at 16±2% as it gave the highest feeding and conveying efficiency for the paper pot.

Experimentation setup in soil bin

The experimental set-up consisted of an indoor soil bin of size 15 m × 1.8 m × 0.6 m, the trolley consists of soil processing trolley at one side and other side with implement trolley. The implement trolley consisted of a tool bar where the furrow opener, furrow closer, ground wheel along with the auger type metering unit, were attached as shown in Figure 2.



a. Side view



b. Top view

Figure 2. Developed experimental setup of auger type metering unit

1. Implement trolley 2. Ground wheel 3. Power transmission system 4. Main shaft 5. Bevel gear holding assembly 6. Seedling feed side of auger box 7. Auger conveyer unit 8. Delivery tube 9. Furrow opener 10. Furrow closer

The auger type metering unit was attached to implement trolley and powered by ground wheels for metering of paper pots. The metering unit power transmission system consisted of a combination of suitable ratio of chain and sprocket as well as bevel gears. The forward speed of operation was controlled by variable speed motor and drive and measured using laser distance sensor. Operating depth was maintained at 50 mm. The data were acquired and recorded using Data Acquisition System (DAS). Data on forward speed and depth of operation were recorded on DAS of HBM make and QuantemX Model (HBM India, A Division of Spectris Technologies Pvt. Ltd. 5th Floor, Arihant Nitco Park, #90 Dr Radhakrishnan Salai, Chennai 600004).

Test procedures

The set-up was initially set for the correct timing of the feeding of seedlings to the discharge point by the auger conveyer. A 7.76 kW electric motor with gearbox was used to give forward motion to the implement trolley and ultimately to the metering unit. The variation in the forward speed ranging from 1.6 to 2.4 km/h was carried out by variable speed motor drive. The calibration for forward speed was carried out to find out the frequency to get desired operating speed. Metering unit was lowered to the ground to set 50 mm depth of operation for the furrow opener and the double disc closer. The inclination angle of the disc closer was set at 15° angle to get minimum required soil coverage with lesser draft (Nandede *et al.*, 2014). A total of 20 pot seedlings of uniform height and potting mix with uniform moisture content were placed on the auger conveyor. As the setup moves forward, the ground wheel starts rotating the auger conveyor through set of chain sprocket and bevel gears. The calibration of the Variable Frequency Drive (VFD) was carried to obtain desired value of frequency to be set to get varied forward speed of the setup. The VFDs' frequency was then set to get selected forward speed. The motor was switched on and set was allowed to move in forward direction. The auger conveyor rotated by extracting the power from ground wheel with set of chain sprocket and bevel gears, seedlings started moving towards seedlings discharge point. The seedlings were in upright orientation and seedlings without any damage were only allowed to enter to the metering unit. The pots that got damaged in the space between the delivery tube and metering auger were removed quickly and were counted (N_c). The seedlings which were not dropped in upright orientation and damaged at the mouth of seedling delivery tube were counted (N_p). Each test was carried out for a test length of 10 m in the prepared soil bed and was replicated thrice. With the help of proximity switch, the data on forward speed of operation were continuously recorded by DAS. After the test, the amount of soil coverage of the seedlings was measured and expressed as a percentage of soil coverage by measuring the height of pot seedling covered with soil using a measuring scale. Angle of inclination of the seedling from vertical was measured with the help of a protractor. Actual plant to plant spacing was measured by a measuring tape in the soil bin. At the end of each test, the soil bed was disturbed and was prepared again following the same procedure to maintain the desired soil conditions for further tests. Performance parameters such as conveying efficiency (CE), feeding efficiency (FE), transplanting efficiency (TE) and overall efficiency (OE) were determined using following formulae:

Conveying efficiency (CE) % $= \dfrac{\text{TNP} - N_c}{\text{TNP}} \times 100$ … (1)

Feeding efficiency (FE) % $= \dfrac{\text{TNP} - N_c - N_f}{\text{TNP} - N_f} \times 100$ … (2)

Transplanting efficiency (TE) % $= \dfrac{\text{TNP} - N_f - Nc - N_p}{\text{TNP} - N_f - N_c} \times 100$ … (3)

Overall efficiency (OE) % = FE × CE × PE/10000 … (4)

Soil covering efficiency of furrow closer % $= \dfrac{Tp_1 + Cp_1}{Tp + Cp} \times 100$ … (5)

Partially soil covered seedlings % $= \dfrac{Tp_2 + Cp_2}{Tp + Cp} \times 100$ … (6)

Percent excessive soil covered seedlings % $= \dfrac{Tp_3 + Cp_3}{Tp + Cp} \times 100$ … (7)

Where,

TNP = Total number of plant fed to the metering mechanism

N_c = Number of pot seedlings damaged on while conveying

N_f = Number of pot seedlings damaged during feeding to drop tube

Np = Number of pot seedlings that failed to drop in upright orientation (seedling inclination of >30 º from vertical)

Tp = Tilted plantings. In which number of seedlings with sufficient amount of soil covered (Tp_1), partially soil covered (Tp_2) and excessive soil covered ($Tp3$) seedlings.

Cp = Correctly planted seedlings. In which number of plants with sufficient amount of soil covered (Cp_1), partially soil covered (Cp_2) and excessive soil covered (CP_3) seedlings.

RESULTS AND DISCUSSION

Pictorial views of seedlings fed to the metering unit (inset) and transplanted seedlings by the developed auger conveyer type metering unit in the soil bin condition are shown in Figure 3. Evaluation of the auger metering unit was carried out using pot seedlings.

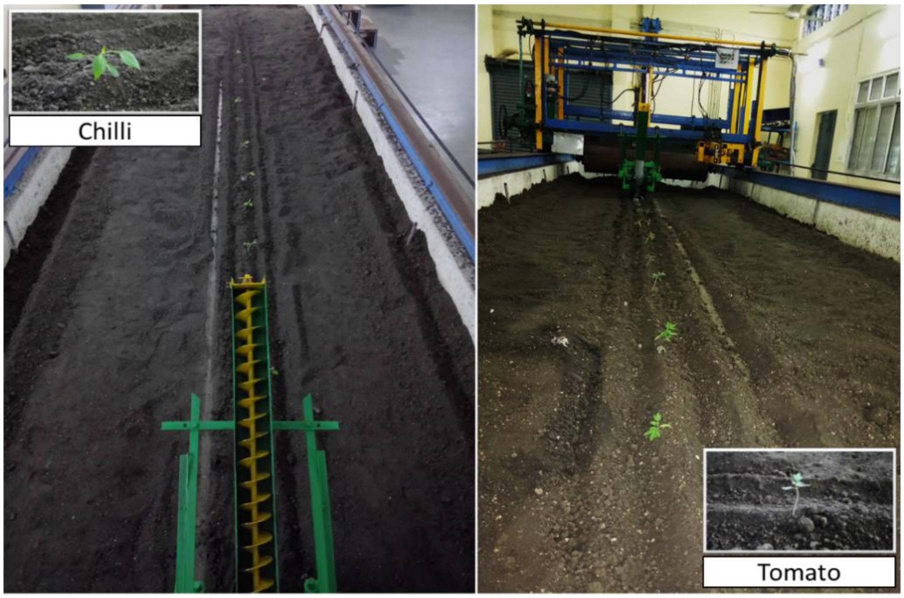


Figure 3. Pictorial views of seedlings fed to the metering unit (inset) and transplanted seedlings by the developed auger conveyer type metering unit in the soil bin condition

Effect of forward speed of operation on different efficiencies of auger conveyer

Selection of the highest possible forward speed of operation for auger conveyor without compromising the transplanting efficiency was carried out. Mean values of FE, CE, PE and OE were plotted against forward speed (Figure 4).

It is evident from Figure 4, that the FE was found 100% and CE, PE and OE using seedlings for a desired plant spacing of 500 mm are found to be above 90% up to the forward speed of 2.0 km/h. Further increase in forward speed to 2.2 and 2.4 km/h, FE was found 90-100% but PE and OE drastically reduced below 85%. For reasonable plant spacing, the feed rate clearly limits the maximum allowable forward speed of the transplanter (Srivastava *et al.*, 2006). Therefore, a negotiation needs to be made between the seedling feed rate requirement and the maximum forward speed achievable, to run planter with acceptable damage of plantings in metering. Literature shows that on vegetable transplanter, a planting rate in the range of 35 to 45 seedlings/min and a forward speed in the range of 0.9 to 1.4 km/h have been achieved for most of the semi-automatic vegetable transplanters, to keep missed plantings within acceptable limits (Singh, 2008; Satpathy and Garg, 2008; Kumar and Raheman, 2008). Tilted planting of 3 to 4% were reported (Singh, 2008) for pocket-type planting devices that used for bare-root seedlings. Narang *et al.* (2011) reported that 2.2 to 4.4% missed plantings for a revolving magazine-type or rotary-cup-type metering device. This indicates the plants that are damaged or not able to feed by metering unit into furrow (missed planting). In automatic transplanters using conveyor type metering mechanism achieved the forward speed of 0.9 km/h (0.026 ha/h for two row) for 45x45 cm spacing tomato seedlings. The planting rate were 32 pot/min seedlings with 4% missed planting. Another commercially available automatic transplanter using a pick-up type metering mechanism achieved the planting rate of 66 seedlings/min (Kumar and Raheman, 2011). In the present study, the developed auger metering mechanism can meter the pot seedlings satisfactorily with forward speed of 1.6 to 2 km/h at planting rate of 53 to 65 seedlings/min.

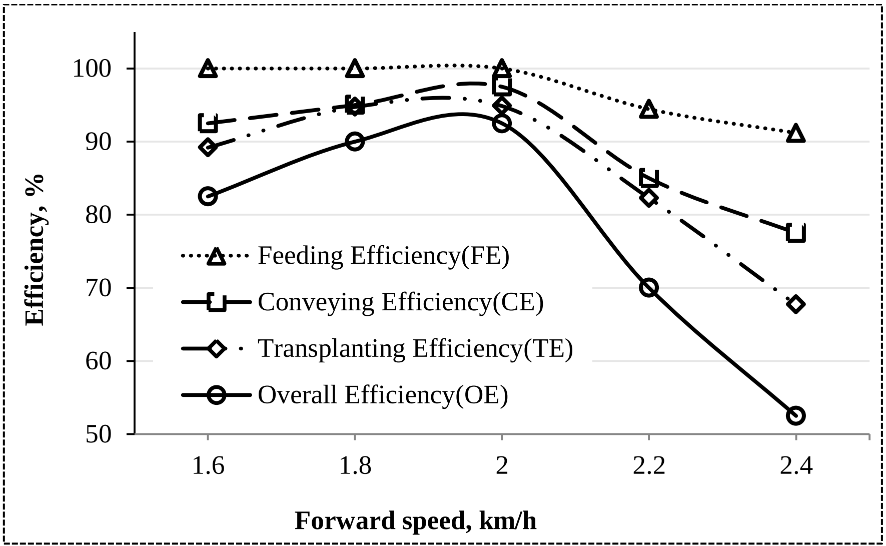


Figure 4. Effect of forward speed of operation on different efficiencies of auger conveyer

Effect of forward speed on seedling tilting and soil coverage

The tilted planted percentage was varied 5 to 25% range for 1.6 to 2.4 km/h, the acceptable level was achieved in speeds of 1.8 km/h and 2 km/h (Figure 5). The reason for increased tilting in lower speed could be due to unbalance of inertia of pot mass (which moves in the direction of forward speed and inclined 30° in vertical plane) and forward speed inertia imparted by machine on pots. The pots stand becomes stable when the relative motion of pot due to inertia becomes nearer to zero prior to reach the surface. After certain speed, tilting increased about 15% and 25% in forward speed of 2.2 and 2.4 km/h, respectively. Similarly, excessive soil cover percentage is decreasing with increase in forward speed. The speeds above 1.8 km/h shows the excessive soil cover over pots depth of about 9 to 15% with decrease in speed of 2.4 to 1.8 km/h, respectively. Though, the excessive soil over of about 15% is acceptable, partially covering percentage is most important factor for root growth and stand support of seedling in new environment. The lowest partial soil coverage percentage was observed with 2 km/h forward speed.

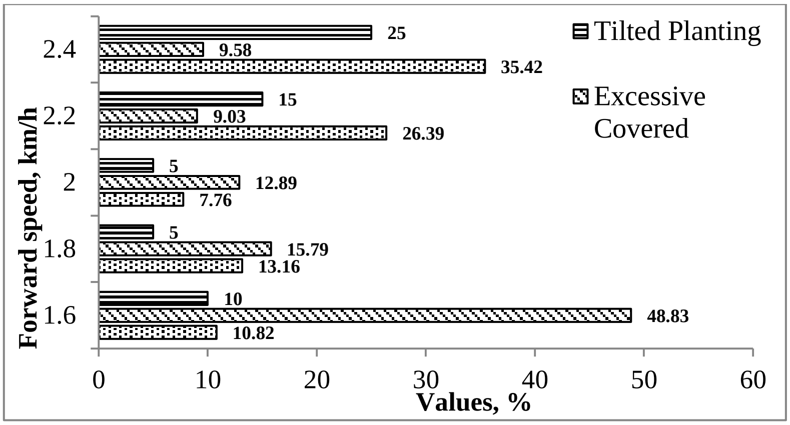


Figure 5. Tilted planting (%), excessive soil covered (%) and partially soil covered (%) observed at different speeds during evaluation of the auger conveyer type metering device

Effect of operating speed on the intra row spacing

The intra-row plant spacing measured in three replications for selected range of speeds are shown in Table 2. The average spacing was varied from 49 to 55 cm with standard deviation (SD) of ±3.34 to ±5.89 cm for intended spacing of 50 cm, when the speed varied between 1.6 to 2.4 km/h. The various researcher considered that spacing is acceptable when it is varying either side of about ± 2 to 3% of its theoretical designed spacing (Chaudhuri *et al.*, 2002; Kumar and Raheman, 2011; Dihingia *et al.*, 2016). In the present study, the increase in forward speed up to 2 km/h shows about ±3.5 cm, further it increases up to about ± 6 cm at 2.4 km/h. The average spacing of all replications shows that, it is in control up to 2 km/h with 49.88 to 50.62 cm, later its average increased (up to 55.4 cm) with increase in deviation (±5.89) at the highest speed selected. Therefore, suitable forward speed to operated auger conveyer type metering device was 2 km/h at acceptable transplanting and spacing deviation.

Table 2. Plant spacing obtained at selected forward speeds

Replication	Measures (cm)	Operating speed, km/h				
		1.6	1.8	2	2.2	2.4
R_1	Range	46-57	45-57	45-58	47-62	44-66
	Mean	51.32	51.00	50.95	53.95	55.58
	SD	3.06	3.64	3.67	4.56	5.91
R_2	Range	44-56	45-56	46-56	42-62	45-66
	Mean	49.68	49.63	49.79	53.26	55.95
	SD	3.74	3.55	3.01	5.06	6.84
R_3	Range	44-57	47-58	44-59	44-61	45-65
	Mean	49.22	51.22	48.89	52.57	54.67
	SD	3.23	3.16	3.47	5.19	4.94
Average range		44.67 to 56.67	45.67 to 57	45 to 57.67	44.33 to 61.67	44.67 to 65.67
Average		50.07	50.62	49.88	53.26	55.40
SD		3.34	3.45	3.38	4.94	5.89

CONCLUSIONS

The feeding and planting efficiency of the developed auger type metering unit were found to be above 90% up to forward speeds of 2.0 km/h. With further increase in speed to 2.2 and 2.4 km/h, the feeding efficiency was observed to be higher than 90%, whereas, the planting efficiency drastically reduced below 85% due to the problem in getting the pot seedlings vertically in the furrow in turn unsuitable for transplanting. Average plant to plant spacing and soil covering efficiency with the developed metering unit was found to be 50±2 cm and 100%, respectively. The forward speed between 1.6 to 2 km/h was found suitable for automatic feeding and metering of vegetable seedlings with the developed auger type metering unit. Operating speed above 2.0 km/h increases the percentage of tilting and partial soil coverage above 15% and 26%, respectively.

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