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Research Paper

Development of a walk-behind type hand tractor powered vegetable transplanter for paper pot seedlings

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A 9.75 kW walk-behind type hand tractor powered 2-row fully automatic vegetable transplanter for individual paper pot seedlings was developed by considering the power availability, paper pot dimensions and space availability in the hand tractor after the complete removal of rotavator tillage assembly. It consisted of two sets of feeding conveyor, metering conveyor, seedling drop tube, furrow opener, soil covering device, an automatic feeding mechanism, a depth adjustment wheel and hitching arrangement. Horizontal slat-type chain conveyor was used as feeding conveyor and horizontal pusher type chain conveyor was used as metering conveyor. The automatic feeding mechanism, with a timing shaft, cam and clutch, was used to coordinate the working of feeding and metering conveyors. The vegetable transplanter carried 108 seedlings on two feeding conveyors in upright orientation, fed them to the metering conveyors and planted them in upright orientation in furrows. The performance of the vegetable transplanter was evaluated for transplanting tomato at 45 × 45 cm spacing in the field at a forward speed of 0.9 km h^{-1}. Field capacity of the transplanter was found to be 0.026 ha h^{-1}. It resulted in the saving of 68% labour and 80% time over the conventional method of manual transplanting. The planting rate of the transplanter was found to be 32 pot seedlings min^{-1} with 4% missed planting and 5% tilted planting. The soil covering efficiency of the developed vegetable transplanter was about 81% and the quality of transplanting was satisfactory.

1. Introduction

India is the second largest producer of vegetables with the production of 129 million metric tons and yield of 16.2 metric tons ha^{-1} in the year 2008–2009 (Government of India, 2009). About 175 types of vegetables are grown in India including 82 field vegetables and 41 root (tuber and bulb) crops (Randhawa, 1998; Subramanian, Varadarajan, & Asokan, 2000). Most of the vegetables like cucurbits (*Cucurbita* spp.), beans (*Phaseolus* spp.), okra (*Abelmoschus esculentus*) and leafy vegetables are sown directly in the field. Vegetables like tomato (*Solanum lycopersicum*), eggplant (*Solanum melongena*) and peppers (*Capsicum* spp.) are first sown in nursery beds and later transplanted manually either on ridges or on a well prepared seedbed (Ghai & Arora, 2007). Manual transplanting of seedlings is labour-intensive, expensive, time consuming and

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often results in non-uniform plant distribution (Kumar & Raheman, 2008; Manes, Dixit, Sharda, Singh, & Singh, 2010; Parish, 2005).

Tractor-mounted 2-row and 3-row semi-automatic vegetable transplanters have been developed in India for bare-root seedlings and plugs (DARE, 2006, pp. 109–128; Manes et al., 2010). Pocket-type metering devices have been provided in the transplanters for bare-root seedlings. The field capacity and labour requirement have been reported to be 0.082–0.092 ha h^{-1} and 44.4 man-h ha^{-1} respectively at a forward speed of 0.8–1.0 km h^{-1}. Rotary cup-type metering devices have been provided in the transplanters for plugs. They had a field capacity of 0.14 ha h^{-1} and labour requirement of 28.6 man-h ha^{-1} when operated at a forward speed of 1.4 km h^{-1}. The quality of transplanting was reported to be satisfactory for both the machines.

Farmers in India allocate a relatively low proportion of their land for vegetables (Birthal, Joshi, & Thorat, 2007). Further, small land holdings (less than 2 ha) contribute about 61% of the total vegetable production (Kumar, Pal, & Joshi, 2004, pp. 9–34), but they comprise about 78% of the total operational holdings (Government of India, 2002). In small holdings, 6.75–10.58 kW walk-behind type hand tractors rather than larger tractors are popular power sources for carrying out different agricultural operations (Dewangan & Tewari, 2008). Therefore, there is a genuine need to develop a hand tractor powered vegetable transplanter for use in small plots and small land holdings. The hand tractor-powered vegetable transplanter has to be a fully automatic machine as an operator could not simultaneously control and manoeuvre the hand tractor and feed the seedlings to the metering unit.

Fully automatic vegetable transplanters require either plugs or pot seedlings. As initial investment on production of plugs is high and mechanisms employed for the removal of seedlings from the tray are complex, use of pot seedlings seems to be a better option (Kumar & Raheman, 2008). Paper pots made with newspaper have been used for raising seedlings (Furuki, Yamanishi, Matsumoto, Honma, & Takada, 2003; Kumar & Raheman, 2010; Ueno, Matsumura, & Miyaji, 2002, pp. 19–32). Past studies reveal that fully automatic vegetable transplanters capable of feeding and metering individual paper pot seedling have not yet been developed. Design of vegetable transplanters depends upon the type of seedlings used. It is not possible to obtain the ready-to-plant paper pot seedlings with pots of uniform dimensions and firmness. In order to overcome the difficulty of handling paper pots of non-uniform dimensions and firmness, past researchers (Nambu & Tanimura, 1992; Suggs et al., 1987; Tsuga, 2000; Yonetani, Matsumoto, & Okishio, 1999) made strands or chains of paper pots. The strand of pots was fed to a mechanism in the transplanter that cut the strand at uniform intervals and dropped individual pots in soil. Hence, the design of devices for seedling pick-up, metering and planting in a fully automatic transplanter for individual paper pot seedlings must accommodate the variability in dimensions of the pots.

The goal of this work was to develop a walk-behind type hand tractor-powered fully automatic vegetable transplanter for paper pot seedlings and evaluate its performance under actual field conditions.

2. Paper pot seedlings for mechanical transplanting

Paper pots seedlings were grown in aluminium trays in a double layer polyethylene-covered unheated greenhouse. The ready-to-plant paper pot seedling of tomato 21 days after seeding and following 4 days of hardening is shown in Fig. 1. Each seedling was grown in a double layered cubical paper pot of 50 cm^3 volume filled with vermicompost, soil and sand in the proportion of 1:1½ :1½ by volume. The volume of pot and the proportion of ingredients in the soil-based vermicompost-amended mix were determined by conducting experiments in two different seasons (Kumar & Raheman, 2010) and applying optimisation techniques to the biomass growth data. Paper pots at the end of seedling stage had wide dimensional variations due to non-uniform wetting of potting mix and pot walls during watering of seedlings in paper pots, non-uniform drying of potting mix after watering, physical pressure from other neighbouring pots in the tray and uncontrolled drying of potting mix during the seedling hardening process. The final dimensions and weight of the paper pot with mix are presented in Table 1.

3. Conceptual working of vegetable transplanter for paper pot seedlings

Several devices have been developed for picking up, metering and planting of plugs (Shaw, 1999), pot and bare-root seedlings (Kumar & Raheman, 2008). Many of these devices cannot be used for the removal of paper pot seedlings from a tray. However, slight modification of the horizontal conveyor with flights to carry the seedlings in upright orientation between the flights (Armstrong & Hanacek, 1984; Sakaue, 1992; Shaw,

Fig. 1 – Ready-to-plant paper pot seedlings of tomato.

Table 1 – Final dimensions and weight of paper 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.

1999) is able to accommodate small variations in dimensions of paper pots. Hence, a horizontal pusher type conveyor with flights to push the pot seedling was selected for metering individual paper pot seedlings and it is referred to as the metering conveyor. As the metering conveyor continuously pushes the seedlings towards the furrow, it is important to feed the single pot seedling in an upright orientation between the flights at the specified interval. In order to achieve this, pot seedlings have to be arranged in the form of a rectangular array with seedlings in each line aligned to enter the space between the flights as and when they reach the metering conveyor. Instead of arranging seedlings in the form of a rectangular array in trays, they can be arranged on a slat type horizontal conveyor such that each seedling on the slat is fed directly between the flights of the metering conveyor at the appropriate time interval. This conveyor is referred to as the feeding conveyor. An automatic feeding mechanism (AFM) was provided to coordinate the working of feeding and metering conveyors so that a linear array of pot seedlings is fed to the metering conveyor at the appropriate time. The conceptual working of the array type vegetable transplanter (AVT) is shown in Fig. 2. It is a fully automatic transplanter as seedlings placed once on the feeding conveyor are fed automatically to the metering conveyor and then planted in the furrow without human intervention.

4. Development of AVT

The AVT consisted of feeding conveyor, metering conveyor, AFM, seedling drop tube, furrow opener and soil covering device. It was designed for attaching to 9.75 kW VST Shakti 130 DI walk-behind type hand tractor (VST Tiller Tractors Ltd., Bengaluru, India). The rotavator tillage assembly is an integral part of the hand tractor and has to be removed completely to attach the vegetable transplanter to the hand tractor. The feeding conveyor was powered from the drive shaft of the rotavator of the hand tractor. The metering conveyor was powered from the ground wheel shaft of the hand tractor. The tractive power of the hand tractor was utilised by the furrow opener and soil covering devices to overcome soil resistance.

4.1. *Number of rows and space for the attachment of AVT in hand tractor*

As tractive power is low and inefficient, the number of rows of seedlings to be planted by the AVT was decided based on maximum utilisation of the tractive power of the hand tractor. Forward speed of the hand tractor during transplanting was assumed to be in the range of 0.9–1.5 km h^{-1} based on the range of forward speed at which the 2WD tractors have been operated when attached to semi-automatic transplanters in India (DARE, 2006, pp. 109–128; Manes et al., 2010). The selected range of forward speed of the hand tractor could be obtained when operated in 1st low gear at 50–90% throttle. The engine performance curves indicated the brake horsepower of the engine at 50% throttle (1200 rpm) as 4.5 kW. About 20% of engine output power is available at the wheel axle of the hand tractor when it is fitted and operating its rotavator (Bhole & Tiwari, 1977). Assuming tractive efficiency as 40% (Kathirvel, Manian, & Balasubramanian, 2001), tractive power of the hand tractor was 0.36 kW.

Considering the average value of unit draft as 30.92 N cm^{-2} (Roul, Raheman, Pansare, & Manchavaram, 2008), the draft requirement of a shovel-type furrow opener (5 cm width of cut) while operating at 8 cm depth was 0.618 kN. The draft required for the soil covering devices was assumed to be 20% of the draft required by the furrow opener, based on the fact that the soil covering devices operate at shallower depth and on soil already disturbed by the furrow opener. Drawbar power required at a forward speed of 0.9 km h^{-1} for a set of furrow opener and soil covering devices was 0.185 kW. Therefore, the number of sets of furrow opener and soil covering devices that could be operated with the available

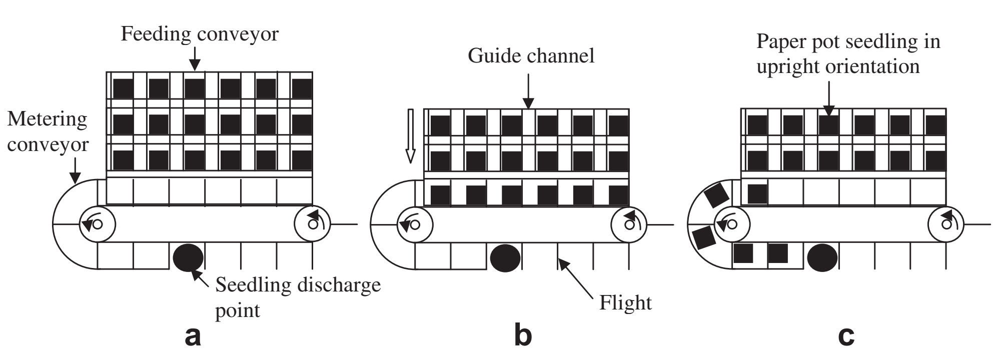

Fig. 2 – Conceptual working of vegetable transplanter for paper pot seedlings (a) Arrangement of paper pot seedlings on feeding conveyor, (b) Feeding of one linear array of seedlings to the metering conveyor, (c) Conveying of the seedlings continuously towards the seedling discharge point.

tractive power = 0.36 ÷ 0.185 = 1.94 ≈ 2. Hence, it was decided to develop a 2-row vegetable transplanter.

The 2-row AVT consisted of two sets of feeding conveyor, metering conveyor, seedling drop tube, furrow opener and soil covering device, and an AFM, depth adjustment wheel and hitching arrangement. 3D solid modelling of the 2-row AVT (Fig. 3) was done in Mechanical Desktop R6 Power Pack (Autodesk, Inc., San Rafael, USA). The solid modelling helped in determining the space available for various components and identifying the possible collision of machine elements during motion. Mechanical design of individual components of AVT was carried out considering the power availability, dimensions of the paper pot and space availability in the hand tractor after the complete removal of rotavator tillage assembly.

During the design process, the overall width of AVT was taken as 1.5 m. After the complete removal of the rotavator assembly, a space 1.0 m long was available behind the transmission casing of the hand tractor for the attachment of AVT. Therefore, space available for the accommodation of AVT behind the hand tractor was 1.0 m × 1.5 m.

4.2. *Feeding and metering conveyors*

The purpose of the feeding conveyor is to carry the pot seedlings in a rectangular array and feed a linear array of pot seedlings in upright orientation on each slat into the space between the flights of the continuously operating metering conveyor, without any damage and tilting of pots. It was designed as a double stranded horizontal slat-type chain conveyor. The function of the metering conveyor is to continuously push the pot seedlings in upright orientation towards the seedling drop tube one by one and drop at the desired in-row spacing. It was designed as a single stranded horizontal pusher type chain conveyor. The feeding conveyor operates 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 AFM.

Overall length and width of each feeding conveyor was 800 and 600 mm, respectively. It ensured a space of 300 mm width and 800 mm length between the two feeding conveyors for providing an AFM. It also ensured a space of 200 mm length over the entire width of AVT for providing furrow openers and soil covering devices. Each slat of the feeding conveyor carried 6 pot seedlings at a centre to centre distance of 76.2 mm. Each feeding conveyor had 18 slats. The two feeding conveyors were supported on a common frame. The frame was supported on a common lateral. The lateral was rigidly hitched to the bolts on the gear box of the hand tractor. The drive shafts of the two feeding conveyors were coupled and powered from the drive shaft of the rotavator through AFM.

Each metering conveyor had 21 flights at a spacing of 76.2 mm and had its own frame. The frame was placed on the frame of the feeding conveyor in such a way that flights of the metering conveyor are directly above the top surface of the last slat of the feeding conveyor towards the drive shaft end. The drive shafts of the two metering conveyors were powered from a common horizontal shaft, which, in turn, was powered by the ground wheel shaft of the hand tractor. A dog clutch was provided to disengage the power to the metering conveyor while turning in the field.

4.3. *AFM*

AFM consisted of a timing shaft, a cam and a clutch as shown in Fig. 4. The input shaft of the AFM (7) was powered from the drive shaft of the rotavator of hand tractor, and the output

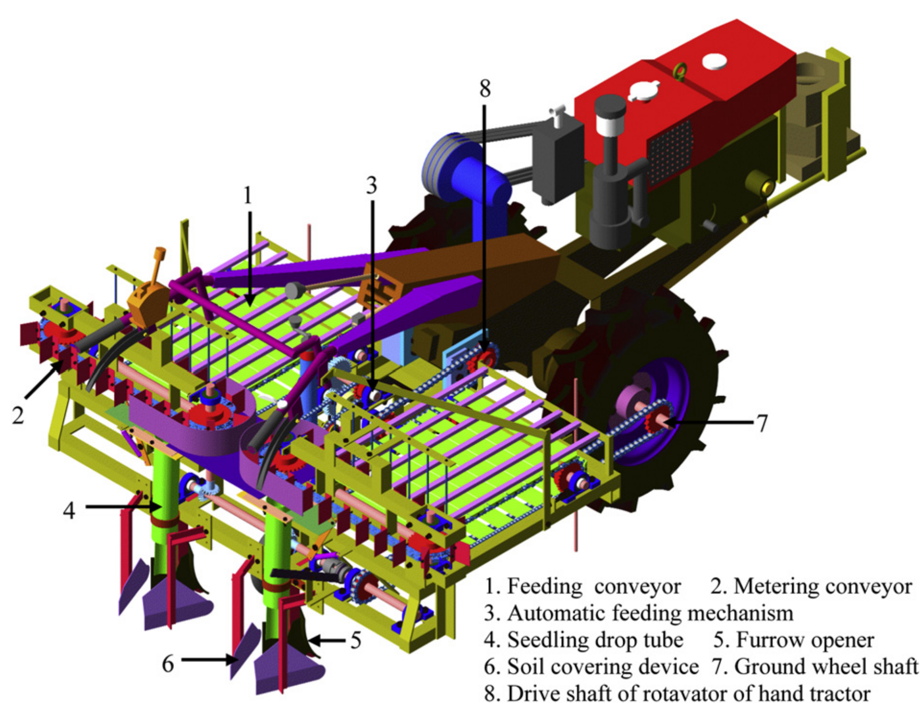

Fig. 3 – Isometric view of the AVT attached to the hand tractor.

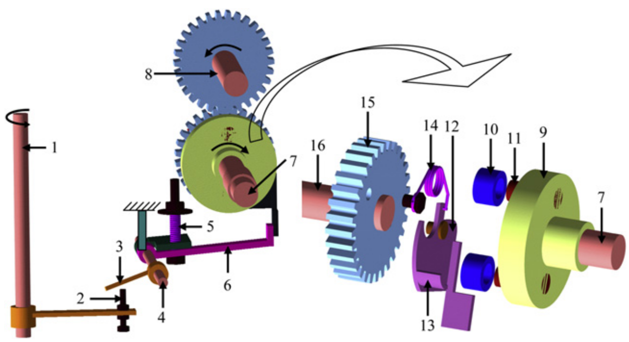

Fig. 4 – Details of automatic feeding mechanism and clutch provided in the mechanism.

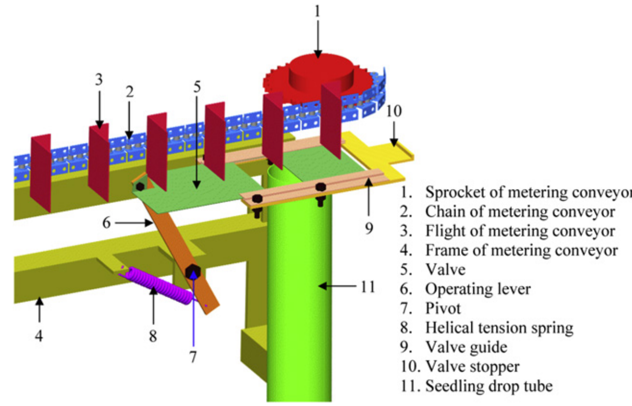

Fig. 5 – Seedling drop tube and quick return valve (Base plate of metering conveyor has been removed).

shaft of the AFM (8) powered the drive shaft of the feeding conveyor.

The timing shaft (1) was operated by the drive shaft of the metering conveyor. The velocity ratio between the timing shaft and the drive shaft of the metering conveyor was such that the timing shaft rotated once in the time required for the forward movement of all the pot seedlings on a slat (one linear array of seedlings) towards the seedling discharge point. In each revolution of the timing shaft, a sharp lobed cam (2) lifts the shorter end of the fulcrum (3) for the time required for the forward movement of one slat of feeding conveyor towards the metering conveyor. 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 the clutch and power is transmitted to the output shaft of AFM (8). As the cam completely passes below the shorter end of fulcrum, the spring returns the longer end of the fulcrum to its original position. The clutch gets disengaged and remains in this condition till the cam lifts the fulcrum in its next revolution.

The type of clutch used in AFM is a ramped clutch with 2 rollers (10) on the driver disc (9) and a matching cap (13) on the driven disc (12) (Fig. 4). When the cap (13) on the driven disc wraps the roller (10) on driver disc, the clutch gets engaged. The clutch gets disengaged when the longer end of the fulcrum (6) holds the cap away from the roller against the force of the torsion spring (14).

The velocity ratio between the output shaft of AFM (8) and the drive shaft of the feeding conveyor is such that the output shaft of AFM rotates one full revolution for the forward movement of one slat of the feeding conveyor towards the metering conveyor. There is no velocity reduction in AFM. Thus, cam (2) has to lift the shorter end of the fulcrum (3) just for one complete revolution of the input shaft of AFM (7).

4.4. *Seedling drop tube and quick return valve*

A PVC pipe was used as the seedling drop tube and it was provided at the seedling discharge point of the metering conveyor (Fig. 5). A quick return valve (QRV) was provided at the mouth of the seedling drop tube just below the base plate of the metering conveyor to ensure that the pot seedling falls in upright orientation through the tube into the furrow. The QRV is a sliding type valve and it is operated by a lever (6). The lever is pivoted (7) on the frame (4) with end towards the valve (5) longer than the other end. The shorter end of the lever is connected to a helical tension spring (8). The longer end of the lever is moved in a radial path by the flight (3) of the metering conveyor. The pot seedling pushed by the flight moves over the valve (5). When the valve loses its contact with the flight, the spring quickly returns the valve back to its original position. It opens the mouth of the seedling drop tube (11). The sudden loss of support makes the pot seedling fall in upright orientation through the tube into the furrow. A valve stopper (10) is provided at the free end of the valve to prevent the impact of the lever on the flights.

4.5. *Furrow opener and soil covering devices*

A reversible shovel-type furrow opener with front face width of 45 mm was selected. It was fitted on the shank using plough bolts. Rectangular boots were attached behind the furrow opener to support the lower end of the seedling drop tube. A pair of blades converging at the rear end was used as the soil covering device. The blades were provided on each side of the seedling drop tube.

Fig. 6 – Overall view of the 2-row hand tractor powered AVT.

An overall view of the hand tractor powered 2-row AVT is shown in Fig. 6. A depth adjustment wheel was provided to support the weight of AVT and adjust the depth of operation of the furrow openers. The weight of the AVT was found to be 2.03 kN. In order to facilitate the easy manoeuvrability of the hand tractor, ballast of 800 N was placed ahead of the engine of the hand tractor.

5. Optimum seedling and operational parameters for the efficient working of AVT

Among various seedling and operational parameters, moisture content of the potting mix, plant height, linear speed of metering conveyor and the ratio of linear speeds of feeding and metering conveyors affect the working of the major components of AVT. In order to study the effect of these parameters, a single row stationary AVT unit powered by an induction motor (Fig. 7) was developed. Feeding rate, planting rate and pot damage during feeding, conveying and planting by the AVT at various combinations of independent parameters was determined for pot seedlings of tomato. The optimum value of independent parameters to obtain maximum feeding rate and planting rate with minimum pot damage during feeding, conveying and planting were identified. Optimum forward speed of hand tractor was determined from the optimum linear speed of the metering conveyor. Optimum velocity ratio between the drive shaft of the rotavator and the input shaft of AFM was determined from the optimum ratio of linear speeds of feeding and metering conveyors. Optimum value of seedling and operational parameters of AVT for planting pot seedlings of tomato is presented in Table 2.

6. Performance evaluation of AVT under actual field conditions

Field performance of the 2-row hand tractor operated AVT was evaluated for transplanting paper pot seedlings of tomato

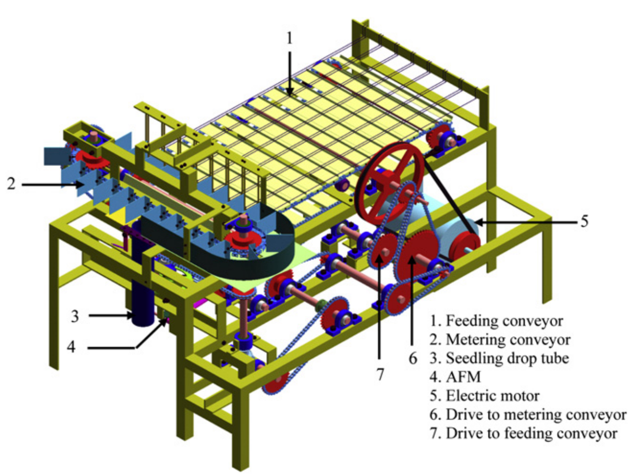

Fig. 7 – Isometric view of stationary single row unit of AVT powered by an electric motor.

Table 2 – Optimum seedling and operational parameters of AVT.

Particulars	Mean ± std. dev.
Average moisture content of potting mix, % (dry basis)	5.0 ± 2.0
Average plant height, cm	12.0 ± 1.0
Forward speed of hand tractor for 45 and 60 cm in-row spacing, km h^{-1}	0.9 and 1.2, respectively
Velocity ratio between drive shaft of rotavator and input shaft of AFM for 45 and 60 cm in-row spacing	1.6 and 2.2, respectively.

at 45 × 45 cm spacing in three well prepared plots each of 25 × 3 m size. The soil was lateritic sandy clay loam having bulk density of 1.32 g cm^{-3} at 9.0 ± 2% moisture content (dry basis). Twenty-five day old pot seedlings of average height 12 cm and potting mix moisture of around 5% (dry basis) were selected. The hand tractor was operated at an average forward speed of 0.9 km h^{-1}. A velocity ratio of 1.6 was set between drive shaft of rotavator and input shaft of AFM. Pre-experimental trials had been undertaken to adjust the working parts such as timing of AFM, furrow openers, soil covering devices and depth adjustment wheel to ensure that pots are planted in upright orientation at appropriate depth in the furrow and sufficient amount of soil is covered around the pot seedlings. A mark was made on the depth adjustment wheel shaft to set the depth of operation of the furrow opener at 8 cm. The row markers were set to plant the seedlings uniformly at a row spacing of 45 cm.

Fifty-four pot seedlings were placed on each feeding conveyor (48 seedlings in the form of 6 × 8 rectangular array on the feeding conveyor and 6 seedlings on the metering conveyor up to seedling discharge point). The AVT thus carried a total of 108 seedlings. The hand tractor was operated along the length of the field. During the operation, time lost for placing the pot seedlings on feeding conveyors, turning at the headland, engagement and disengagement of clutches and depth adjustments were recorded. The total time required for transplanting each plot was noted. The actual field capacity, fuel consumption and percent wheel slip of hand tractor were determined. After the completion of operation in each plot, the number of missed plantings (in-row spacing greater than 67.5 cm), tilted plantings and correctly planted seedlings were counted. The amount of soil covering both correctly planted and tilted seedlings were recorded separately as sufficiently soil-covered, partially soil-covered and excessively-soil covered seedlings.

After the operation, tilted seedlings were placed in upright orientation in the furrow. Sufficient amount of soil was covered around all the pot seedlings. The labour required for the correct placement and soil covering of the seedlings was recorded. All the seedlings were immediately watered. The population of established plants was recorded two days after transplanting. Missed plantings were filled and labour required for filling of plants was noted down. The cost of mechanical transplanting using AVT could then be determined.

For the purpose of comparison, tomato seedlings were transplanted at 45 × 45 cm spacing in two plots using pot seedlings and bare-root seedlings by conventional methods of manual transplanting. When bare-root seedlings are used, slightly older seedlings are preferred. Hence, 35 days old bare-root seedlings were used. The performance of transplanting using AVT and manual method of transplanting were compared in terms of field capacity, labour requirement, quality of work and cost of operation.

7. Results and discussion

A comparison of field performance, quality of work and cost of transplanting using AVT and manual method of transplanting of paper pot seedlings (MTP) and bare-root seedlings (MTB) is shown in Table 3.

7.1. *Field capacity and labour requirement*

At an average forward speed of 0.9 km h^{-1}, the percent wheel of slip of hand tractor varied from 2.50 to 3.73%. The average fuel consumption was 1.42 l h^{-1}. The mean (±standard deviation) depth of placement of pot seedlings was 6.3 (±1.5) cm. The field capacity of the AVT was found to be 0.026 ha h^{-1} with a field efficiency of 31.88%. Park et al. (2005) reported the field capacity of 0.045 ha h^{-1} for the self-propelled walk-behind type fully automatic vegetable transplanter for Chinese cabbage.

The labour requirement for transplanting using the AVT was found to be 103 man-h ha^{-1}. This included the labour requirement of 25 man-h ha^{-1} for refilling of missed plantings and correct placement of tilted plantings. The conventional manual transplanting required 229 and 320 man-h ha^{-1} for paper pot and bare-root seedlings, respectively (Table 3). Thus, mechanical transplanting by AVT resulted in the saving of 55% labour and 72% time over the manual transplanting of paper pot seedlings, and 68% labour and 80% time over manual transplanting of bare-root seedlings, respectively. Saving of labour and time in the range of 70–93% and 75–78%, respectively have been reported for the tractor operated 2-row semi-automatic vegetable transplanters in India (Chaudhury et al., 2002; Manes et al., 2010; Satpathy & Garg, 2008). Park et al. (2005) reported a saving of 88% labour by use of self-propelled walk-behind type automatic vegetable transplanter.

7.2. *Quality of work*

The AVT had an average planting rate of 32 pot seedlings min^{-1} per row. The missed and tilted plantings were found to be 4 and 5%, respectively (Table 3). The reported planting rate in the semi-automatic vegetable transplanters for bare-root seedlings varied from 35 to 45 seedlings min^{-1} (DARE, 2006, pp. 109–128; Satpathy & Garg, 2008; Manes et al., 2010). Fully automatic transplanters have a planting rate of above 60 seedlings min^{-1} (Suggs et al., 1987; Shaw, 1997; Tsuga, 2000). Park et al. (2005) reported missed planting of 2.2–3.0% for self-propelled walk-behind type fully automatic vegetable transplanter that used plug seedlings. Missed planting rates of 2.9–9.3%, 3–4% and 2.9–3.5% have been reported by Choudhury et al. (2002), Manes et al. (2010), and Satpathy and Garg (2008), respectively for semi-automatic vegetable transplanters that used bare-root seedlings. In the semi-automatic vegetable transplanters, missed plantings occurred when the labourer failed to feed the metering unit with the seedling due to higher speed of operation. In the present study, missed plantings occurred due to damage to pots during the conveying process by the metering conveyor. Missed plantings due to failure of the pick-up system of a fully automatic vegetable transplanter to remove seedlings from the tray accounted for 3.5% (Kim, Park, & Kwak, 2001). Missed planting of 4% has been reported for chain of paper pot seedlings in a fully automatic vegetable transplanter (Tsuga, 2000). Choudhury et al. (2002) reported tilted planting of 4. 0–13.4% for the semi-automatic vegetable transplanter and it was attributed to soil condition in the field. In the present study, pot seedlings got tilted after falling in upright orientation in the furrow due to unevenness of the furrow soil and partial covering of the soil around the seedling pots.

The soil covering efficiency of the vegetable transplanter was found to be about 81%. About 12% of the pot seedlings were covered with excessive amount of soil and about 7% of the pot seedlings were partially covered with soil (Table 3). The plant distribution and soil cover around the seedlings were almost uniform in the field transplanted manually with

Table 3 – Comparison of field performance of AVT with manual method of transplanting of paper pot seedlings (MTP) and bare-root seedlings (MTB).

Particulars	AVT	MTP	MTB
Field capacity, ha h^{-1}	0.026	0.0087	0.0066
Labour requirement (including refilling), man-h ha^{-1}	102.46	228.62	319.83
Missed planting, %	4.01	–	–
Tilted planting, %	5.14	–	6.0
Partially soil covered seedlings, %	7.39	–	–
Excessive soil covered seedlings, %	11.90	–	28.0
Cost of operation (including refilling), ₹ ha^{-1}	29,954, 27,769, 26,996 and 26,584 for annual use of 100, 200, 300 and 400 h	24,294	5997
Cost of paper pots and mix, ₹ ha^{-1}	20,000	20,000	0.00

pot seedlings. The plant distribution was also observed to be almost uniform in the field transplanted manually with bare-root seedlings. However, about 6% of the seedlings were found to be tilted and about 28% of the seedlings were found to be excessively covered with soil after manual transplanting of bare-root seedlings.

7.3. Cost of operation

The initial cost of the walk-behind type hand tractor was taken as ₹120 000 (US$ 2700). Its typical annual use would be 800 h on small and medium farms (NABARD, 2007). Assuming a ten year life, and depreciation and interest at 10% p.a., the cost of operation of hand tractor alone is ₹120 (US$ 2.7) per hour for 800 h of annual use. The initial total cost AVT was taken as ₹60 000 (US$ 1350). Its useful life was assumed to be 10 years. The cost of preparation of paper pot along with potting mix of ₹405 (US$ 9) per 1000 pots was added as additional cost.

Cost of mechanical transplanting using AVT was found to be 4.4–5.0 times higher than that of conventional manual transplanting of bare-root seedlings (Table 3). The cost of paper pots and potting mix was the major component of the cost of operation using paper pot seedlings. It accounted for 67–75% of the total cost of mechanical transplanting and 82% of the total cost of manual transplanting. Singh (2008) reported 23.9% saving in cost for tractor operated 2-row semi-automatic vegetable transplanter and Park et al. (2005) reported 29% saving in cost for walk-behind type fully automatic vegetable transplanter over conventional method of transplanting vegetables. Parish (2005) stated that automatic vegetable transplanters are expensive and require a very high level of plant quality and uniformity. The higher cost of mechanical transplanting in the present study could be attributed to the high cost of preparation of paper pot seedlings and low field efficiency (31.88%) of the AVT.

The low values of field capacity and field efficiency of the AVT could be attributed to a loss of 68% of the total operating time. Time loss in placing the pot seedlings on feeding conveyors accounted for 50% of the total operating time. About 18% of total operating time was lost during depth adjustment, operation of clutches and turning at the headland. This is a substantial loss of time and it has to be reduced to improve the field coverage. Efforts are being made to develop a mechanical system for the quick transfer of pot seedlings (as a rectangular array) from the tray to the feeding conveyor using a multi-celled tray with replaceable base. Efforts are also being made to reduce the time involved in turning at the headland.

8. Conclusions

This is the first attempt to develop a fully automatic vegetable transplanter for individual paper pot seedlings using walk-behind type hand tractor as the source of power. Use of AVT has been found to save 68% labour and 80% time involved in transplanting of vegetables besides increasing the annual use of the hand tractor in small farms. Cost of operation has been found to be 4.4–5.0 times higher than that of conventional manual method of transplanting bare-root seedlings. Being the first prototype, field capacity and field efficiency of the AVT is low. Efforts are being made to increase the field capacity and field efficiency by reducing the time involved in placing pot seedlings on the feeding conveyor in the form of a rectangular array and turning of the machine at the headland.

REFERENCES

Armstrong, E. C., & Hanacek, W. A. (1984). *Automatic soil plug loader*. US patent No. 4443151.

Bhole, N. G., & Tiwari, A. D. (1977). Power losses in power tillers. *The Harvester (Indian Institute of Technology, Kharagpur, India)*, 19, 62–66.

Birthal, P. S., Joshi, P. K., & Thorat, A. (2007). *Diversification of Indian agriculture towards high value crops: the role of small holders*. Washington: International Food Policy Research Institute.

Chaudhuri, D., Singh, V. V., & Dubey, A. K. (2002). Refinement and adoption of mechanical vegetable transplanters for Indian conditions. *Agricultural Engineering Today, 26*(5-6), 11–20.

DARE.. (2006). *Agricultural engineering and technology*. *In DARE/ICAR Annual Report 2005-06*. New Delhi, India: Department of Agricultural Research and Education, Ministry of Agriculture, Government of India.

Dewangan, K. N., & Tewari, V. K. (2008). Characteristics of hand-transmitted vibration of hand tractor used in three operational modes. *International Journal of Industrial Ergonomics, 39*(1), 239–245.

Furuki, T., Yamanishi, H., Matsumoto, H., Honma, Y., & Takada, K. (2003). Folding paper type biodegradable paper pot. *Shizuokaken Nogyo Suisanbu, Kankyo Shinrinbu Norin Suisan Kankei Shiken Kenkyu Seika Joho, 2002*, 26–27, (In Japanese).

Ghai, T. R., & Arora, D. (2007). *Horticulture vegetable science (vegetables, tubers and spice crops), in tropical and subtropical vegetables*. New Delhi, India: National Science Digital Library, National Institute of Science Communication and Information Resources, Council of Scientific and Industrial Research.

Government of India. (2002). *Agricultural census 2002*. New Delhi, India: Agricultural Census Division, Ministry of Agriculture.

Government of India. (2009). *Indian horticultural database-2009*. New Delhi, India: National Horticultural Board, Ministry of Agriculture.

Kathirvel, K., Manian, R., & Balasubramanian, M. (2001). Tractive performance of power tiller tyres. *Agricultural Mechanization in Asia Africa and Latin America, 32*(2), 32–36.

Kim, H. J., Park, S. H., & Kwak, T. Y. (2001). Development of an automatic transplanter for cabbage cultivation. Seoul, Korea: *Korea automatic dynamic analysis of mechanical systems conference, 8–9 Nov*.

Kumar, S., Pal, S., & Joshi, P. K. (2004). Vegetable sector in India: an overview. In *Proceedings of national seminar on impact of vegetable research in India, (pp. 9–34)*. New Delhi, India: National Centre for Agricultural Economics and Policy Research.

Kumar, G. V. P., & Raheman, H. (2008). Vegetable transplanters for use in developing countries: a review. *International Journal of Vegetable Science, 14*(3), 232–255.

Kumar, G. V. P., & Raheman, H. (2010). Volume of vermicompost based potting mix for vegetable transplants determined using fuzzy biomass growth index. *International Journal of Vegetable Science, 16*(4), 335–350.

Manes, G. S., Dixit, A. K., Sharda, A., Singh, S., & Singh, K. (2010). Development and evaluation of tractor operated vegetable transplanter. *Agricultural Mechanization in Asia Africa and Latin America, 41*(3), 89–92.

NABARD.. (2007). *Use of power tiller in agricultural operations*. Mumbai, India: National Bank for Agriculture and Rural Development.

Nambu, T., & Tanimura, M. (1992). Development of automatic transplanter using chain pot for vegetable crops. *Acta Horticulturae, 319*, 541–546.

Parish, R. L. (2005). Current developments in seeders and planters for vegetable crops. *HortTechnology, 15*(2), 1–6.

Park, S. H., Kim, J. Y., Choi, D. K., Kim, C. K., Kwak, T. Y., & Cho, S. C. (2005). Development of walking type Chinese cabbage transplanter. *Journal of the Korea Society for Agricultural Machinery, 30*(2), 80–81.

Randhawa, K. S. (1998). Recent advances in efficiency of vegetable growing in India. *Acta Horticulturae, 220*, 35–44.

Roul, A. K., Raheman, H., Pansare, M. S., & Manchavaram, R. (2008). Predicting the draught requirement of tillage implements in sandy clay loam soil using an artificial neural network. *Biosystems Engineering, 104*(4), 476–485.

Sakaue, O. (1992). Development of automated seedling production and transplanting system using robotics. *Acta Horticulturae, 319*, 557–562.

Satpathy, S. K., & Garg, I. K. (2008). Effect of selected parameters on the performance of a semi-automatic vegetable transplanter. *Agricultural Mechanization in Asia, Africa and Latin America, 39*(2), 47–51.

Shaw, L. N. (1997). Automatic transplanter for vegetables. *Proceedings of Florida State Horticultural Society, 110*, 262–263.

Shaw, L. N. (1999). Removing and handling modular vegetable seedlings from nursery trays. *Proceedings of Florida State Horticultural Society, 112*, 153–155.

Singh, S. (2008). Research highlights. *All India coordinated research project on farm implements and machinery*. Bhopal, India: Central Institute of Agricultural Engineering.

Subramanian, S. R., Varadarajan, S., & Asokan, M. (2000). India. In M. Ali (Ed.), *Dynamics of vegetable production, distribution and consumption in Asia* (pp. 99–138). Shanhua, Taiwan: Asian Vegetable Research and Development Centre, Asian World Vegetable Centre.

Suggs, C. W., Peel, H. B., Thomas, T. N., Eddington, D. L., Gore, J. W., & Seaboch, T. R. (1987). Self feeding transplanter for tobacco and vegetable crops. *Applied Engineering in Agriculture, 3*(2), 148–152.

Tsuga, K. (2000). Development of fully automatic vegetable transplanter. *Japan Agricultural Research Quarterly, 34*(1), 21–28.

Ueno, H., Matsumura, N., & Miyaji, M. (2002). In *Bulletin of experimental farm. Effects of biodegradable pot on growth and quality of pumpkin seedling, 24*. Matsuyama, Japan: Faculty of Agriculture, Ehime University.

Yonetani, T., Matsumoto, I., & Okishio, Y. (1999). Development and improvement of a transplanter for leafy vegetables. *Bulletin of Hyogo Prefectural Agricultural Institute, 47*, 44–47, (In Japanese).