Original Article
Journal of Biosystems Engineering
J. of Biosystems Eng. 41(1):21-33. (2016. 3)
http://dx.doi.org/10.5307/JBE.2016.41.1.021
eISSN : 2234-1862
pISSN : 1738-1266

Development of a Hopper-Type Planting Device for a Walk-Behind Hand-Tractor-Powered Vegetable Transplanter

Pramod Chandra Dihingia[1], G. V. Prasanna Kumar[1]*, Pallab Kumar Sarma[2]

[1]Department of Agricultural Engineering, Triguna Sen School of Technology, Assam University, Silchar 788011, Assam, India
[2]All India Coordinated Research Project on Dryland Agriculture, Biswanath College of Agriculture, Biswanath Chariali, Assam, India

Received: January 13rd, 2016; Revised: February 12nd, 2016; Accepted: February 16th, 2016

Abstract

Purpose: In order to ensure that vegetable seedlings (with a soil block around their roots) are planted in an upright orientation after metering in a vegetable transplanter, they need to be dropped freely from a certain height. The walk-behind hand-tractor-powered machines do not have sufficient space to drop the seedlings from that height. In the present work, a hopper-type planting device was developed for the walk-behind hand-tractor-powered vegetable transplanter to ensure that the soil block seedlings are planted in an upright orientation. **Methods:** Various dimensionless terms were developed based on the dimensional analysis approach, and their effect on the planting of soil block seedlings in an upright orientation (planting efficiency) was studied. The optimum design dimensions of the hopper-type planting device were identified by the Taguchi method of optimization. **Results:** The ratio of the height of free fall to the sliding distance of the seedling on the surface of the hopper had the highest influence on planting efficiency. The planting efficiency was highest for plants with a height 15 ± 2 cm. The plant handling Froude number, in interaction with the design of the hopper-type planting device, also significantly affected the planting efficiency. Of the hopper design factors, the length of the slide of the seedlings on the surface of the hopper was most important, and induced sufficient velocity and rotation to cause the seedling to fall in an upright orientation. An evaluation of the performance of the planting device under actual field conditions revealed that the planting efficiency of the developed planting device was more than 97.5%. **Conclusions:** As the seedlings were fed to the metering device manually, an increase in planting rate increased missed plantings. The planting device can be adopted for any vegetable transplanter in which the seedlings are allowed to drop freely from the metering device.

Keywords: Dimensional analysis, Hand tractor, Planting device, Planting efficiency, Taguchi method, Vegetable transplanter

Introduction

The use of plug seedlings to establish vegetable crops in the field is an accepted practice in many Asian countries (Singh et al., 2005; Russo, 2006). The planting of seedlings in an upright orientation is very crucial for their growth and yield (Kumar and Raheman, 2011). Therefore, vegetable transplanters include various planting devices, such as pockets (PAU, 2004), vertical descending cups or buckets (Munilla and Shaw, 1987; Kim et al., 2001), split cone cups, or transplanting discs (Harrison et al., 1990) to place the plants in an upright orientation in the soil.

Many researchers have reported the development of seedling pick-up mechanisms to extract the seedlings from the tray cells and place them in the soil in an upright orientation. The vegetable transplanter developed by Choi et al. (2002) extracted the seedlings from the tray cells using a five-bar mechanism, and then placed them

***Corresponding author:** G. V. Prasanna Kumar
Tel: +91-3842-270989; **Fax:** +91-3842-270802
E-mail: gvpk@yahoo.com

on a hopper that dropped the seedlings onto the soil. The vegetable transplanter developed by Feng et al. (2000) had a flexible seedling lifter to straighten the plug seedling, and drop it through a tube into the furrow in an upright position. The pick-up device developed by Park et al. (2005) for a walk-behind vegetable transplanter moved in an elliptical path to remove the plant from the tray cells and drop it into the furrow. The seedling pick-up mechanisms ensured the planting of seedlings in an upright orientation with a high success rate. However, mechanical transplanting requires seedlings of uniform size, shape, and firmness (Parish, 2005).

In India, gravity-fed vegetable transplanters have been developed (Sivakumar and Durairaj, 2014). In a gravity-fed transplanter, a metering device drops the soil block seedlings through a tube. The tube guides the seedlings into an upright orientation on the soil. Transplanting with a tractor-powered semi-automatic vegetable transplanter with a rotary-cup-type or revolving-magazine-type metering mechanism involved dropping the soil block seedlings under the force of gravity through a vertical tube (Narang et al., 2011; Nandede et al., 2013). Walk-behind hand-tractor-powered vegetable transplanters that work in the same manner as that of a gravity-fed transplanter have also been developed. In most of these machines, conveyor-type metering devices have been used. Kumar and Raheman (2011) employed a horizontal conveyor with vertical flights as the metering device. The flights conveyed the individual paper pot seedlings in an upright orientation by pushing them over a plate toward the seedling drop tube. The quick return valve at the mouth of the tube opened suddenly, and the tube guided the seedling to fall in an upright orientation into the furrow. Mohanty et al. (2015) used a horizontal conveyor with slats (small trays) as the metering device. The slats carried the seedling in a horizontal position, and then dropped it into a tube. The seedling fell down freely through the tube into the furrow.

The planting of seedlings by dropping them freely requires tall plants with heavy soil blocks around the root masses of the plants (Figure 1). The tall plants and heavy soil blocks around the root masses of the plants ensures the planting of the seedlings in an upright orientation. Kumar and Raheman (2011) used individual paper pot seedlings of 65 to 74 g of weight (including the weight of the soil and the pot) and 12 cm in plant height. Mohanty et al. (2015) reported plants of a height of 15 to 25 cm as most suitable for mechanical transplanting.

Figure 1. Ready-to-plant soil block tomato seedling.

The falling of seedlings (with heavy soil blocks around the root portion) from the metering device to the soil, and its resting on the soil, are physical phenomena. Here, the soil block around the root portion of the seedling is heavy, and the seedlings fall by force of gravity, with the soil block hitting the soil first. However, the soil block may fall with the seedling in an upright orientation or tilted in any direction. Hence, there is a need to modify the existing method of direct dropping of soil block seedlings by providing an assist for free falling in an upright orientation. The height of fall of the seedlings, the height of the plants, the initial orientation of the plants on the metering device, and the design and operational parameters of the components involved in the planting of seedlings affect the orientation of the fall of the seedlings.

Keeping these factors in view, the present work was undertaken with the following objectives:

(i) To develop a hopper-type planting device for the planting of tomato seedlings in an upright orientation.

(ii) To identify the optimum design and operational parameters of the metering and planting devices for the efficient planting of tomato seedlings.
(iii) To evaluate the performance of the developed planting device under actual field conditions.

Materials and Methods

In the present work, a hopper-type planting device was developed for the walk-behind hand-tractor-powered vegetable transplanter (Figure 2). The vegetable transplanter had a horizontal conveyor-type seedling-metering device. The semi-circular troughs were attached to the conveyor at a center-to-center distance of 10 cm. Each trough was manually fed with a soil block seedling in the horizontal position with the plant oriented in the direction of forward travel of the machine. As each trough passed over the sprocket of the chain conveyor, a soil block seedling fell out of the trough and dropped down.

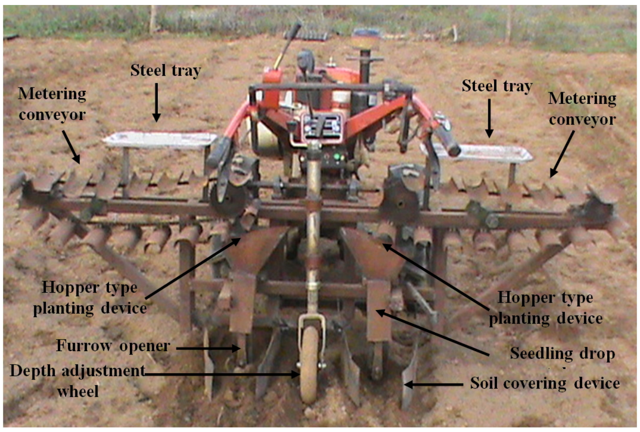

Figure 2. Walk-behind hand-tractor-powered vegetable transplanter.

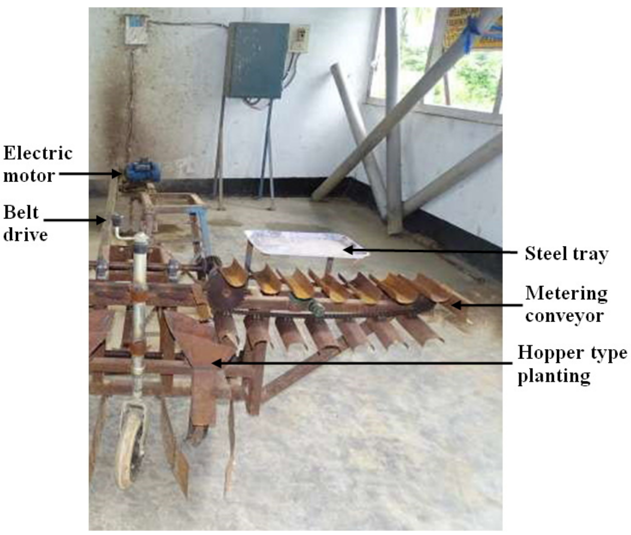

Figure 3. Laboratory set-up for the evaluation of the performance of the planting device.

It was observed during the trials that, if a soil block seedling was dropped from a suitable height from the hopper, and then allowed to move into a vertical tube, most of the seedlings fell with the plants in an upright orientation. Therefore, instead of dropping the soil block seedlings directly into the tube, a hopper was used as an assist to move the seedlings into the tube for achieving the upright orientation of the plants.

In the present work, the metering device was operated at the selected speeds using an electric motor, as shown in Figure 3. However, the machine was kept in a static condition, without any forward motion. The seedlings were dropped onto the hopper (planting device), and then allowed to move into a vertical tube. The seedlings were allowed to fall onto the concrete floor through the tube. The orientation of the plant was observed after the fall. The floor was immediately cleaned for the observation of the fall of the next plant. The study on the variation in orientation of the plant after its fall from the metering device onto the concrete floor under the static condition of the machine (zero forward speed) provides insight into the effect of various seedling, design and operational parameters on the efficient planting of soil block seedlings by the mechanical transplanter under actual field conditions. Once it is ensured that the plants fall in an upright orientation, it is possible to select the appropriate design and operational schemes for the metering device, planting device, seedling drop tube, furrow opener, and soil covering devices for effective mechanical transplanting.

Dimensional analysis

The fall of soil block seedlings with the plants in an upright orientation was studied by considering the various seedling, design and operational parameters shown in Table 1. The design parameters are depicted in Figure 4. The feeding rate refers to the number of soil block seedlings fed by the metering conveyor to the hopper per unit time. The planting rate refers to the number of soil block seedlings dropped through the drop tube in an upright orientation per unit time. The coefficient of friction between the soil block of the seedling and the hopper surface (μ) remained constant throughout the experiment. Therefore, this was not considered for further analysis. The 13 original variables

Table 1. Basic physical parameters for the fall of soil block seedlings in an upright orientation from a seedling metering conveyor and hopper-type planting device

Parameters	Symbol	Unit	Length (L)	Mass (M)	Time (T)
Height of seedling	H	cm	1	0	0
Mass of seedling with soil block	m	g	0	1	0
Radius of rotation of metering conveyor	r	cm	1	0	0
Height of free fall of seedling	h	cm	1	0	0
Length of slide of seedling	l	cm	1	0	0
Coefficient of friction between soil block of plant and hopper surface	μ	-	0	0	0
Angle of slide of seedling	θ	°	0	0	0
Representative dimension of cross section of drop tube	d	cm	1	0	0
Length of drop tube	L	cm	1	0	0
Centrifugal force imparted by metering conveyor on seedling	F	N	1	1	−2
Acceleration due to gravity	g	cm s^{-2}	1	0	−2
Plant feeding rate	Q_f	Number s^{-1}	0	0	−1
Planting rate	Q_p	Number s^{-1}	0	0	−1

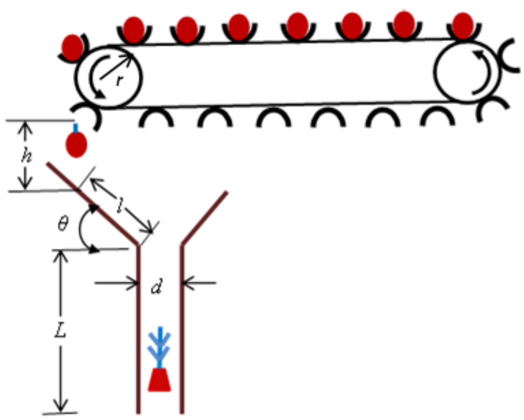

Figure 4. Various design parameters of hopper-type planting device.

were reduced to a total of 12 variables by

$$f(H, m, r, h, l, \theta, d, L, F, g, Q_f, Q_p) = 0 \tag{1}$$

By the Buckingham π theorem (Langhaar, 1980), it follows that any homogeneous equation relating 12 variables must admit the representation

$$\phi(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7, \pi_8, \pi_9) = 0 \tag{2}$$

with

$$\pi_1 = \frac{H}{r}, \pi_2 = \frac{h}{r}, \pi_3 = \frac{l}{r}, \pi_4 = \sin\theta, \pi_5 = \frac{d}{r}, \pi_6 = \frac{L}{r},$$
$$\pi_7 = \frac{F}{mg}, \pi_8 = Q_f\left(\frac{r}{g}\right)^{1/2}, \pi_9 = Q_p\left(\frac{r}{g}\right)^{1/2} \tag{3}$$

The ratio of the height of free fall to the length of the slide of the seedlings (β) is given by:

$$\beta = \frac{h}{l\sin\theta} = \frac{\pi_2}{\pi_3\pi_4} \tag{4}$$

The ratio of the representative dimension of the cross section to the length of tube (φ) is given by:

$$\varphi = \frac{d}{L} = \frac{\pi_5}{\pi_6} \tag{5}$$

The plant handling Froude number (Fr) is expressed as:

$$Fr = \pi_7 = \frac{mv^2}{r\,mg} = \frac{v^2}{g\,r} \tag{6}$$

where v represents the forward velocity of the feeding conveyor.

$$\text{Planting efficiency} = \eta_p = \frac{Q_p}{Q_f} \times 100 = \frac{\pi_6}{\pi_7} \times 100 \tag{7}$$

A tube with a hollow square cross section with a side length (d) of 50 mm on the inner side and a length (L) of 50 cm was used as the seedling drop tube. Therefore, φ was not considered as a variable for further analysis. It is therefore convenient to combine $\pi_1, \pi_2, \ldots, \pi_9$ to form the independent dimensionless group Π_1, Π_2, Π_3, and Π_4, which is defined as:

$$\Pi_1 = \alpha = \frac{H}{r} \tag{8}$$

(ratio of seedling height to radius of rotation)

$$\Pi_2 = \beta = \frac{h}{l \sin \theta} \tag{9}$$

(ratio of height of free fall to length of slide of seedling)

$$\Pi_3 = Fr = \frac{v^2}{g\, r} \text{ (plant handling Froude number)} \tag{10}$$

$$\Pi_4 = \eta_p \text{ (planting efficiency)} \tag{11}$$

The foregoing dimensionless groups show that planting efficiency is determined by three dimensionless parameters, viz.:

$$\eta_p = \phi(\alpha, \beta, Fr) \tag{12}$$

Experiment and data analysis

The purpose of the experiments was to study the effect of α, β, and Fr on the planting efficiency, and to identify the optimum values of α, β, and Fr for achieving maximum planting efficiency. The experiments were conducted in the laboratory using soil block tomato seedlings (Figure 1) grown in Pro-trays of 100 cm^3 total cell volume (28-cell trays). The growth medium used for the production of the plants consisted of 70% top soil and 30% vermicompost, on a volume basis. The seedlings were grown to a sufficient height for mechanical transplanting. The moisture content of the soil block at the time of the extraction of the plants with their soil blocks from the tray cells was 22 ± 2% (dry basis). The mass of each seedling, with its soil block, was 68.47 ± 3.22 g.

Mechanical transplanting requires tall plants (Kumar and Raheman, 2011; Nandede et al., 2013). The height of the seedlings is an important parameter for the efficient feeding, conveying, and planting of soil block seedlings in vegetable transplanters (Kumar and Raheman, 2011). Keeping this fact in mind, three values of α were chosen: 1.55, 2.33, and 3.10, with the height of the plants in the range of 10–20 cm. Three values of Fr were selected: 0.0054, 0.0116, and 0.0295, with the linear speed of the metering conveyor in the range of 3.52–8.21 m·min^{-1}. The metering conveyor could be operated in the selected range using the forward speeds available in the 1st, 2nd, and 3rd low speeds of the hand tractor. A total of nine values of β were considered, taking three values each for h (7, 12, and 17 cm), l (9, 14, and 19 cm), and θ (40, 50, and 60°) by the Latin square design. The nine values of β in ascending order were: 0.43, 0.65, 0.82, 1.21, 1.33, 1.39, 1.40, 1.54, and 2.47. The minimum values of h and l were based on the minimum clearance available between the trough of the metering conveyor and the hopper, and the maximum values were constrained by the strength of the soil block of the seedling. The values of θ were constrained by the limiting angle of friction between the soil block of the seedling and the surface of the hopper, and by the smooth flow of the seedling toward the drop tube, without bouncing or hitting the walls of the tube.

The experiments were conducted on the on the test set-up shown in Figure 3. In each run, 100 soil block seedlings were manually fed to the metering conveyor without missing any troughs. The feeding rate requirement at the three selected values of Fr for obtaining a plant spacing of 45 cm was 33.33, 48.89, and 77.78 seedlings·min^{-1}. Hoppers with nine different configurations were prepared, based on the nine values of β. The randomized complete block design of experiments with three replications for each combination of α, β, and Fr was followed. A total of 243 experiments were conducted. The seedlings dropped through the tube were collected. The number of seedlings that fell down in a perfect upright orientation without considerable damage was noted. The planting efficiency was calculated.

Data were subjected to analysis of variance (ANOVA) in the SPSS software to determine the significance of the primary and interaction effects. When the effect of an independent parameter was found to be significant, the Ryan–Einot–Gabriel–Welsch (R–E–G–W) multiple F test was used to separate the means.

Identification of optimum levels of independent parameters

As the levels of β were selected based on the Latin square design of experiments, the Taguchi method was used for the identification of the optimum values of h, l, and θ (factors of β). In the Taguchi method, the signal-to-noise ratios (S/N ratio) serve as the objective functions for optimization, help in data analysis, and predict the optimum results (Phadke, 2009). The S/N ratio is the ratio of the mean to the standard deviation, and is the measure of the deviation of the response (dependent parameter) from the desired value. Lower variability in an experiment is ensured through maximizing the S/N ratio. However, depending on the type of response desired, Taguchi classified the S/N ratio into three categories: the smaller-the-better, the larger-the-better, and the nominal-the-better (Ross, 1998; Roy, 2001).

Since the goal of the present work is to maximize the upright orientation of the plants during planting, planting efficiency is a 'larger-the-better' type of quality characteristic. The standard formula for computing the S/N ratio for this type of response is:

$$(S/N)_i = -10\,log\left[\frac{1}{n}\Sigma_{j=1}^{n}\frac{1}{y_{ij}^2}\right] \tag{13}$$

where i is the experiment number, y_{ij} is the magnitude of the planting efficiency for the j^{th} replication of the i^{th} experiment, and n is the number of replications for the experimental combination. The S/N ratio was computed using Eq. (13) for each of the nine experimental runs. Since the experimental design is orthogonal, the factor effects can be separated in terms of the S/N ratio. The average values of the S/N ratios of the three independent factors (h, l, and θ) at each of the levels were calculated. The levels corresponding to the highest S/N ratio values were chosen for each factor as representing the optimum condition for maximizing the planting efficiency. The difference ($\triangle$) between the maximum and minimum values of the average S/N ratio for each independent factor was determined. The independent factors were ranked in terms of contribution to planting efficiency according to the descending values of $\triangle$.

The mean response (average value of planting efficiency) for each factor at different levels was determined. The response values were analyzed in terms of planting efficiency to extract the main effects of the independent parameters. The ANOVA technique was then applied to determine the statistically significant parameters at the 5% level of significance.

One of the distinct features of the Taguchi method is that it determines the optimum value in the form of the S/N ratio. The predicted S/N ratio at the optimal process conditions was computed by the following mathematical equation (Roy, 2001):

$$S/N_{predicted} = \overline{S/N} + \Sigma_{k=1}^{m}(S/N_k - \overline{S/N}) \tag{14}$$

where $\overline{S/N}$ is the mean of all the S/N ratios, S/N_k is the S/N ratio at the optimal level for the k^{th} parameter, and m is the number of independent parameters that significantly affect the planting efficiency.

The theoretical maximum value of the planting efficiency at the optimal process conditions was determined using the following equation:

$$\eta_{p_{predicted}} = \sqrt{10\frac{S/N_{predicted}}{10}} \tag{15}$$

Confirmation experiment

Confirmation experiments were conducted at the optimal conditions to validate the predicted results. The procedure mentioned above was followed for three replications.

$\eta_{p_{predicted}} \pm CI$ gives the 95% confidence interval for the predicted value of planting efficiency. The value of CI was estimated using the following equation:

$$CI = \sqrt{F_{(0.05,\,1,\,df_{error})} MSS_{error}\left[\frac{N}{1+df_{total}} + \frac{1}{R}\right]} \tag{16}$$

where $F_{(0.05,\,1,\,df_{error})}$ is the F-ratio required for a 95% confidence interval, df_{error} and df_{total} are the degrees of freedom of error and total, respectively, MSS_{error} is the mean sum of the squares of the error, N is the total number of experiments, and R is the number of trials for the confirmation experiment.

Evaluation of performance of planting device under actual field conditions

A 2-row vegetable transplanter (Figure 2) was developed, considering the tractive power of the walk-behind hand tractor. It consisted of two sets of metering conveyors, steel trays, hopper-type planting devices, seedling drop tubes, furrow openers, soil-covering devices, as well as a depth-adjustment wheel, a dog clutch, and a hitch arrangement. The performance of the hopper-type planting device was evaluated under actual field conditions using the developed 2-row hand-tractor-powered vegetable transplanter. Two plots of 23×10 m were prepared for the planting of tomato seedlings at a 45×45 cm spacing. A total of 1000 seedlings were planted in each plot, with 50 plants in each row. The plots contained inceptisol soil of a sandy loam texture with a bulk density of 1.30 g·cm^{-3} and a moisture content of 11 ± 2% (dry basis). Twenty-eight-day-old soil block tomato seedlings with an average plant height of 15 ± 2 cm were used.

The depth adjustment wheel was adjusted to set the furrow opener to penetrate and make a furrow of 8 cm in depth. The depth of operation of the soil-covering device was adjusted to cover the soil block seedlings with an adequate quantity of soil immediately after the fall of the plants through the drop tube. The steel tray near each metering conveyor was loaded with soil block seedlings for feeding to the troughs of the metering conveyor. Two skilled farm workers operated the hand tractor by each holding a handle and feeding the seedlings from the steel tray to the troughs of the metering conveyor. The hand tractor was operated along the length of the field at a constant forward speed of 0.9 km·h^{-1} (in 1st low speed) in the first plot, and at a constant forward speed of 1.32 km·h^{-1} (in 2nd low speed) in the second plot. These two forward speeds correspond to the first two values of Fr (0.0054 and 0.0116) chosen for the laboratory experiments.

After the completion of the transplanting operation in each plot, the number of missed plantings (in-row plant spacing greater than 67.5 cm, i.e., 1.5 times the desired plant spacing of 45 cm) was counted and noted. The orientation of each plant in each row was observed and noted as being a perfectly upright orientation, sideways tilted, forward tilted, or backward tilted. In addition, the number of seedlings in each row without soil blocks or with disintegrated soil blocks was also noted. The seedlings with disintegrated soil blocks were generally fully covered with soil. All the seedlings were watered immediately after planting.

Results and Discussion

Effect of seedling, design and operational parameters on planting efficiency

The planting efficiency was affected by α and β (Table 2). This indicates that for the selected design of the metering conveyor, the seedling height, height of free fall, and length of slide of seedling on the hopper affected the planting efficiency. The value of Fr did not have a significant effect on planting efficiency (Table 2). This reveals that the range of linear speed of the metering conveyor considered for the experiment did not induce sufficient centrifugal force to have a significant effect on the planting efficiency. Further, it indicates that the intra-row plant spacing can be varied by varying the linear speed of the metering conveyor in relation to the forward speed of the hand tractor, rather than by varying the distance between the troughs of the conveyor. The mean value of the planting efficiency was significantly high when α = 2.33 (Table 3). This indicates that the soil block seedlings with a plant height of 15 ± 2 cm were most suitable for planting. The mean value of the planting efficiency was significantly high for β = 0.65 (Table 3). However, β in interaction with *Fr* significantly affected the planting efficiency (Table 2).

The variation in planting efficiency with β and Fr is presented in Figure 5. The combination of β = 0.65 and Fr = 0.0116 resulted in the highest planting efficiency. There was no significant difference between the planting efficiency when Fr decreased from 0.0116 to 0.0054 at a constant β = 0.65. When $\beta \geq 1.21$, there was no significant difference in planting efficiency by varying Fr at a given value of β. Furthermore, the F-value associated with β is also the highest among the factors considered for the experiment

Table 2. Analysis of planting efficiency

Source of variation	df	SS	MSS	F
α	2	749.00	374.00	47.59[a)]
Fr	2	39.40	19.70	2.51
β	8	35700.00	4470.00	567.93[a)]
$\alpha \times Fr$	4	20.10	5.04	0.64
$\alpha \times \beta$	16	129.00	8.04	1.02
$Fr \times \beta$	16	478.00	29.90	3.80[a)]
$\alpha \times Fr \times \beta$	32	231.00	7.20	0.92
Error	162	1270.00	7.87	

[a)]Significant at 1% level of significance

Table 3. Variation in planting efficiency (η_p) with variation in α and β

A	η_p	β	η_p
1.55	72.00	0.43	76.20 d
2.33	76.20 a	0.65	91.30 a
3.10	74.80 b	0.82	82.00 c
		1.21	57.10 g
		1.33	88.40 b
		1.39	67.60 f
		1.40	81.30 c
		1.54	69.80 e
		2.47	55.30 h

Letters following the planting efficiency values indicate levels of significant difference. For example, 82.00 and 81.30, both marked by the letter “c,” are at the same level of significant difference.

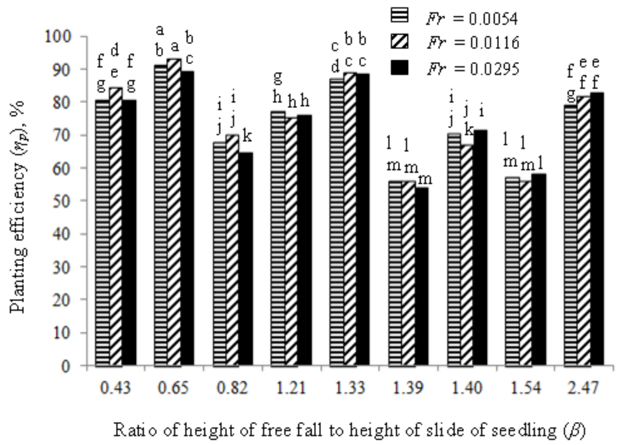

Figure 5. Effect of interaction of β and Fr on planting efficiency. Bars with the same letter above them indicate no significant difference between them.

(Table 2). These facts reveal β to be the major factor affecting the planting efficiency. Hence, the optimum values of the factors of β were identified for all combinations of β and Fr when α = 2.33.

Effect of factors of β on planting efficiency

The average values of planting efficiency (average of three replications) for the nine experimental runs of the orthogonal array test when α = 2.33 and Fr = 0.0054, 0.0116, and 0.0295 are presented in Table 4. Planting efficiency varied from 54 to 96%. The highest planting efficiency of 94–96% was obtained in the 2nd experimental run, which corresponded to h = 7 cm, l = 14 cm, and θ = 50°. The 7th experimental run, corresponding to h = 17 cm, l = 9 cm, and θ = 50°, resulted in the lowest planting efficiency of 54–58%. The S/N ratio for each experimental run was calculated using Eq. (13) and is also given in

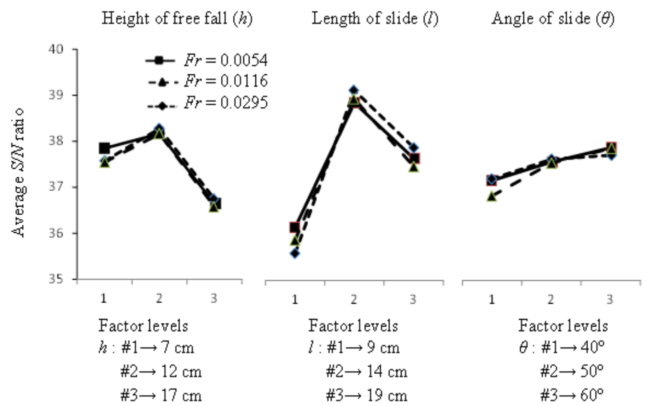

Figure 6. Effect of various factors of β on planting efficiency (S/N ratio).

Table 4.

In order to determine the effect of the factors of β on the planting efficiency, factor effects were separated in terms of the S/N ratio. The average values of the S/N ratio for the three factors of β at each level are shown in Figure 6, and the corresponding planting efficiency is given in Table 5.

Effect of height of free fall of soil block seedlings (h)

The range of the height of free fall of the soil block seedlings that was selected in the present work did not change the orientation of the plants during free fall. The free fall of soil block seedlings from a height induced velocity in the seedlings. The higher the height of the free fall, the higher the velocity of the soil block seedling. When the height of free fall was 7 cm, the soil block seedlings experienced a smooth fall from the trough of the metering conveyor to the hopper. As the height of free fall increased, the soil block portion moved at a higher

Table 4. Average values of planting efficiency and S/N ratio for orthogonal array test when α = 2.33

Experiment No.	Factors of β				Average planting efficiency (%)			S/N ratio		
	h, cm	l, cm	θ, °	β	Fr = 0.0054	Fr = 0.0116	Fr = 0.0295	Fr = 0.0054	Fr = 0.0116	Fr = 0.0295
1.	7	9	40	1.21	62	58	60	35.83	35.25	35.54
2.	7	14	50	0.65	94	96	92	39.46	39.64	39.27
3.	7	19	60	0.43	82	78	78	38.26	37.83	37.83
4.	12	9	60	1.54	74	70	72	37.37	36.89	37.14
5.	12	14	40	1.33	90	92	88	39.08	39.27	38.88
6.	12	19	50	0.82	80	86	84	38.05	38.68	38.48
7.	17	9	50	2.47	58	54	56	35.25	34.62	34.94
8.	17	14	60	1.40	80	84	86	38.05	38.48	38.68
9.	17	19	40	1.39	68	72	64	36.64	37.14	36.11

Table 5. Average values of planting efficiency at various levels of factors of β

Factors of β	Average planting efficiency (%) at								
	Level # 1			Level # 2			Level # 3		
	Fr = 0.0054	Fr = 0.0116	Fr = 0.0295	Fr = 0.0054	Fr = 0.0116	Fr = 0.0295	Fr = 0.0054	Fr = 0.0116	Fr = 0.0295
h[a]	79.33	77.33	76.67	81.33	82.67	81.33	68.67	70.00	68.67
l[b]	64.67	60.67	62.67	88.00	90.67	88.67	76.67	78.67	75.33
θ[c]	73.33	74.00	70.67	77.33	78.67	77.33	78.67	77.33	78.67

[a] h: #1→ 7 cm, #2→ 12 cm, #3→ 17 cm
[b] l: #1→ 9 cm, #2→ 14 cm, #3→ 19 cm
[c] θ: #1→ 40°, #2→ 50°, #3→ 60°

Table 6. Optimum parameters of β and contribution of factors

Factors of β	Highest S/N ratio			Value of level corresponding to highest S/N ratio			△			Rank
	Fr = 0.0054	Fr = 0.0116	Fr = 0.0295	Fr = 0.0054	Fr = 0.0116	Fr = 0.0295	Fr = 0.0054	Fr = 0.0116	Fr = 0.0295	
h	38.17	38.28	38.16	12 cm	12 cm	12 cm	1.52	1.53	1.59	2
l	38.86	39.13	38.94	14 cm	14 cm	14 cm	2.71	3.54	3.05	1
θ	37.90	37.73	37.88	60°	60°	60°	0.72	0.51	1.04	3

velocity on the inclined surface of the hopper. However, when the height of free fall was increased to 17 cm, disintegration of the soil block increased, reducing the planting efficiency. Table 5 and Figure 6 indicate that the planting efficiency of the soil block seedlings at all three selected values of *Fr* was high when the height of free fall was 12 cm.

Effect of length of slide (l)

The length of the slide of the soil block seedlings on the hopper imparted velocity to the seedlings. Moreover, the angle of inclination of the hopper surface was greater than the angle of limiting friction. The soil block portion being heavier, it gained greater momentum than the plants during the movement of the seedlings on the inclined surface of the hopper. This resulted in the turning of the soil block seedlings during its passage down the inclined surface of the hopper. The seedlings were fed into the drop tube with the soil block portion entering the drop tube first. As the seedlings fell through the drop tube, they completely achieved an upright orientation. The length of slide of 9 cm on the hopper surface seemed insufficient to turn the seedlings adequately enough to result in high planting efficiency. The length of slide of 14 cm resulted in the highest planting efficiency (Figure 6). The length of slide of 19 cm induced a high velocity and a turning effect in the soil block of the seedling that led to abrupt contact of the soil block with the walls of the drop tube, causing breakage of the soil block.

Effect of angle of slide (θ)

Variations in the angle of slide had a negligible effect on the planting efficiency (Table 5 and Figure 6), although the planting efficiency did increase with an increase in the angle of slide. This is due to an increase in the velocity of the soil block in relation to the plant. The higher velocity of the soil block caused it to enter the drop tube earlier than the plant. This resulted in higher planting efficiency.

The magnitude of planting efficiency and the S/N ratio reveals that of the three factors of β, the length of slide (l) had the greatest influence on planting efficiency, while the angle of slide (θ) had the least influence (Table 5 and Figure 6). Further, the planting efficiency was greatest when Fr = 0.0116.

Optimum levels of factors of β

The factor levels corresponding to the highest S/N ratio values were chosen for each factor from Figure 5, and are listed in Table 6. The combination of the levels of factors of β that correspond to the highest S/N ratio at all three values of Fr is height of free fall = 12 cm, length of slide = 14 cm, and angle of slide = 60°. In the Taguchi method, this represents the optimum condition for achieving the maximum planting efficiency.

The difference (△) between the maximum and minimum

Table 7. Analysis of variance of planting efficiency for factors of β

Source	df	Fr = 0.0054			Fr = 0.0116			Fr = 0.0295		
		SS	MSS	F ratio	SS	MSS	F ratio	SS	MSS	F ratio
h	2	834.67	417.33	34.74[a)]	728.00	364.00	29.64[a)]	738.67	369.33	41.91[a)]
l	2	2450.67	1225.33	102.00[a)]	4104.00	2052.00	167.10[a)]	3042.67	1521.33	172.62[a)]
θ	2	138.67	69.33	5.77[b)]	104.00	52.00	4.24[b)]	330.67	165.33	18.76[a)]
Error	20	240.27	12.01		245.60	12.28		176.27	8.81	
Total	26	3664.27			5181.60			4288.27		

[a)]Significant at 1% level of significance.
[b)]Significant at 5% level of significance.

Table 8. Results of confirmation experiments

	Fr = 0.0054				Fr = 0.0116				Fr = 0.0295			
	Replications			Mean	Replications			Mean	Replications			Mean
	1	2	3		1	2	3		1	2	3	
Planting efficiency, %	95	98	97	96.67	98	99	96	97.67	96	97	97	96.67
Feeding rate, Number of seedlings per min per row	33.33				48.89				77.78			
Planting rate, Number of seedlings per min per row	32.22				47.75				75.19			

values of the S/N ratio for each control factor is presented in Table 6. It indicates that the length of the slide on the hopper surface (l) has the highest contribution to the planting efficiency, followed by the height of free fall (h) and the angle of slide (θ), i.e., length of slide > height of free fall > angle of slide.

The ANOVA of the planting efficiency for the factors of β was carried out by the Taguchi method according to the factors' contribution (Table 7). From the calculated F ratios, it can be inferred that the factors of β considered in the experimental design are statistically significant at a 95% confidence limit. It can be observed from Table 7 that on the basis of the F ratio, the length of slide and height of free fall are the most significant of all factors, and show the highest positive impact on the planting efficiency. The angle of slide showed the least impact on planting efficiency, of all the factors of β.

Prediction of planting efficiency at optimal factors of β

The S/N ratio of the planting efficiency at the optimal parameters of β was predicted using Eq. (14). The average of the S/N ratios ($\overline{S/N}$) of all the levels of the parameters of β (nine values shown in Figure 6) was calculated ($\overline{S/N}$ = 37.55, 37.53, and 37.43 at Fr = 0.0054, 0.0116, and 0.0295, respectively). As all the parameters of β significantly affect the planting efficiency (Table 7), the values of the highest S/N ratio of all three parameters listed in Table 6 were considered for the prediction of the planting efficiency. The predicted value of the S/N ratio was 39.82, 40.07, and 40.13 at Fr = 0.0054, 0.0116, and 0.0295, respectively. The theoretical maximum value of the planting efficiency at the optimal parameters of β was determined using Eq. (15), and was 97.91, 100.86, and 101.51% at Fr = 0.0054, 0.0116, and 0.0295, respectively. The theoretical maximum values that were more than 100% may have been due to variations in various independent parameters of the experiment.

Validation of taguchi method of optimization

The results of the confirmation experiments conducted at the optimal settings of the factors of β (height of free fall = 12 cm, length of slide = 14 cm, and angle of slide = 60°) are shown in Table 8. The 95% confidence interval for the predicted value was calculated using Eq. (16). On an average, a planting efficiency of 96.67, 97.67, and 96.67% was obtained at Fr = 0.0054, 0.0116, and 0.0295, respectively. This value was within the range (greater than 89.45, 92.30, and 94.26% at Fr = 0.0054, 0.0116, and 0.0295, respectively) of the 95% confidence interval. This validated the Taguchi optimized factors of β.

Planting rate of the planting device varied from 32 to

75 seedlings·min^{-1} in the range of Fr values considered for the experiment. As there is a negligible difference in the planting efficiency with variations in Fr, the developed planting device can be used at higher planting rates to increase the output capacity of the transplanting machine.

Performance of planting device under actual field conditions

Figure 7 shows the 2-row hand-tractor-powered vegetable transplanter with a hopper-type planting device during operation in the field. The performance parameters of the planting device are given in Table 9. The hopper-type planting device had an average planting rate (number of seedlings planted in unit time per row) of 31 and 41 seedlings·min^{-1} per row in the 1st low and 2nd low forward speeds, respectively. This is less than the planting rate achieved in the laboratory (32 to 75 with 48 seedlings·min^{-1}). The lower planting rate in the field is due to an increase in missed plantings with an increase in forward speed. The percent of missed plantings in the present study was 0 and 5% in the 1st low and 2nd low forward speeds, respectively. This is due to the requirement of a higher feeding rate (33.33 and 48.89 seedlings·min^{-1} per row at the two selected forward speeds) as the forward speed is increased. The machine required two persons, both of whom had to regulate the forward motion of the hand tractor along a straight line, as well as feed the metering conveyor. For a reasonable plant spacing, the feed rate clearly limits the maximum allowable forward speed of the transplanting machine (Srivastava et al., 2006). Therefore, a compromise needs to be made between the feeding rate requirement and the forward speed, to minimize missed plantings. In the past, researchers have also reported higher missed plantings with an increase in the forward speed of the semi-automatic vegetable transplanter. Hence, a planting rate in the range of 35 to 45 seedlings·min^{-1} and a forward speed in the range of 0.9 to 1.4 km·h^{-1} has been recommended for most of the semi-automatic vegetable transplanters, to keep missed plantings within acceptable limits (Kumar and Raheman, 2008; Satpathy and Garg, 2008; Singh, 2008). Missed plantings of 2.9–3.5% and 3–4% were reported by Satpathy and Garg (2008) and Manes et al. (2010), respectively, for pocket-type planting devices that used bare-root seedlings. Narang et al. (2011) reported 2.2–4.4% missed plantings for a revolving-magazine-type or rotary-cup-type metering device.

Figure 7. Operation of 2-row hand-tractor-powered vegetable transplanter with hopper-type planting device.

The planting efficiency of the hopper-type planting device attached to a hand-tractor-powered vegetable transplanter was more than 97.48% at the two selected forward speeds. The planting efficiency was on par with that observed in the laboratory. The soil condition and soil coverage by the soil covering devices also assisted in the upright orientation of the plants. The highest sideways tilted planting of 1.40% was observed for the lowest forward speed of travel (1st low speed). The forward tilted planting of

Table 9. Performance parameters of planting device under actual field conditions

Particulars	v = 0.90 km·h^{-1}	v = 1.32 km·h^{-1}
Planting rate, Number of seedlings·min^{-1} per row	31.17	41.08
Missed planting, %	0.00	5.30
Average plant spacing, cm	42.07	42.16
Planting efficiency, %	98.00	97.48
Sideways tilted planting, %	1.40	1.05
Forward tilted planting, %	0.00	0.42
Disintegrated soil block plants, %	0.60	1.05
Wheel slip, %	6.50	11.28

0.42% was observed at the higher forward speed of travel (2^{nd} low speed). The soil block of about 1% of the total plants disintegrated during the fall of the seedlings, through contact with the components of the planting device.

During the performance evaluation of the hopper-type planting device, the drive wheels of the hand tractor experienced wheel slip in the range of 6.50–11.28%. This altered the desired intra-row plant spacing of 45 cm; the average actual intra-row plant spacing was found to be about 42 cm.

Conclusions

A hopper-type planting device that was developed for the hand-tractor-powered vegetable transplanter worked well both in the laboratory and the field. About 97.5% of the soil block seedlings were planted in an upright orientation. The performance of the planting device was best in the 1^{st} low speed of the hand tractor, for which the planting rate of the device was 31 seedlings·min^{-1} per row. A low forward speed resulted in a low rate of field coverage by the hand tractor, and increased the cost of operation. On the other hand, an increase in the forward speed increased both the missed plantings and the slip of the hand tractor wheels. However, an increase in field coverage and a decrease in missed plantings can be achieved by employing an independent operator for the hand tractor and one laborer to feed each metering device. Field coverage, missed plantings, wheel slip, and cost of operation are the most important parameters that need to be duly considered for the effective adoption of the developed planting device.

Conflict of Interest

The authors have no conflicting financial or other interests.

References

Choi, W. C., D. C. Kim, I. H. Ryu and K. U. Kim. 2002. Development of a seedling pick-up device for vegetable transplanters. Transactions of American Society of Agricultural and Biological Engineers 45(1):13-19.

Feng, D., W. Geng and D. Zunyuan. 2000. Study on block seedling transplanter with belt feeding mechanism. Transactions of Chinese Society of Agricultural Machinery 31(2):42-45.

Harrison, R., D. Harrison and P. B. Zuhoski Jr. 1990. Computer operated automatic seedling plant transplanting machine. United States Patent application 4947579, 14 Aug.

Kim, H. J., S. H. Park and T. Y. Kwak. 2001. Development of an automatic transplanter for cabbage cultivation. Seoul, Korea: Korea Automatic Dynamic Analysis of Mechanical Systems Conference, 8-9 Nov.

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

Kumar, G. V. P. and H. Raheman. 2011. Development of a walk-behind type hand tractor powered vegetable transplanter for paper pot seedlings. Biosystems Engineering 110:189-197.

Langhaar, H. L. 1980. Dimensional analysis and theory of models. New York: Krieger Pub. Co.

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

Mohanty, D. K., M. Mahapatra and D. Behera. 2015. Effect of selected parameters on tray angle for smooth dropping of seedlings in semi-automatic vegetable transplanter. Agricultural Engineering 1:41-49.

Munilla, R. D. and L. N. Shaw. 1987. A high speed dibbling transplanter. Transactions of American Society of Agricultural and Biological Engineers 30(4):904-908.

Nandede, B. M., R. Kumar and D. Padhee. 2013. Evaluation of multistage automatic vegetable transplanter (MAVT) for pot seedlings of tomato. BIOINFOLET - A Quarterly Journal of Life Sciences 10(1b):193-195.

Narang, M. K., I. S. Dhaliwal and G. S. Manes. 2011. Development and evaluation of a two row revolving magazine type vegetable transplanter. Journal of Agricultural Engineering 48(3):1-7.

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

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

PAU. 2004. Report of the all India coordinated research project on farm implements and machinery. Ludhian, India: Punjab Agricultural University.

Phadke, M. S. 2009. Quality engineering using robust design (2nd ed.). London: Pearson.

Ross, P. J. 1998. Taguchi technique for quality engineering. New York: McGraw-Hill.

Roy, R. K. 2001. Design of experiments using the Taguchi approach: 16 steps to product and process improvement. New York: John Wiley and Sons.

Russo, V. M. 2006. Biological amendment, fertiliser rate and irrigation frequency for organic bell pepper transplant production. HortScience 41:1402-1407.

Satpathy, S. K. and I. K. Garg. 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.

Singh, B., H. L. Yadav, M. Kumar and N. P. S. Sirohi. 2005. Effect of plastic plug-tray cell size and shape on quality of soilless media grown tomato seedlings. Acta Horticulturae 742:57-60.

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

Sivakumar, S. and C. D. Durairaj. 2014. Development of a gravity fed automatic vegetable transplanter. International Journal of Agricultural Engineering 7(1):177-179.

Srivastava, A. K., C. E. Goering, R. P. Rohrbach and D. R. Buckmaster. 2006. Engineering Principles of agricultural machines. St. Joseph: American Society of Agricultural and Biological Engineers.