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Development and Evaluation of Vertical Cup with Split Base Type Metering Mechanism Cum Dibbler for Semi-Automatic Transplanter Using Cell Feed Type Nursery

S. Bhambota*, A.K. Dixit, G.S. Manes and S.K. Singh

Department of Farm Machinery and Power Engineering, PAU, Ludhiana-141002, India

**Corresponding author*

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A B S T R A C T

A vertical cup with split base type metering mechanismwas developed for transplanting cell type nursery. The metering mechanism holds the nursery seedling, dig a hole in the soil at desired depth and releases the seedlings in the hole in near vertical position without any damage. The developed metering mechanism was evaluated in the laboratory for transplanting artificial nursery grown in trays having three different cell sizes 50, 98 and 105 cells/tray at three different feedrates i.e 50, 65 and 80 feeds per minute respectively forthree subjects. Plant missing increased with increase in feed rate for all the subjects and average plant missing for cell C3 and feed rates of 50 plugs/min, 65 plugs/min, and 80 plugs/min was respectively: 0.0%, 0.51%, and 7.92% for subject S1; 2.00%, 1.03%, and 5.00% for subject S2; and 5.33%, 4.62%, and 20.42% for subject S3. However, the effect of cell size on plant missing was non-significant. Plant doubling was observed only for one subject at highest feed rate (2.41%). Quality of feed index decreased with increase in feed rate for all the subjects. The performance of the developed metering mechanism was found satisfactory for planting cell type nursery at 65 plugs/min in the laboratory evaluation

Introduction

At present shortage of about 30 million tonnes of vegetables has been estimated. With increase in population, India has to produce about 225 million tonnes of vegetable by the year 2030 in order to meet the demand (Vanitha *et al*2013). It is, therefore, necessary to shift more area under vegetable cultivation in India. Cultivation of vegetables is highly labour intensive. Labour requirements for transplanting of vegetables are 184-274 man-h/ha (Garg and Dixit 2002) which is very high.It is, therefore, apparent that mechanization of labour intensive operations like transplanting is essential for increase in the area under cultivation for vegetable crops.

Two types of vegetable transplanters are available viz automatic and semi-automatic. Plug/cell type nursery is commonly used in vegetable transplanters (Ladeinde *et al* 1995; Juric *et al* 1997; Anon 2004; Craciun and Balan 2005; Mandhar and Hebbar 2005; Ghadge *et al* 2008). However, some attempts have been made to develop vegetable transplanters using bare root type of seedlings also (Chaudhari *et al* 2001; Chaudhari *et al* 2003; Satpathy 2003; and Manes *et al* 2010). All the semi-automatic vegetable transplanters developed differ mainly w.r.t. the type of metering mechanism. Planting rates ranging from 50-80 plants/min have been recommended for semi-automatic machines for missing to be in acceptable limits (Splinter and Suggs 1968a; Suggs 1979; Way and Wright 1987). Higher planting rates cause very high missing in semi-automatic machines. Critical analysis of the design aspects of the machine indicate that although rotary magazine type metering mechanism has been commonly employed in semi-automatic vegetable transplanters by various research workers (Anon. 2004; Narang *et al* 2011; Nandede and Raheman, 2016), it has an inherent design deficiency because the free fall of the seedlings from a height allows no control on the orientation of the seedlings when it falls on the ground. Moreover, the seedlings can possibly be damaged during movement in the magazine as well as by the free fall impact on the ground. A picker wheel type metering mechanism was also developed for bare root type nursery (Manes *et al* 2010), butthe main problem with this type of metering mechanism was that the operator has very limited time available for feeding the seedlings in the picking fingers having narrow slot resulting in low field capacity.

Materials and Methods

Metering mechanism should be such that the seedlings are placed, carried, and safely released in the soil at proper depth and without any damage to the seedlings as well as in proper orientation (i.e. nearly in erect position).Therefore, the metering mechanism for the proposed vegetable transplanter comprising of a vertical wheel with nursery holding cups in vertical position was selected. The metering mechanism holds the nursery seedling, dig a hole in the soil at desired depth and releases the seedlings in the hole in near vertical position without any damage. Therefore, design basis of metering wheel included determining type and size of cup, diameter of disc of metering wheel, direction of rotation of the metering wheel, and mechanism to open and close cupsand mechanism to keep nursery holding cups vertical.

Cup type and size

The cup was made of two parts; the upper part that has a square opening for feeding seedling into the cup and the lower part that is similar to dibbler for making hole and dropping seedling into it. So, the upper part of the cup was made from a square hollow section and the lower part was truncated pyramid with two opposite sides in V-shape to penetrate into soil and the V opened at the tip to create a hole for dropping seedling. The metering mechanism was designed on the bases of maximum plant spread diameter (D_s) and length of seedling (L_s) at the time of transplanting of tomato, chilli and brinjal and it was observed maximum in case of chilli(D_s=115mm and L_s=150mm; Bhambota 2018), fraction by which plant canopy can be collapsed (X_c, assuming 40% of plant spread diameter), length of seedling in the upper portion of cup (assuming 75% of maximum length of seedling) and was calculated as

Size of cup opening = $D_s * (1 – X_c)$ = 115*0.60= 69 mm~70 mm (say) (1)

Now, total length of the cupcan be calculated as

$$Lc = Lcu + Lcl \qquad (2)$$

Where;
Lc = Length of the cup

Lcu = Length of the upper portion of cup
Lcl = Length of the lower V shaped part of the cup
Lcu= maximum length of seedling * fraction of length of seedling in the cup
= 150 mm x 0.75 = 112.5 mm

Lcl = (width of cup / 2) x $Cot15^0$ (3)
Lcl= (70 mm / 2) x $Cot15^0$ = 35 mm x $Cot15^0$ = 130.6 mm
Substituting values of Lcu and Lcl in Equation (2)

Lc = 112.5 mm + 130.6 mm = 243.1 mm or approximately = 244 mm (4)

The split part of the cup was extended to top of the upper rectangular part and was pivoted to the upper rectangular part of the cup. The opening and closing of the V was achieved with the help of a roller follower and a cam. The slanting faces of the V carried the roller followers. The V remained open as long as the roller follower was on the cam and the moment the roller follower left the cam, it returned to closed position with the help of a spring. Other two faces of the V-shaped part were part of a truncated pyramid (Fig. 1) and these faces were 94 mm wide at top and 30 mm wide at bottom. The V-shaped part was mounted on the metering discs of the metering wheel with the help of pin (Fig. 2).

Diameter of the metering disc of the metering wheel

The number of cups on the disc depends upon diameter of metering discs (D_m) which is governed by full arm reach of 5^{th} percentile to pick the nursery seedling from tray (756 mm), half arm reach of 5^{th} percentile (304 mm) to easily put the nursery into the cup from location of seat (Gite *et al*2009). Assuming 50 mm clearance on both sides of rotating metering discs, maximum diameter of the disc of metering discs is calculated below:

D_m = 2 x Half arm reach – 2 x clearance on both sides of the metering discs
or = (2 x 304 mm) – (2 x 50 mm) = 505 mm (say)
Therefore; diameter of the metering discs is 505 mm.

The cup would be mounted on the metering discs in the grooves on the periphery of the disc with the help of a pin. Conservatively assuming a clearance of 25% of cup length between adjacent cups, Equation 5 below gives the number of cups (Nc) on the metering discs was calculated as

Nc = (Circumference of the metering discs) / (Lc + 25% of Lc) (5)
= (π* Dm) / (Lc + 25% of Lc)

Nc = (π* 505 mm) / (244 mm + 25% of 244 mm) = 5.2 cups or 5 cups
Thus, metering discs of 505 mm diameter can hold five (5) cups only.

Direction of rotation of the metering wheel

The lower part of the cup is V-shaped and it has to penetrate in to the soil and opens to dig a hole like dibbler for releasing seedling. Considering the extent of soil disturbance, the rotation of the metering wheel was kept in the same direction as that of ground wheel.

Mechanism for opening and closing of cups

For each cup, two cam assemblies each consisting of a cam plate and a cam were mounted on the cam discs (Fig. 3)The opening and closing of the cup has beenplotted as wheel rotated from 0^o to 360^o (Fig 4). The lower part of the cup penetrates to full depth when metering wheel rotates by 180^o.

The cup began to open at 185^o rotation of metering wheel; it fully opens at 200^o rotation of the metering wheel; and it remains fully open from 200^o to 295^o rotation. The cup fully closes at 310^o rotation of the metering wheel.

Mechanism to keep nursery holding cups vertical

To hold thecups in vertical position, the mechanism used was similar to the mechanism used on pick-up type reel in grain combines. Metering discs and eccentric discs are positioned in such a way that that the straight lever is horizontal. Because straight lever maintains the vertical position of the cup, five straight levers (one for each cup) were provided.

Laboratory evaluation of the metering mechanism

Laboratory evaluation of metering mechanism was conducted to determine the feed rate (plugs/min) at which the quality of transplanting in terms of plant missing/doubling is satisfactory. Transplanting performance in terms of plant missing/ doubling was studied at three levels of feed rates (based on review) namely 50 plugs/min (F1), 65 plugs/min (F2), and 80 plugs/min (F3) for three subjects of different age (25, 35 and 45 years of S1, S2 and S3 respectively) and body structure which typically represented the agriculture workers of the Punjab. Measurements of transplanting performance parameters were taken for a duration of 30 minutes for each of the experiment. Artificial nursery was developed using POP which could be used repeatedly till the POP cell got damaged (Fig. 6). The metering mechanism was mounted on a frame, the height of which could be adjusted. This arrangement was similar to the set up employed for testing of seed drills/planters (Fig. 7). The reading of missing was taken for a duration of 1 minute at 25th minute interval after the start of feeding. It was taken as a miss when the operator was unable to feed the cup, and double when he puts 2 or more seedlings in the same cup. The quality of feed index was calculated by subtracting the percentage of plant missing and doubling from 100.

Results and Discussion

Plant missing

The effect of federate, cell size and subject on plant missing is shown in Table 2a and Fig. 8.The effect of feed rate (F) as well as subject (S) was highly significant (at 1% level). However, the effect of cell size (C) was found to be non-significant even at 1% level. It may be observed from table that the average missing increased with increase in feed rate (F) for all the cell sizes and subjects. For example, the average missing was observed to be 0.0%, 0.51% and 7.92% for feed rates of 50 plugs/min, 65 plugs/min, and 80 plugs/min, respectively for subject S1 and cell C3. Therefore, plant missing is bound to increase at higher feed rates. The plant missing significantly differed amongst the various subjects. For example, the average plant missing was 7.92%, 5.00%, and 20.42% for subjects S1, S2, and S3, respectively for feeding plug type nursery of cell C3 at 80 plugs/min. The subject S3 consistently showed relatively poor performance as compared to subject S1 and S2 at all feed rates (F) and cell sizes (C). This might be due to inability of the subject S3 to adjust to the increased work demand, although all the subjects were given the same training to feed the metering mechanism. The effect of cell size as well as the interaction (C x F) was non-significant. This indicates that the variations in the size of the nursery plugs for different cell sizes were not sufficiently large to cause problems in manually uprooting, handling, and feeding the plugs into the metering mechanism. The average plant missing for combination F3 S3 gave the highest average plant missing. This is because the average plant missing was the highest for highest feed rate (F3) and the subject S3. There was no significant difference in missing between F1 and F2 for all subjects and the interaction (C x F) was also non-significant. Average plant missing was observed to be lowest for combinations F2 S1, F2 S2, and F1 S2. Further, average plant missing was highest for the combination C2 S3 and these were lowest for the combinationsC3 S1, C1 S2, C3 S1, and C3 S2.

Plant doubling

No doubling was experienced for feed rates of 50 and 65 plugs/min for all the subjects (S) and cell sizes (C). Doubling ranging from 1.1% to 2.41% were observed at higher feed rate of 80 plugs/min (Table 2b). This value is rather low as compared to the plant missing which were observed to be very high at higher feed rate of 80 plugs/min. It is, therefore, obvious that doubling is not a significant parameter for evaluating cup type of metering mechanism on plug type nursery especially when feed rate for plug type nursery is controlled or restricted by the plant missing. Further, the doubling might be low because the subjects were trained to uproot either single plug from the tray or sort out single plug even if two plugs are picked from the tray before feeding the plugs into the metering mechanism.

Table.1 Brief specifications of the metering mechanism

Sr. No.	Parameters		Specifications
1.	Shape and size of cup, mm	:	Vertical cup type having upper part square hollow section and lower part truncated pyramid V-shaped (split in the middle)
2.		:	505
3.	Diameter of metering disc, mm	:	5
4.	Number of cups	:	Variable (changing gear ratios)
5.	Plant to plant spacing	:	Cam and roller mechanism
6.	Mechanism for opening cups	:	Eccentric disc type
7.	Mechanism for keeping the cups in upright position Drive to the metering mechanism	:	Pneumatic ground wheel (through chains and sprockets)
8.	Type of furrow opener	:	Truncated part of cup acts as dibbler

Table.2 Effect of feed rate (F), cell size (C), and subject (S) on missing, doubling, and quality of feed index in laboratory evaluation of the machine

a. Missing										
Feed rate (F)	**Mean for C X S X F**									**Mean of Feed rate (F)**
	C1			**C2**			**C3**			
	S1	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	
50(F1)	4.67	0.00	6.00	0.00	0.00	4.67	0.00	2.00	5.33	2.51^b
65(F2)	1.03	0.00	5.64	1.54	2.05	8.21	0.51	1.03	4.62	2.73^b
80(F3)	11.67	9.58	13.75	9.58	9.58	20.42	7.92	5.00	20.42	12.00^a
Mean of cell size (C)	5.81^a			6.23^a			5.2^a			
Mean of Subject (S)	S1 $(4.1)^b$			S2 $(3.25)^b$			S3 $(9.9)^a$			
b. Doubling										
Feed rate (F)	**Mean for C X S X F**									**Mean of Feed rate (F)**
	C1			**C2**			**C3**			
	S1	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	
50(F1)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
65(F2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
80(F3)	0.00	0.00	0.00	0.00	0.00	2.41	1.10	0.00	2.02	0.61
c. Quality of feed index, %										
Feed rate (F)	**Mean for C X S X F**									**Mean of Feed rate (F)**
	C1			**C2**			**C3**			
	S1	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	
50(F1)	95.33	100.00	94.00	100.00	100.00	95.33	100.00	98.00	94.67	97.48
65(F2)	98.97	100.00	94.36	98.46	97.95	91.79	99.49	98.97	95.38	97.26
80(F3)	88.33	90.42	86.25	90.42	90.42	81.99	93.18	95.00	81.60	88.62

Fig.1 Detailed drawing of the upper cup (left) and lower (right) part of the cup

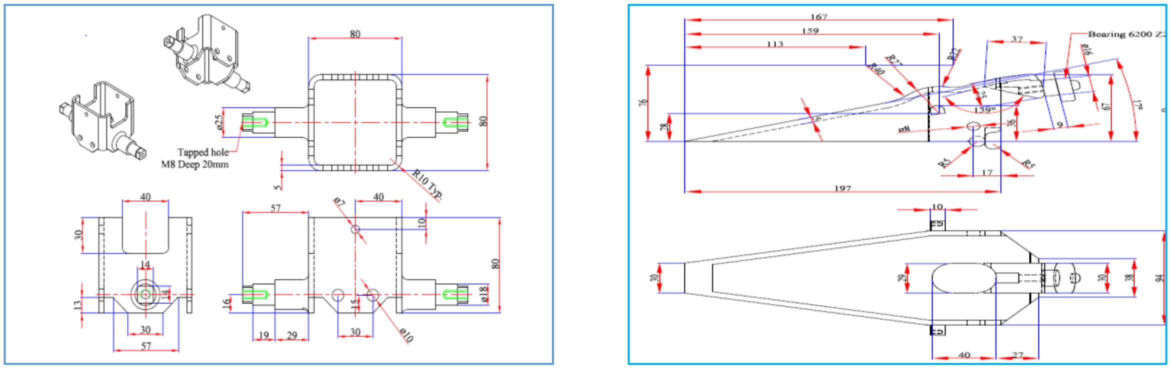


Fig.2 Detailed drawing of cup assembly

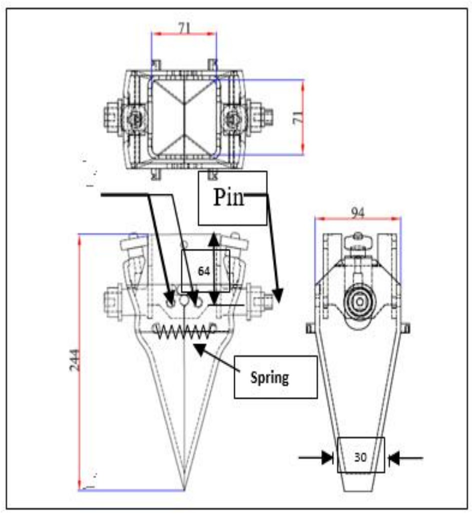


Fig.3A schematic view of the cams for opening and closing of the cups

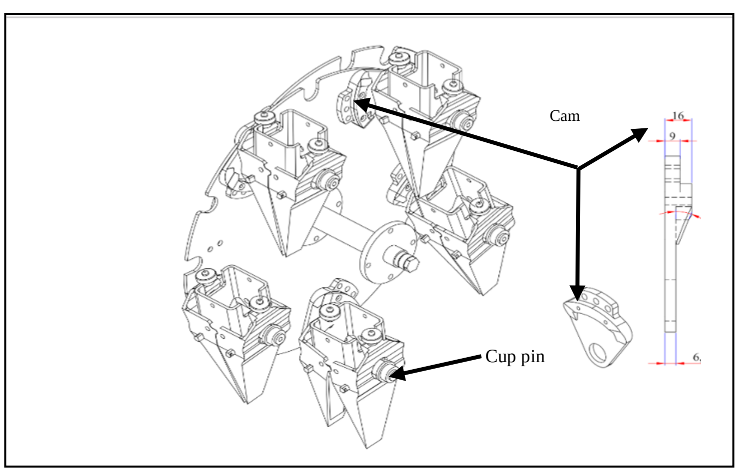


Fig.4 Motion of a point on top of cup relative to metering wheel

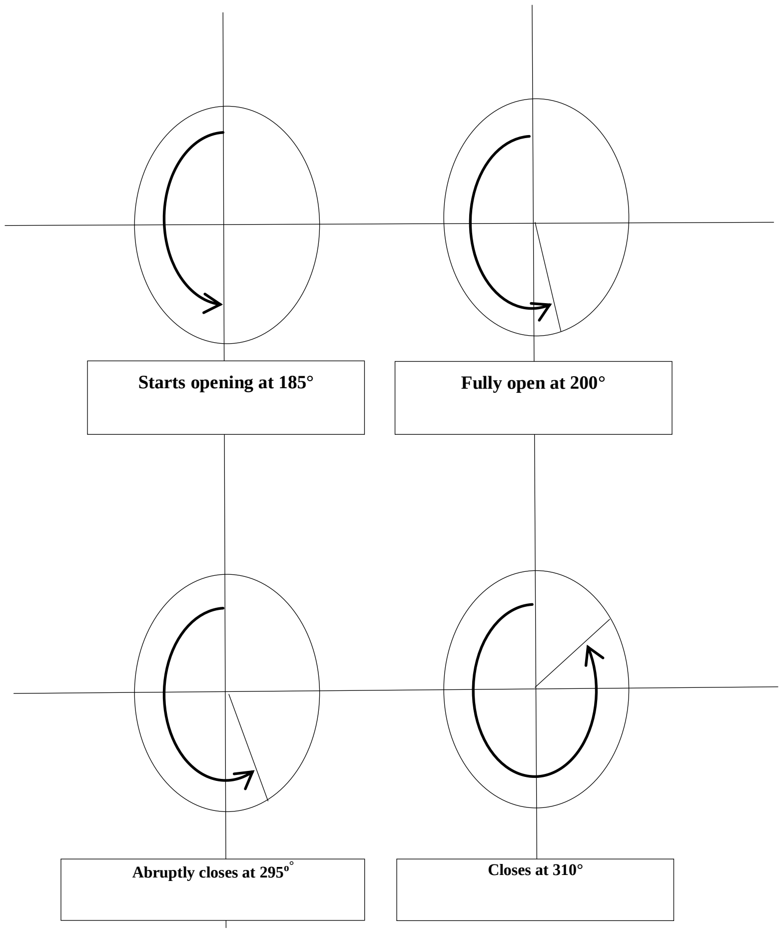


Fig.5A schematic view of metering mechanism

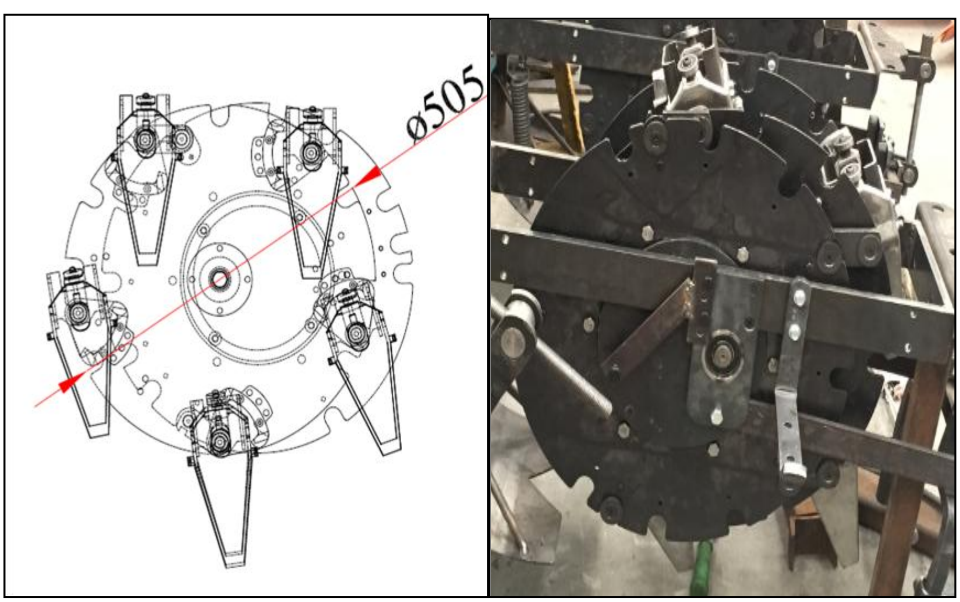


Fig.6 A view of the artificial plants embedded in pop in different cell sizes

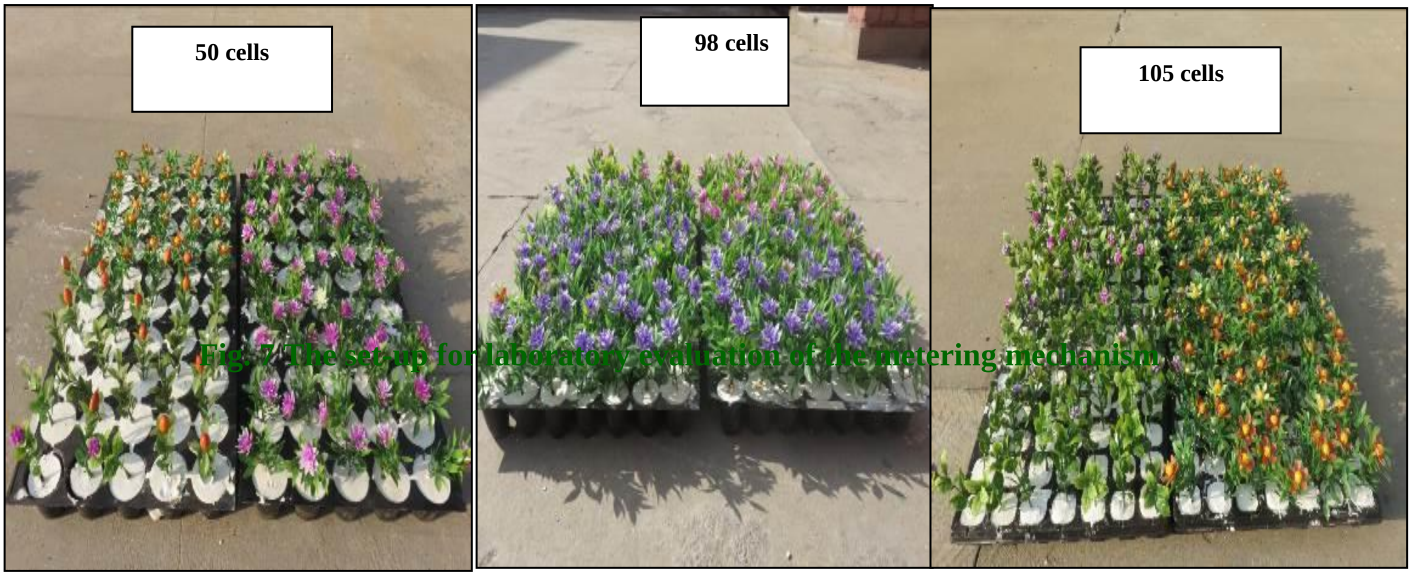


Fig. 7 The setup for laboratory evaluation of the metering mechanism

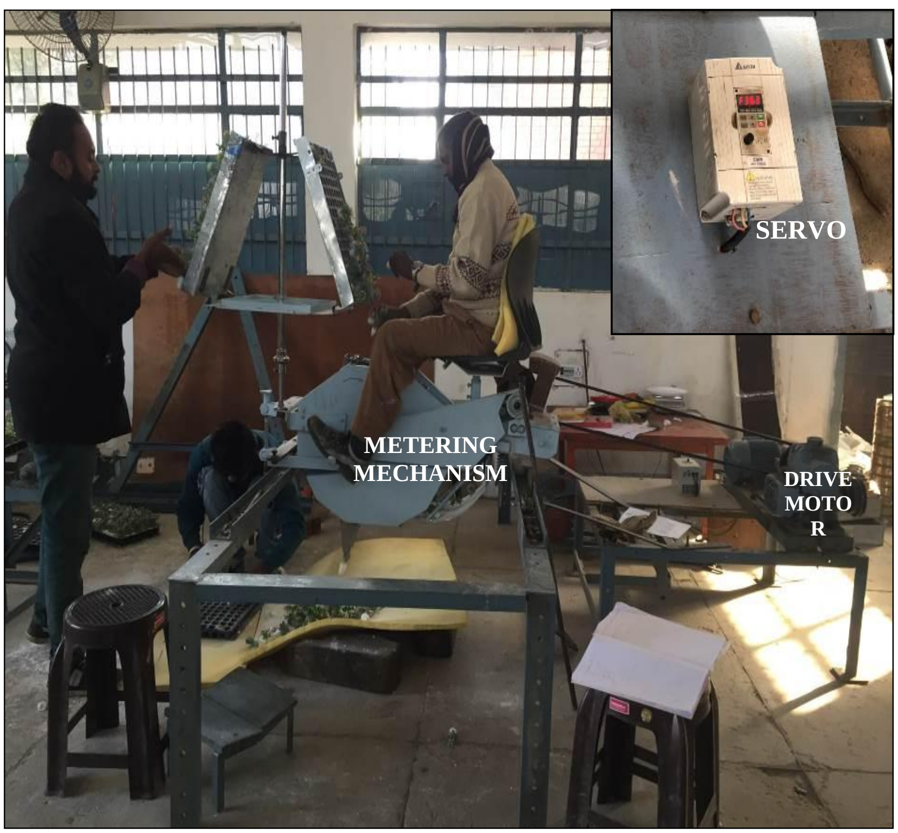
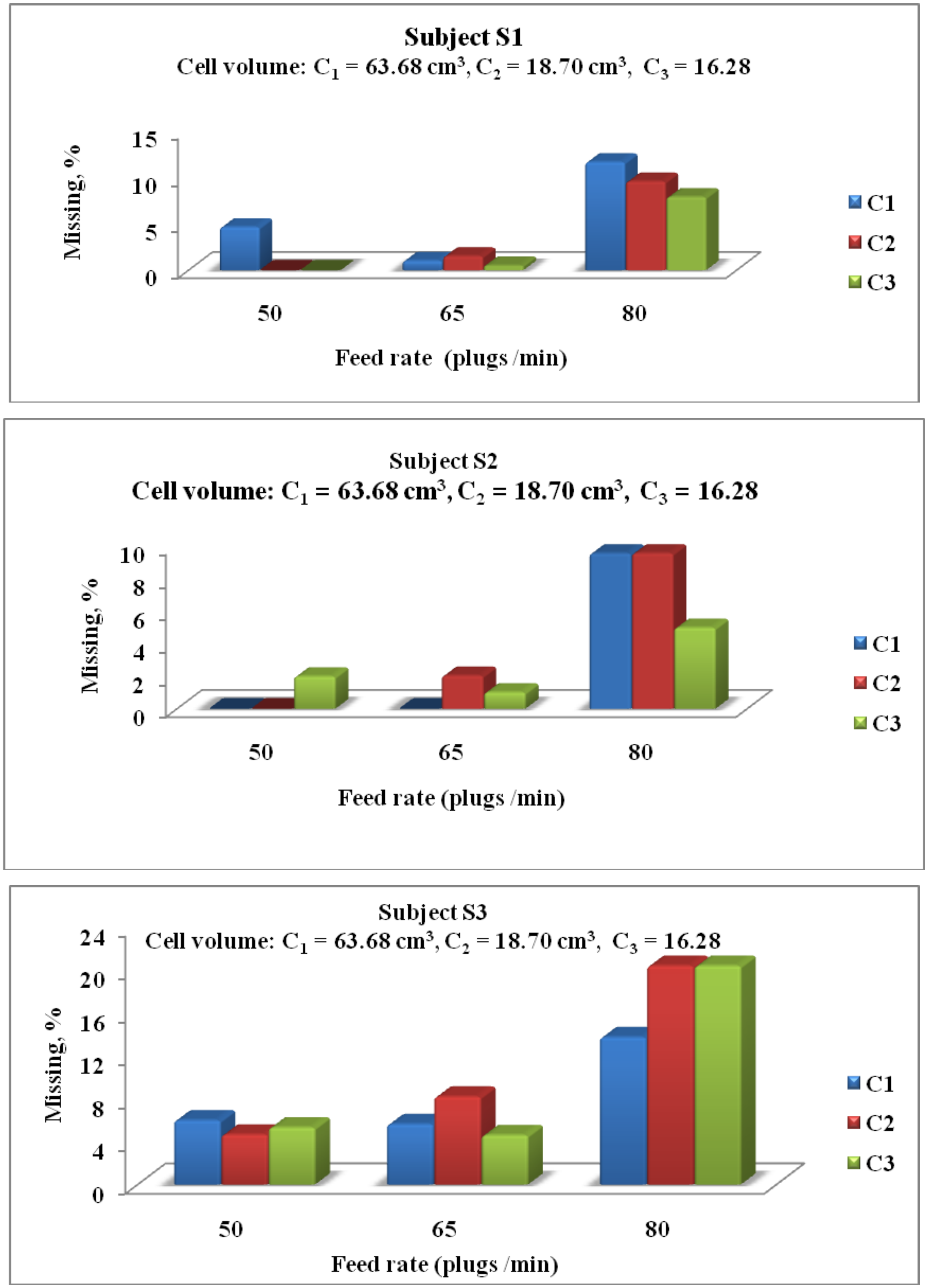


Fig.8 Effect of feed rate (F) and cell size (C) on average plant missing for different subjects



Quality of feed index

This index is derived from average plant missing and doubling as indicated in Table 2c. The quality of feed index was 95% to 100% for subjects S1 and S2 and 92% to 95% for subject S3 for feed rates up to 65 plugs/min. Quality of feed index was 88% to 95% for subjects S1 and S2 for feed rate of 80 plugs /min and 82% to 86% for subject S3.

Quality of feed index decreases with increase in plant missing and plant doubling. Since the doubling was rather rare (except at higher feed rates), variations in the quality of feed index followed mainly the variations due to plant missing.

Hence concluded as follows

1. The effect of feed rate (F) as well as subject (S) on plant missing in the laboratory studies was highly significant.
2. Plant missing increased with increase in feed rate for all the subjects. Average plant missing for cell C3 and feed rates of 50 plugs/min, 65 plugs/min, and 80 plugs/min was respectively: 0.0%, 0.51%, and 7.92% for subject S1; 2.00%, 1.03%, and 5.00% for subject S2; and 5.33%, 4.62%, and 20.42% for subject S3.
3. No plant doubling was observed for feed rates of 50 plugs/min and 65 plugs/min for all the subjects and cell sizes, in the laboratory studies. Maximum plant doubling observed was 2.41% at a feed rate of 80 plugs/min for cell size C2.
4. Quality of feed index decreased with increase in feed rate for all the subjects. Quality of feed index for cell C3 and feed rates of 50 plugs/min, 65 plugs/min, and 80 plugs/min was respectively: 100.00%, 99.49%, and 90.98% for subject S1; 98.00%, 98.97%, and 95.00% for subject S2; and 94.67%, 95.38%, and 77.57% for subject S3. Quality of feed index was quite high for subjects S1 and S2 up to feed rates of 65 plugs/min.
5. The performance of the developed metering mechanism was found satisfactory for planting cell type nursey at 65 plugs/min in the laboratory evaluation.

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