Automatic feeding mechanism of a vegetable transplanter

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Abstract: An automatic feeding mechanism consisting of a timing shaft, an actuating device and a clutch for feeding paper pot seedlings from a horizontal slat type chain conveyor to a horizontal pusher type chain conveyor of a vegetable transplanter was developed. The slat type chain conveyor carried the pot seedlings in upright orientation in the form of a rectangular array with each linear array of pot seedlings on a slat. The pusher type chain conveyor received a linear array of pot seedlings and delivered them to the seedling drop tube. Feeding of each linear array of pot seedlings to the pusher type conveyor at appropriate times was done using an automatic feeding mechanism. The laboratory evaluation indicated that the feeding rate of 33 to 50 pot seedlings per minute can be achieved with single set of conveyors. The feeding mechanism also worked effectively under actual field conditions with 98% to 99% of all the pot seedlings were properly separated and fed for planting when the forward speed of the vegetable transplanter was 0.9 km/h. The feeding mechanism has the general application of singulating rectangular array of items on the slat type chain conveyor in any industry and machine in motion on a level surface.

Keywords: automatic feeding mechanism, chain conveyor, feed index, singulation, vegetable transplanter

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1 Introduction

Planting of good quality seedlings at appropriate spacing, depth and with sufficient soil cover around the seedlings is one of the most labor intensive operations in the production of vegetables, particularly tomato (*Solanum lycopersicum*), eggplant (*Solanum melongena*) and peppers (*Capsicum* spp.). In India, labor requirement for manual transplanting of vegetables varies from 240 to 320 man-h /ha[1-3]. Tractor mounted 2-row and 3-row semi-automatic vegetable transplanters have been developed in India for bare-root seedlings and plugs[2,4]. Pocket-type metering devices have been provided in the transplanters for bare-root seedlings. The field capacity and labor requirement have been reported to be 0.082 to 0.092 ha/h and 44.4 man-h/ha, respectively at a forward speed of 0.8 to 1.0 km/h. Rotary cup type metering devices have been provided in the transplanters for plugs. They had the field capacity of 0.14 ha/h and labor requirement of 28.6 man-h/ha when operated at a forward speed of 1.4 km/h. The quality of transplanting was reported to be satisfactory for both the machines.

Recently walk-behind type hand tractor powered vegetable transplanter for paper pot seedlings (Figure 1) has been developed[3]. It was a 2-row machine with provision to vary both row spacing and in-row plant spacing in the range of 45 to 60 cm. It had two sets of feeding conveyor, metering conveyor, seedling drop tube, furrow opener and soil covering device, and an automatic feeding mechanism, a depth adjustment wheel and hitching arrangement. The feeding conveyor was a horizontal slat type chain conveyor with a provision to keep the individual paper pot seedlings in the form of a rectangular array. Each linear array of pot seedlings was kept on a slat in upright orientation. The metering conveyor was a horizontal pusher type chain conveyor with flights to push the pot seedlings in sequence to the

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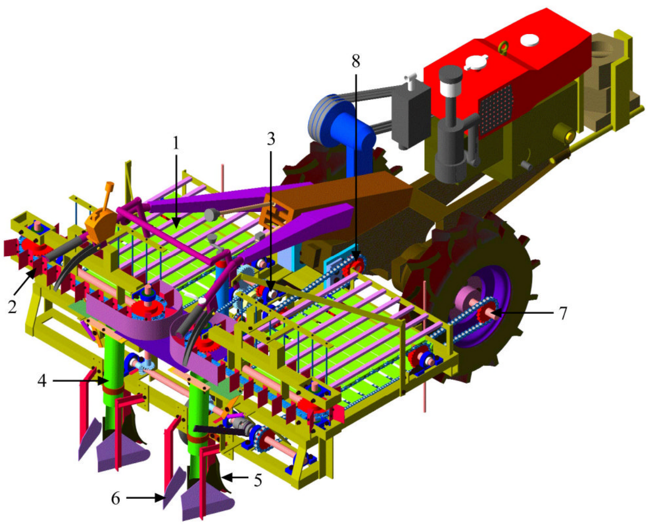
seedling drop tube, which in turn allowed the seedlings to drop in upright orientation in the furrow. The feeding conveyor operated at intervals only for the time required to move one linear array of pot seedlings (on the slat) towards the metering conveyor. The engagement and disengagement of drive power to the feeding conveyor at appropriate times was done using an automatic feeding mechanism (AFM). The transplanter is called array type vegetable transplanter and it has been found to be successful for planting paper pots seedlings of tomato, eggplant and chili peppers under field conditions in India. Ready-to-plant paper pot seedling of tomato is shown in Figure 2. The pot was double layered cubical paper pot made using newspaper and filled with a potting mix of vermicompost, top soil and sand in the proportion of 1:1½:1½ by volume[5]. Its average dimensions and weight are presented in Table 1.



1. Feeding conveyor 2. Metering conveyor 3. Automatic feeding mechanism 4. Seedling drop tube 5. Furrow opener 6. Soil cvering device 7. Ground wheel shaft 8. Drive shaft of rotavator of hand tractor

Figure 1 Isometric view of hand tractor powered array type vegetable transplanter

Figure 2 Ready-to-plant paper pot seedling of tomato

Table 1 Dimensions and weight of seedling pot with mix

Particulars	Mean ± std. dev.
Maximum width and breadth/mm	45.0 ± 3.0
Width and breadth at the bottom/mm	36.0 ± 2.0
Height/mm	36.0 ± 2.0
Maximum diagonal length/mm	64.0 ± 4.0
Weight of paper pot seedling at potting mix moisture content of 5%±2%, 10%±2% and 15%±2% (dry basis)/g	65.0±2.0, 68.0±2.0 and 74.0±2.0, respectively.

AFM is the most important component of the array type vegetable transplanter. It is basically a mechanism which engages the power to horizontal slat type chain conveyor at intervals to feed multiple pot seedlings on the slat in the space between the flights of the horizontal pusher type chain conveyor. The mechanism has to be simple in design and should not require any mechanical adjustments when in-row plant spacing and forward speed of the hand tractor are varied. The present work consists of the following:

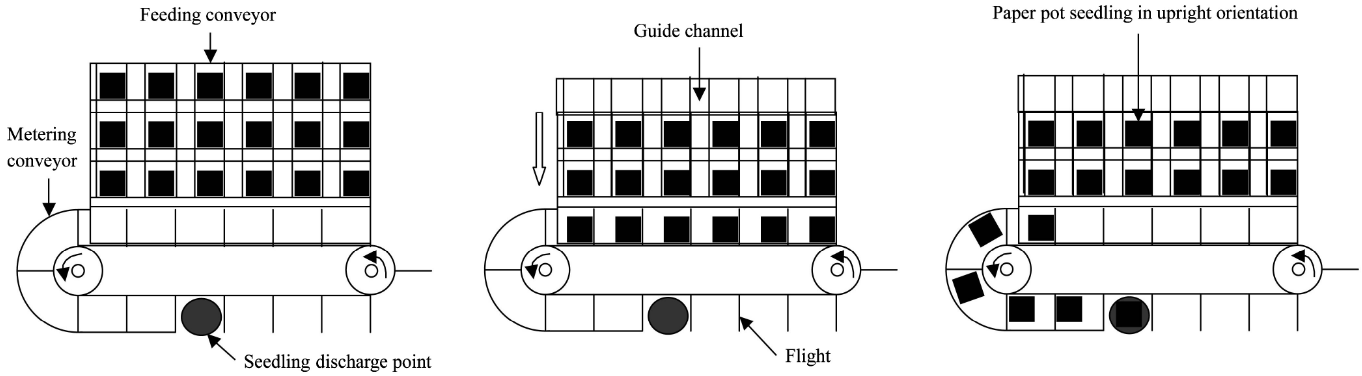
i) Development of AFM and its laboratory evaluation to identify the ideal set of linear speeds of feeding and metering conveyors for the effective feeding of pot seedlings.

ii) Evaluation of the efficacy of feeding pot seedlings under actual field conditions.

2 Materials and methods

2.1 Purpose of AFM

The metering conveyor operates continuously and is powered from the ground wheel shaft of the hand tractor. The flights of the metering conveyor are directly above the last slat of the feeding conveyor and they push the pot seedlings placed on the last slat towards the seedling drop tube (Figure 3). Flights on the metering conveyor are provided at 76.2 mm spacing. Feeding conveyor is powered from the drive shaft of the rotavator of the hand tractor, which in turn is powered directly from the hand tractor engine at a fixed velocity ratio. Each slat of the feeding conveyor carried 6 pot seedlings at a center to center to distance of 76.2 mm. The AFM is provided between the drive shaft of the rotavator of the hand tractor and drive shaft of the feeding conveyor. The purpose of the AFM is to engage the power to the feeding conveyor to feed 6 pot seedlings (on a slat) at a time in the space between the flights of the continuously operating metering conveyor. The flights push these seedlings towards the seedling drop tube. Once these 6 pot seedlings were pushed away from slat, feeding conveyor has to operate again to feed another set of 6 pot seedlings (Figure 3). Thus, working of AFM is independent of in-row plant spacing and forward speed of the hand tractor.



a. Arrangement of paper pot seedlings on feeding conveyor

b. Feeding of one linear array of seedlings to the metering conveyor

c. Conveying of the seedlings continuously towards the seedling discharge point

Figure 3 Working of AVT for paper pot seedlings

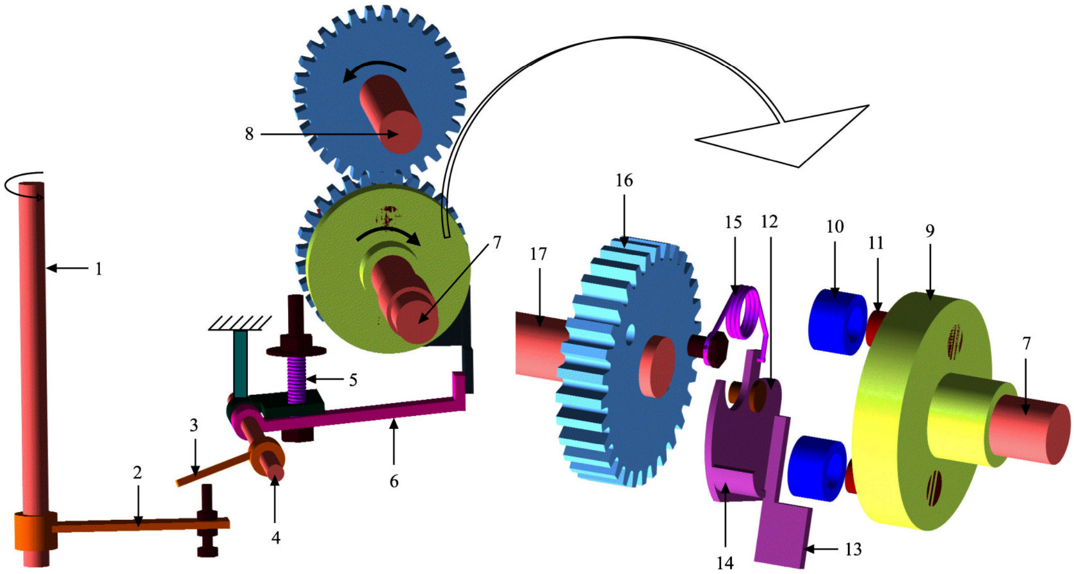
2.2 Design and working of AFM

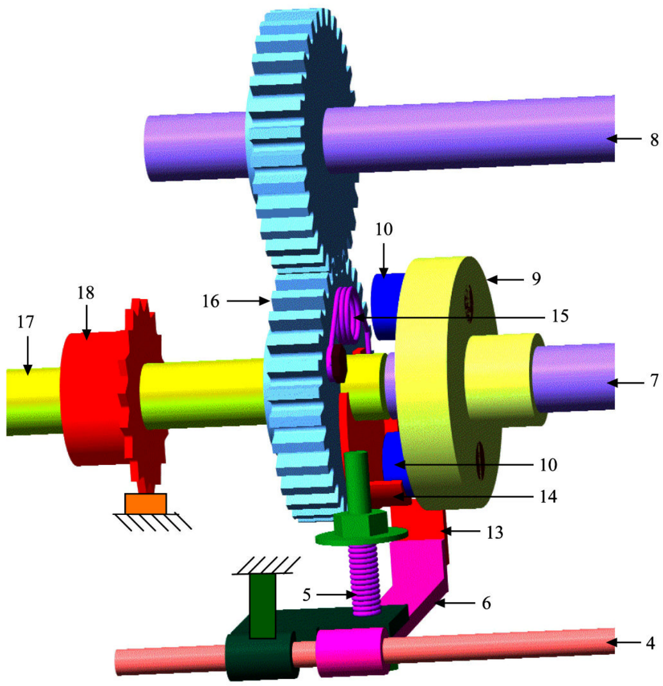
AFM consists of a timing shaft, an actuating device and a clutch as shown in Figure 4. Input shaft of the AFM (7) is powered from the drive shaft of the rotavator of hand tractor. The output shaft of the AFM (8) drives the drive shaft of the feeding conveyor.

Timing shaft (1) is operated by the drive shaft of the metering conveyor. Velocity ratio between the timing shaft and the drive shaft of the metering conveyor is such that the timing shaft rotates once in the duration equal to the time required for the forward movement of 6 pot seedlings on a slat (one linear array of seedlings) towards the seedling drop tube. In each revolution of the timing shaft, actuating arm (2) lifts the shorter end of the fulcrum (3). The fulcrum (3 and 6) pivots around the actuating shaft (4) and its longer end (6) moves downwards compressing the spring (5). This causes engagement of clutch and the power is transmitted to the output shaft of AFM (8). As the actuating arm moves further, shorter end of fulcrum moves down. The spring expands and it returns the longer end of fulcrum to its original position. The clutch gets disengaged and it remains in this condition till the actuating arm lifts the fulcrum in its next revolution.

The type of clutch used in AFM is a ramped clutch as shown in Figure 5. The driver disc (9) has two rollers (10) on pins (11). The pins are rigidly supported on the driver disc. The driver disc is mounted on the input shaft of the AFM (7). The driven disc (12) has a cap (14) matching to the curvature of the roller. The driven disc along with a torsion spring (15) is supported on a spur gear (16). The gear is mounted on the driven shaft (17) of the clutch. The driven disc has an extension arm (13) which helps in engagement and disengagement of the clutch. When the fulcrum actuates the extension arm, the driven disc rotates about a pivot pin. This causes disengagement of the clutch. The driven shaft of the clutch has a pawl and ratchet (18) which prevents the output shaft from rotating when the clutch is disengaged (Figure 4). The output shaft of AFM (8) has to rotate in opposite direction to the direction of rotation of driven shaft of the clutch (17). The spur gear set (16) facilitates this requirement.

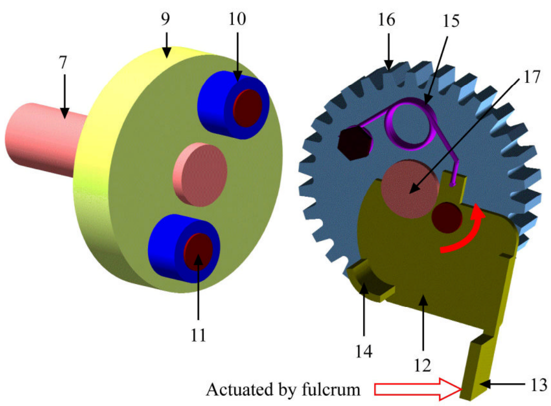
When the longer end of the fulcrum (6) moves downwards, cap (14) on driven disc wraps the roller (10) on driver disc (Figure 4). The clutch gets engaged. The power gets transmitted to the output shaft of AFM (8) and it powers the drive shaft of the feeding conveyor. When the longer end of fulcrum (6) returns to its original position, it holds the cap away from the roller against the force of torsion spring (15). The clutch gets disengaged and the feeding conveyor stops. Thus, the clutch is engaged only for the duration to feed one linear array of pot seedlings to the metering conveyor.





1. Timing shaft
2. Actuating arm
3. Short end of fulcrum
4. Actuating shaft
5. Spring
6. Long end of fulcrum
7. Input shaft of AFM
8. Output shaft of AFM
9. Driver disc
10. Roller
11. Pin
12. Driven disc
13. Extension arm of driven disc of clutch
14. Cap
15. Torsion spring
16. Gear
17. Driven shaft of clutch
18. Pawl and ratchet

Figure 4 Details of AFM and clutch provided in the AFM



7. Input shaft of AFM
9. Driver disc
10. Roller
11. Pin
12. Driven disc
13. Extension arm of driven disc of clutch
14. Cap
15. Torsion spring
16. Gear
17. Driven shaft of clutch

Figure 5 Assembled view of driving and driven members of clutch

The chain of the feeding conveyor is supported on a 24 tooth sprocket and it has to revolve through ¼ revolutions to feed a linear array of pot seedlings to the metering conveyor. A velocity ratio of 1:4 is provided between the drive shaft of feeding conveyor and output shaft of AFM. This results in one complete revolution of the output shaft of AFM while feeding a linear array of pot seedlings. There is no velocity reduction in AFM. Hence, input shaft of AFM revolves for one complete revolution while feeding a linear array of pot seedlings. The design of actuating device should be such that it should get the clutch engaged only for one complete revolution of the input shaft of AFM.

Design dimensions of the various components of clutch (diameter and width of roller, radial distance of roller from the center of the shaft, diameter of pin, angle of wrap of the cap on the roller, diameter of torsion spring wire, diameter of torsion spring, number of turns, distance of load from spring axis) were determined considering the maximum torque required for the operation of the feeding conveyor.

2.3 Laboratory evaluation of AFM

The efficacy of working of AFM is affected by various seedling and operational parameters, like, moisture content of the potting mix (MC), plant height (HT), linear speed of metering conveyor (SMC) and ratio of linear speeds of feeding and metering conveyors (RFM). In order to study the effect of these parameters on the efficacy of feeding paper pot seedlings to metering conveyor of AVT, a single row stationary unit of AVT powered by an induction motor (Figure 6) was developed. Total 77 pot seedlings could be placed on the feeding conveyor (1) of the set-up in the form of 7 × 11 rectangular array. Metering and feeding conveyors were powered separately (6 and 7) from the same electric motor.

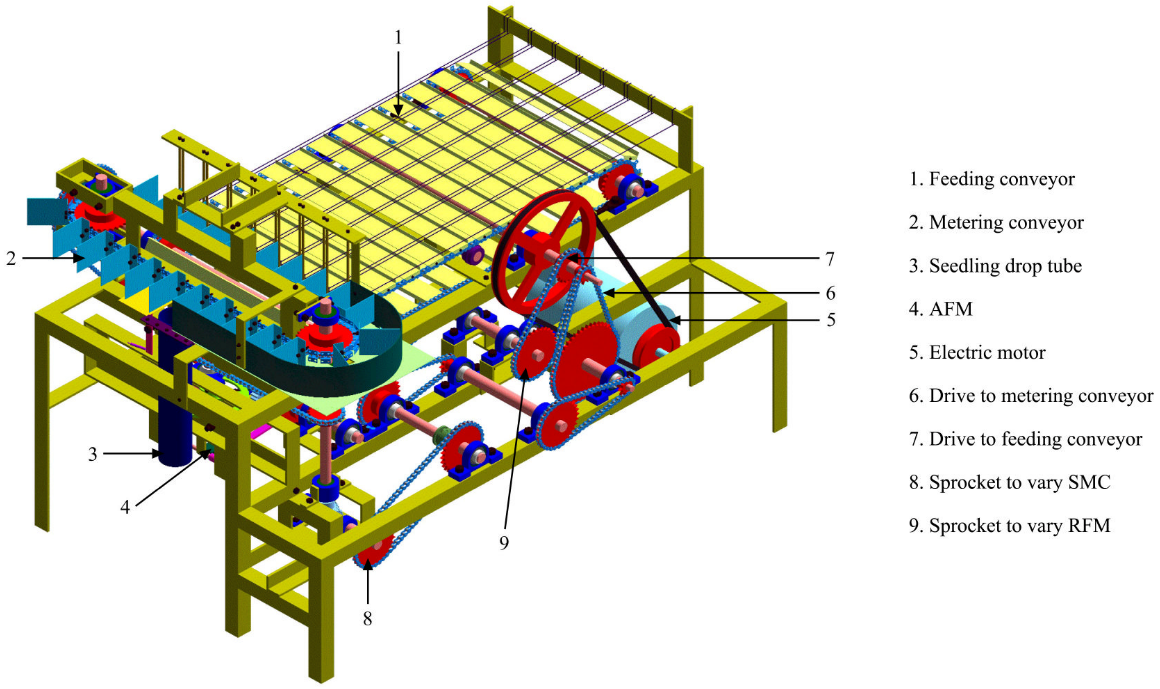


Figure 6 Isometric view of stationary single row unit of AVT powered by an electric motor

Experiments were conducted considering 3 levels of MC (5%±2%, 10%±2%, 15%±2% dry basis), 3 levels of HT (6±1 cm, 9±1 cm, 12±1 cm for tomato; 6±1 cm, 8± 1 cm, 10±1 cm for eggplant and peppers), 5 levels of SMC (4.233 cm/s, 4.939 cm/s, 5.644 cm/s, 6.350 cm/s, 7.055 cm/s) and 3 levels of RFM (2.812, 4.018, 7.500). The range of values of SMC corresponds to the range of forward speed of the hand tractor from 0.9 to 1.5 km/h for planting at 45 cm in-row plant spacing. SMC was varied by fitting appropriate size of sprockets (8). The values of RFM corresponds to 1 mm, 9 mm and 18 mm gap between the pot and the flight (the flight that push the pot) till the pot fully enter the space in between the flights of the metering conveyor. RFM at each values of SMC was varied by fitting appropriate size of sprocket (9). The dependent parameter was feed index. It was determined as follows:

$$Feed\ index = 1 - \frac{Number\ of\ pots\ damaged\ or\ tilted}{Total\ number\ of\ pot\ seedlings\ placed\ on\ the\ feeding\ conveyor} \quad (1)$$

The design of experiment was randomized complete block design for tomato, eggplant and peppers with 3 replications for each combination of MC, HT, SMC and RFM.

Pot seedlings of uniform MC and HT were placed on the feeding conveyor in the form of 7 × 11 rectangular array. SMC and RFM were set by fitting appropriate size of sprockets (8 and 9). Electric motor was switched on. As the AFM started working, pots that got damaged and the pots that got tilted while feeding pot seedlings to the metering conveyor were collected from the set-up and counted. The seedlings in upright orientation and without any damage were only allowed to enter the metering conveyor. Feed index was calculated.

Data were subjected to analysis of variance in the IBM® SPSS® Statistics Base module (IBM Corporation, NY) to determine the significance of main and interaction effects. Data were plotted to identify the ideal seedling and operational parameters for the effective feeding of pot seedlings.

2.4 Field evaluation of AFM

The AFM was fitted to the 2-row array type vegetable transplanter powered by a walk-behind type hand tractor. The efficacy of AFM was evaluated for transplanting paper pot seedlings of tomato at 45 × 45 cm spacing in 3 well prepared plots of 25 × 3 m size. The soil of the plots was lateritic sandy clay loam having bulk density of 1.32 g/cm^3 at (9.0%±2%) moisture content (dry basis). Pre-experimental trials were conducted (Figure 7) and it indicated that the optimum forward speed of the hand tractor for the efficient working of array type vegetable transplanter under field condition as 0.9 km/h. This necessitated the setting of linear speeds of metering conveyor to 4.233 cm/s for planting with in-row plant spacing of 45 cm. Linear speed of feeding conveyor was set based on the optimum value of RFM obtained during laboratory evaluation of AFM. The pot seedlings with appropriate HT and MC were placed on two feeding conveyors in the form of 6 × 8 rectangular array. The transplanter was operated along the length of the field. Pot seedlings were placed manually on the feeding conveyors at the end of each run. During operation, number of pots tilted and damaged while feeding was recorded at every instant of feeding pot seedlings to the metering conveyors.

Figure 7 Field evaluation of array type vegetable transplanter

3 Results and discussion

3.1 Results of laboratory evaluation

Variation in feed index with MC, HT and SMC at different values of RFM for the pot seedlings of tomato is presented in Figure 8. It indicates that at RFM = 4.018, feed index was almost 1.00 irrespective of variation in MC, HT and SMC. When the RFM = 2.812, gap between the pot and the flight just after the pot has completely entered the space between the flights was just 1 mm and a slight variation in the dimension of pot caused pot damage. This was particularly noticeable at higher values of MC due to absorption of water by the paper pots, softening of pots and subsequent increase in dimension of pots. When RFM = 7.5, pot seedlings on the slat were increasingly susceptible to sliding forward and tilting. Pots with lower values of MC and higher values of HT had high susceptibility to sliding and tilting. Further, at higher values of SMC, speed of the feeding conveyor was also higher and it also resulted in tilting of pots. Similar trend was also observed when the pot seedlings of eggplant and peppers were used. Further, feed index for eggplant and peppers seedlings were at par with that observed for tomato seedlings.

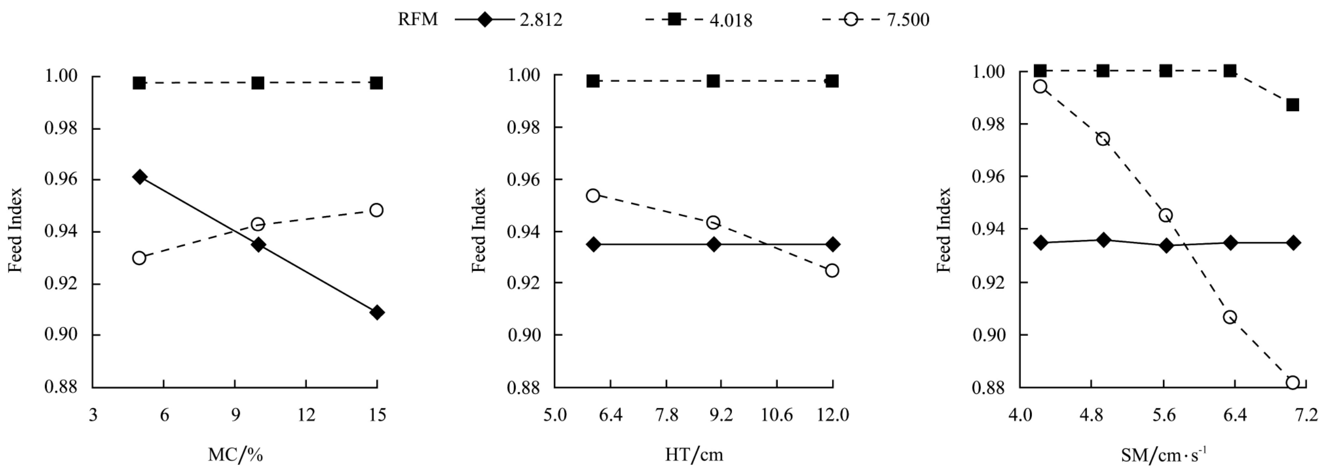


Figure 8 Variation in feed index with MC, HT and SMC at different RFM for tomato seedlings

The analysis of variance (ANOVA) of feed index with MC, HT, SMC and RFM is presented in Table 2. It indicates that feed index is affected by main effects (MC, HT, SMC and RFM) and interaction of RFM with MC, HT and SMC. Further, F values associated with RFM, SMC and their interactions were comparatively higher than those associated with other parameters. This indicates that the operating parameters and their interactions (RFM and SMC) had the higher influence on feed index than the seedling parameters and their interactions (MC and HT). Therefore, SMC up to 6.35 cm/s and RFM = 4.018 could be set for effective feeding of the pot seedlings in the array type vegetable transplanter (Figure 8). MC and HT had no influence on the feed index in this set of linear speeds of feeding and metering conveyors. These findings reveal that the AFM can operate without causing any damage and tilting of pots in the range of forward speed of hand tractor from 0.9 to 1.35 km/h for transplanting with in-row plant spacing of 45 cm. This also indicates that the feeding rate of 33 to 50 pot seedlings per minute can be achieved with single set of feeding and metering conveyors.

Table 2 ANOVA of feed index with MC, HT, SMC and RFM when pot seedlings of tomato, eggplant and chili peppers were used

Source	Tomato	Eggplant	Chili peppers
MC	37.77**	38.36**	38.46**
HT	27.23**	11.75**	11.76**
SMC	202.34**	217.78**	217.53**
RFM	1403.48**	1333.33**	1335.37**
MC×HT	1.17^{NS}	0.69^{NS}	0.69^{NS}
MC×SMC	1.09^{NS}	0.75^{NS}	0.75^{NS}
HT×SMC	0.80^{NS}	0.73^{NS}	0.73^{NS}
MC×HT×SMC	0.54^{NS}	0.21^{NS}	0.21^{NS}
MC×RFM	129.61**	133.34**	134.03**
HT×RFM	27.26**	11.76**	11.76**
MC×HT×RFM	1.17^{NS}	0.69^{NS}	0.69^{NS}
SMC×RFM	157.55**	168.74**	168.62**
MC×SMC×RFM	1.09^{NS}	0.75^{NS}	0.75^{NS}
HT×SMC×RFM	0.80^{NS}	0.73^{NS}	0.73^{NS}
MC×HT×SMC×RFM	0.54^{NS}	0.21^{NS}	0.21^{NS}

Note: ***P*<0.01, NS: Non-significant; NS: Non significant.

3.2 Results of field evaluation

Forward speed of the hand tractor was set at 0.9 km/h. Linear speeds of metering conveyor and feeding conveyor were set at 4.233 and 17.00 cm/s (optimum RFM = 4.018), respectively. Twenty-five days old pot seedlings of average height (12 ± 1) cm and potting mix moisture of (5% ± 2%) dry basis were selected for the field evaluation.

The feed index for the pot seedlings of tomato varied from the range of 0.98 to 0.99 in the three plots. The feed index under actual field condition was slightly lower than that observed in laboratory. This might be due to minor machine vibration under dynamic condition in field.

The long term use of AFM both in the laboratory and under actual field conditions indicated that developed design of AFM is reliable and free of frequent maintenance. The AFM has general application of singulating rectangular array of items on the slat type chain conveyor in any industry and machine in motion on a level surface. The singulating capacity was found to be 50 items per minute (for one pair of feeding and metering conveyors) with items kept in linear array (on each slat) at 76.2 mm (3”) spacing. Further, a single unit of the developed AFM can operate several feeding conveyors if drive shafts of all the feeding conveyors are coupled together.

4 Conclusions

A simple, reliable and fully mechanical automatic feeding mechanism to feed the paper pot seedlings from the horizontal slat type chain (feeding) conveyor to horizontal pusher type chain (metering) conveyor was developed. The feeding mechanism worked without causing any damage and tilting of pots with the feeding rate of 33 to 50 pot seedlings per minute. The developed feeding mechanism has the applications in industries where items on the horizontal slat type chain conveyor (arranged in the form of rectangular array) need to be singulated. A single unit feeding mechanism can be used to operate several feeding conveyors if drive shafts of all the feeding conveyors are mechanically coupled.

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