

# Development and Evaluation of Semi-Automatic Six Row Onion Seedlings Transplanter

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## Abstract

A six row semi-automatic plug metering type onion seedling transplanter was developed and evaluated for transplanting onion seedlings. The major components of transplanter consist of three-point hitch, plug metering system, funnel, press wheel and power transmission system. One person was required for feeding in each row. Performance evaluation of the transplanter was carried out for transplanting of 60 days old onion seedlings. Manual transplanting operation was also carried out to compare the performance and economics of mechanical transplanting with the developed machine. The field capacity and

field efficiency of the developed six row semi-automatic onion seedling transplanter was 0.078 ha/h and 76.53%, respectively. The labour requirement in mechanical transplanting was 115 man-h/ha as compared to 400 man-h/ha in manual transplanting. No significant differences were observed in plant mortality with mechanically and manually transplanted seedlings. The estimated cost of the unit was Rs. 62,500 (US \$1,000). The operational cost of mechanical transplanting, with plant geometry of 0.10 × 0.20 m, was Rs 8042 (US \$135) /ha as compared to Rs 12,000 (US \$200)/ha for manual transplanting.

**Key words:** India, Onion, transplanter, plug mechanism,

## Introduction

Onion (*Allium Cepa*) is an important vegetable crop grown all over the world. It is probably a native of Asia, perhaps moved from Palestine to India. Onion is grown and distributed in all parts of the world. The world production is about 85.94 million tonnes of bulbs from 4.45 million ha (NHB, 2015). China and India are the leading onion producing countries. In India, it is grown especially in South and Central parts. It is cultivated very extensively in Maharashtra and Gujarat as a cash crop due to its high potential for export. More than 20% of the area under its cultivation is found in Maharashtra which accounts for

30% of total onion production. The other states are Himachal Pradesh, Orissa, Karnataka, Uttar Pradesh, Tamil Nadu and Madhya Pradesh. Onion crop is sown by various methods such as direct seed sowing, planting bulbs in field and raising nursery seedlings with subsequent transplanting in field. In India most common method is transplanting because of high yield and better quality produce. However, transplanting of onion seedlings is done manually in all onion growing regions in India because of non-availability of suitable machines. Moreover, there is a sizeable increase in acreage and production of onion in India. In terms of area, there is an increase from 0.87 to 1.22 million ha, while production has increased from 9.38 to 19.30 million tonnes from 2000-01 to 2013-14, respectively (NHRDF, 2014). But, manual transplanting of onion seedling is very tedious and labour intensive than mechanical transplanting as the operation is done in odd posture (bending posture). The labour requirement in manual transplanting of vegetable seedlings is also as high as 253 man-h.ha<sup>-1</sup> (Satpathy, 2003). Vegetable crops are very sensitive to climatic conditions and require timely operations. However, labour shortage during peak season causes delay in transplanting, leading to drastic reduction in yields (Chaudhari *et al.*, 2002).

There are number of semiautomatic transplanters developed for

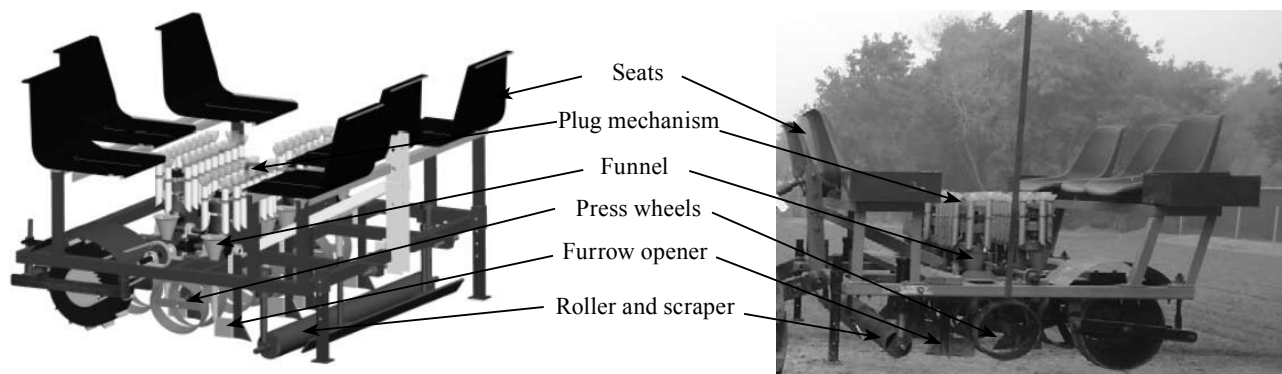
other vegetable crops like tomato, brinjal etc., but as such low cost efficient onion seedling transplanter is not available. In a study by Narang *et al.* (2011), 2-row vegetable transplanter with revolving magazine type metering mechanism was developed for brinjal seedlings. It was reported that plant missing varied from 2.22 to 4.44 per cent, upright plants, depth of planting, plant mortality after 20 days were in the range of 85-90%, 5 to 6 cm and 3.33 to 4%, respectively. The average field capacity of the machine was 0.122 ha.h<sup>-1</sup> for brinjal crop. Imad (1995) developed a single-row vegetable seedlings transplanter consisting of feeding belt system to facilitate the establishment of bare-rooted transplants. The speed of transplanting ranged from 2 to 7 transplants per min per row. The theoretical capacity of the machine varied between 0.09 and 0.72 ha/h (for a single row). Hayashi *et al.* (2006) developed a planting machine for chrysanthemum cuttings using rotating cups. They developed two models of planting machines suitable for chrysanthemum cuttings: a standard model for cuttings with no lower leaves, and a model that automatically removes the lower leaves. Both models were semi-automatic with rotating cups to facilitate a supply task of an operator with two operators working side by side. In developed countries like USA, Japan, China and Holland onion transplanting operation is done with me-

chanical transplanters. Considering the smaller land sizes under onion crop, the semi-automatic transplanters may be suitably adopted for Indian conditions. As the demand for mechanization of onion production has increased in India due to shortage of labor, an attempt have been made to develop semiautomatic onion seedling transplanter that is structurally simple, functionally accurate and economically feasible. The objective of this study was to develop a six row semi-automatic onion seedling transplanter suitable to Indian conditions and evaluate its performance.

## Materials and Methods

### Design Details of Onion Seedling Transplanter

Based on the biometric properties of onion seedlings, optimum operating conditions, and plug type onion seedling transplanter, a prototype was first designed and fabricated accordingly. The part modelling of different components, their assembling and drawings were prepared using CAD software "Pro Engineer Wildfire 4.0". The assembled prototype onion seedling transplanter along with its components is shown in **Fig. 1**. The transplanter consist of main frame with hitching system, ground wheel, furrow openers, press wheels, six row metering system, dropping funnels, operator's seat for six persons. The design details of



**Fig. 1** Prototype onion seedling transplanter

the components are:

**Plug metering assembly**

The plug metering assembly was fitted on a vertical shaft powered with pair of bevel gears with speed ratio of 1:1. This speed ratio was obtained by using bevel gears set having 15 teeth each. The plug assem-

bly (Fig. 2) was made of 1.2 m long chain and two 15 teeth driving and driven sprockets in which driving sprocket powered by vertical plug metering assembly shaft. Twenty plugs (Fig. 3 a) were fitted on a periphery of chain at an equal distance of 6 cm each by means of specially

designed holding clamps made of GI sheet. The whole plug assembly was mounted on a closed frame such that it could rotate around it. A stationary cam was fitted at the delivery end of the frame just above the dropping funnel to open the lid of plugs.

**Dropping funnel**

Seedling dropping from the plug falls in the direction of travel of machine. A drop funnel made of MS sheet was provided to guide the seedlings vertically in the opened furrow (Fig. 3 b). The diameter of funnel was 110 mm at top and 30 mm at bottom and height was 100 mm. The MS contour or conduit pipe of 30 mm diameter and 300 mm length was connected at the bottom of funnel as a drop chute. A parabolic cut was made at the bottom of 150 mm of the drop chute pipe.

**Furrow opener**

The chisel type furrow opener (Fig. 3 c) was provided immediately at the back of the dropping funnel to open a thin continuous furrow which requires low draft. The cross-section of the furrow formed by furrow opener should be such that the furrow wall supports the seedlings vertically straight after being dropped from the dropping funnel. The triangular shape soil working tool attached to the standard made up of M.S. flat of 10 mm thickness having 55 mm length and 80 mm height along the standard. The cutting edge was of 110 mm length. The standard was made up of M.S. flat of 40 × 6 mm size with 270 mm length. At the rear, the runners were connected to a standard connecting a drop chute in order to maintain the furrow walls till the seedlings falls in the furrow. At the upper back end of standard the clamping attachment was provided.

**Press wheels for furrow closing cum compaction**

Each press wheel was made of mild steel flat of 5 mm thick and 76 mm wide. The flat was bent with

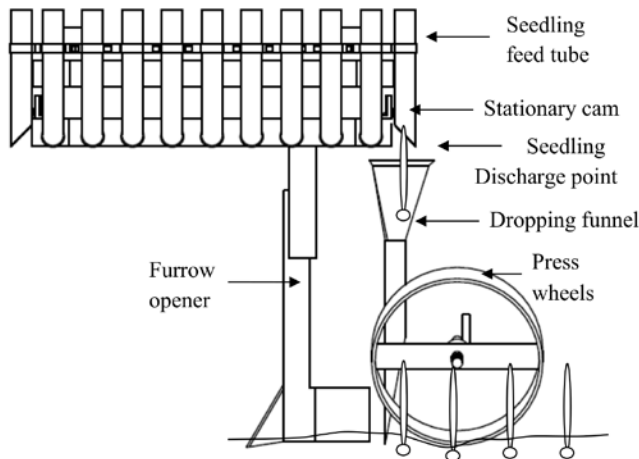
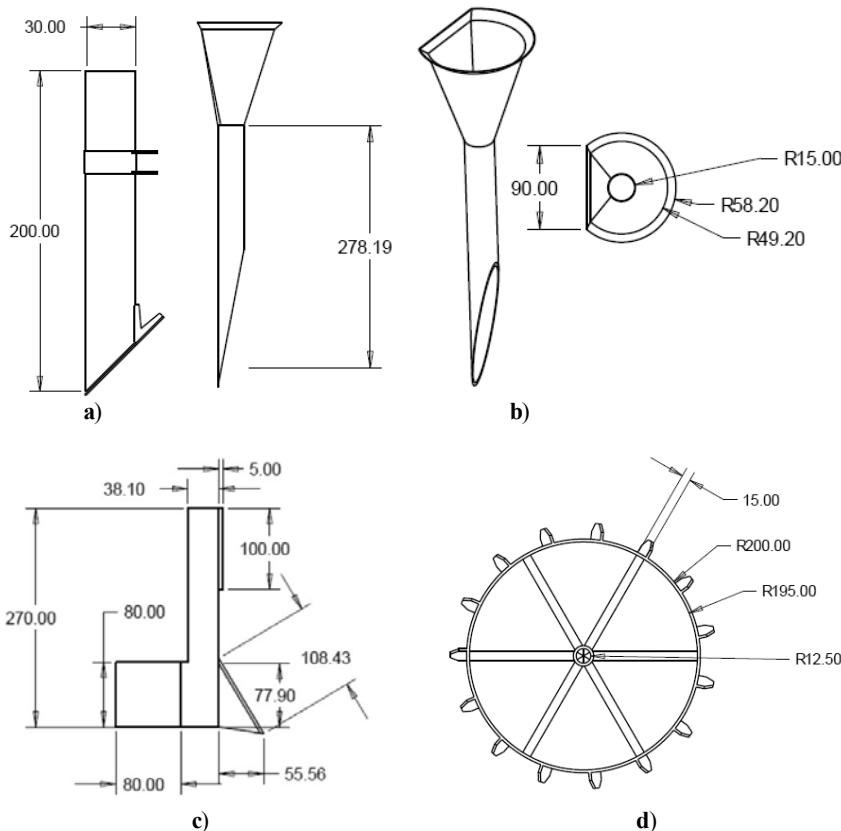


Fig. 2 Plug metering system



Note: All dimensions are in mm

Fig. 3 Design details of different components of onion seedling transplanter a) Plug, b) Funnel, c) Furrow opener, d) Ground wheel

a diameter of 244 mm to form a wheel. The width of the wheel was 64 mm. M.S. flat of 40 mm width and 6 mm thickness was attached to the wheel from inner side as spokes for support. A hub (inner diameter of 20 mm and outer diameter of 38 mm) was welded at the centre of the wheel on flat. The two press wheels were mounted on a 20 mm single axle bent downward at an angle of 150° at the centre such that the face of wheel makes an angle of 30° with horizontal. The distance between the two wheels at the bottom end was 25 mm and 150 mm at the top end. As the press wheel advances over the root and bulb of seedling, the soil over it would be compacted anchoring the seedling firmly in soil.

#### **Power transmission mechanism**

The ground wheels were provided on both sides of the machine. But the power was given to the metering mechanism from drive wheel at the right side of the machine. The other ground wheel functioned as a support wheel when machine was completely lowered down during its operation. Both ground wheels were also adjusted to control the depth of operation. Power transmission system consisted of following components.

#### **Ground wheel**

A closed ground wheel with lugs on the periphery was provided at each side of the machine. M.S. flat of 100 × 6 mm was used for the rim. The outer diameter of rim was 360 mm. The flat discs of same size made up of 16 gauge MS sheet were

welded to rim along its both edges and the centre hub. The lugs were provided on the outer periphery of rim of drive wheel to minimize the slippage. The lugs were of trapezoidal shape having 100 and 60 mm parallel sides with 25 mm height, welded on outer periphery of the rim (**Fig. 3 d**).

#### **Main shaft**

A 25 mm diameter MS shaft was provided along 1.6 m length of main frame in between two ground wheels for transmission of the power from ground wheel to metering systems. This shaft was supported on three self-aligning bearings mounted on the main frame. A sprocket with 21 teeth was mounted on the shaft which was driven by a 25 teeth sprocket on ground wheel axle.

#### **Plug assembly shaft**

The step type vertical driving shaft of the plug assembly was driven by 15 teeth bevel gear on a 25 cm long horizontal shaft connected to a main shaft by means of a pair of bevel gears each with 15 teeth. The 10 teeth bevel gear was fitted on the lower end of vertical shaft having 25 mm diameter and upper end of shaft was connected to a 15 teeth driving sprocket. The overall length of the shaft was 250 mm.

#### **Seating arrangement**

A seating attachment for operators to fill the plugs with onion seedlings was developed at the front and at the rear end of the machine. Six plastic seats were mounted on the main frame by providing necessary support of frames made of angle iron

to accommodate six persons to feed seedlings in metering device. The three operators sat at the rear end and three at the front facing each other (**Fig. 1**).

#### **Seedling trays**

Four seedling trays of size 0.35 × 0.20 × 0.12 m made of 18 gauge GI sheet were provided at four corners of machine for keeping seedlings.

#### **Main frame**

The complete frame was made up of 50 × 50 × 5 mm and 40 × 40 × 5 mm MS square pipes. Main frame was provided with three point linkage and different components namely metering mechanism, furrow opener, press wheels and power transmission system mounted on it. An auxiliary frame for operator's seats was also mounted on the main frame on both sides. The dimension of main frame was 1.65 × 1.41 × 0.05 m.

#### **Performance Evaluation of Prototype Onion Seedling Transplanter**

The prototype onion seedling transplanter was tested (**Fig. 4**) for transplanting recommended 60 days old healthy onion seedlings for two commonly planted varieties (variety-N-53, Pusa Riddhi) on a plot of 1000 m<sup>2</sup>. The speed of travel was adjusted to match the feeding rate compatible to the operator. The transplanter was operated at 0.18 m.s<sup>-1</sup> (0.7 km.h<sup>-1</sup>) for recommended plant and row spacing of 100 mm × 200 mm, respectively. The field performance evaluation of prototype onion seedling transplanter was done according to RNAM test code (RNAM, 1983) for paddy transplanter. Manual transplanting operation was also carried out for both the varieties (N-53 and Pusa Riddhi) in two different control plots to compare the results with mechanical transplanting. The following parameters were recorded

#### **Seedling mortality**

In order to assess the damage to seedlings during mechanical transplanting, a control plot of 200 m<sup>2</sup> was transplanted manually with



**Fig. 4** Field performance evaluation of prototype onion seedling transplanter

seedlings grown on same date and in same batch. Observations for mortality of seedlings occurring after 10, 20 and 30 days after transplanting were recorded for both manually and mechanically transplanted onion seedlings.

#### Per cent miss transplanting

The seedling feed tubes that were missed to feed by the operator, results in wide spacing between the consecutive transplanted onion seedlings and expressed as the percent miss in transplanting. Percent miss in transplanting was calculated using above formula

$$\% \text{ miss} = S_m / (S_f + s_m) \times 100$$

Where,

% miss = Percent miss in transplanting

$S_m$  = Number of seedlings missed by operator to feed in seedling feed tubes

$S_f$  = Number of seedlings fed by operator in seedling feed tubes

#### No of seedlings per hill

The number of seedlings per hill was measured by counting the number of plants per hill in the same line along one meter length. The number

of seedlings per hill was measured at five different locations randomly.

#### Theoretical field capacity, ha/h

The theoretical field capacity (ha/h) of machine was measured in field by considering the width of operations and the travel speed of the tractor.

$$\text{Theoretical field capacity} = (\text{Width of operation (m)} \times \text{Travel speed (km/h)}) / 10$$

#### Field efficiency, per cent

Field efficiency (per cent) was calculated as follows from the test data.

$$E_f = \text{Effective field capacity (E}_e\text{)} / \text{Theoretical field capacity (E}_T\text{)} \\ = (W_e \times V_e \times T_p) / (W_t \times V_t \times (T_p + T_N)) \times 100$$

Where,

$E_f$  = Field efficiency, per cent

$W_e$  = Effective working width, m

$W_t$  = Theoretical working width, m

$V_e$  = Effective operating speed, m/s

$V_t$  = Theoretical operating speed, m/s

$T_p$  = Productive time, s

$T_N$  = Non-productive time, s

#### Draft

Draft was measured by two

tractors and a dynamometer. The transplanter was mounted on a tractor at the front of which the spring type dynamometer was attached. Another auxiliary tractor was used to pull the machine mounted tractor through the spring dynamometer. The auxiliary tractor pulled the machine mounted tractor with the latter tractor in neutral gear but with the machine in the operating position. The pull was recorded in the dial gauge of dynamometer. In the same field, machine was kept in lifted position on ground and recorded the draft at no load condition. The difference gives the draft of the machine.

$$D = P \cos \theta$$

Where,

$D$  = Draft, N

$P$  = Pull measured by dynamometer, N

$\theta$  = Angle between the line of pull and the horizontal, degrees

#### Labor requirements, man-h/ha

The total number of labours required per ha during the field evaluation of onion transplanter was recorded. One tractor operator (skilled) labour and six operators (unskilled) to drop the onion seedlings and two helpers (unskilled) were required to assist the onion seedlings droppers to supply the cut onion seedling. As such total nine labours (including unskilled and skilled) were required to operate the developed onion transplanter.

#### Labour required by manual method, man-h/ha

The total number of labours required per hectare by traditional method was recorded for transplanting onion seedlings.

**Table 1** Performance evaluation of 6-row semi-automatic tractor mounted onion seedling transplanter

Variety	N-53		Pusa Riddhi	
	Traditional	Mechanical	Traditional	Mechanical
Area, m <sup>2</sup>	142.8	500	290	500
Row to row spacing, cm	-	20.7	-	19.9
Plant to plant spacing, cm	13.25	12.9	12.33	12.4
Planting depth, cm	1.7	2.9	2.1	3.02
Width of operation, m	-	1.21	-	1.22
Percent miss transplanting, %	0	4.66	0	5.39
No of seedlings per hill	1	1.13	1	1.07
Plant density, No./m <sup>2</sup>	35.25	32.6	35.75	32.6
Moisture content of Soil, (db), %	5.09	11.45	5.23	12.03
Bulk density, g/cc	1.49	1.35	1.42	1.34
Travel speed, m/s	-	0.18	-	0.18
Theoretical field capacity, ha/h	0.0098	0.078	0.0075	0.078
Effective field capacity, ha/h	-	0.057	-	0.061
Field efficiency, per cent	-	74.39	-	78.68
Fuel consumption, L/h	-	2.57	-	2.4
Wheel slippage, per cent	-	2.94	-	2.94
Draft, kN	-	3.45	-	3.53

## Results and Discussion

### Field Performance Results

After the completion of both manual and mechanical transplanting operations in a selected area, different performance parameters were recorded (Table 1). The average row

spacing at different locations were 20.7 and 19.9 cm for N-53 and Pusa Riddhi respectively against set row spacing of 20 cm. The average plant spacing for developed transplanter were 12.9 and 12.4 cm for N-53 and Pusa Riddhi respectively against recommended plant spacing of 10 cm. Whereas in manual transplanting it was 13.25 and 12.33 cm for N-53 and Pusa Riddhi respectively. The average plant to plant spacing observed in both methods of transplanting were comparable and close to the targeted plant spacing of 10 cm. The variations in spacing in mechanical transplanting can be attributed to the variations in skid values owing to inherent field variations in moisture content, bulk density and small surface undulations. The average planting depth for N-53 and Pusa Riddhi were respectively 2.9 and 3.02 cm with mechanical transplanting and 1.7 and 2.1 cm with manual transplanting. The depth of transplanting was adequate for sustenance and establishment of seedlings in field. The number of seedlings per hill in mechanical transplanting for N-53 and Pusa Riddhi was 1.13 and 1.07 respectively as against precise one seedling per hill in manual transplanting. The percent miss transplanting in mechanical transplanting for N-53 and Pusa Riddhi were 4.66 and 5.39 percent respectively which were closer to recommended acceptable limit of 4 percent. The average plant density in mechanical transplanting was 32.6 seedlings per m<sup>2</sup> against 35.25 and 35.75 seedlings per m<sup>2</sup> in manual transplanting for N-53 and Pusa Riddhi. The reduced plant density in mechanical transplanting was due to increased percent miss

transplanting and increased plant spacing as compared to manual transplanting. The forward speeds of 0.18 m/s could be maintained in field while transplanting with machine to achieve maximum field capacity and minimum missing. However, soil bin studies also revealed that the travel speed of 0.18 m/s was optimum to achieve higher successful transplanting rates and field capacity, if seedling feeding rates were not the limiting factor. The theoretical field capacity in manual transplanting ranged from 0.0075 to 0.0098 ha/h against 0.0780 ha/h in mechanical transplanting indicating the satisfactory performance of onion seedling transplanter. The effective field capacity for complete duration of experimentation ranged from 0.057 to 0.061 ha/h. The reduced field efficiency of transplanter (76.53%) was attributed to non-productive time during turning at head lands, loading and unloading of seedlings from seedling tray, adjustments made during the operation of machine and initial adjustments to start the transplanting operation. The loading of pre-cleaned and de-topped seedlings before the start of transplanting operation would reduce the non-productive time to a great extent. The average wheel slippage (per cent) was recorded 2.94 per cent which was within acceptable limit of 5% to affect the plant spacing. The draft required to pull six row onion seedling transplanter in field ranged from 3.45 to 3.53 kN which was observed within drafting capacity of 35 hp tractors. The fuel consumption in operation of six row semi-automatic onion seedling transplanter was found to be 2.4 to 2.57 L/h which shows

normal fuel consumption of tractor with transplanter in operation.

### Seedling Mortality

The percent seedling mortality for N-53 and Pusa Riddhi increased respectively from 2.93 to 4.17 percent and 3.59 to 5.52 percent in mechanical transplanting and 1.28 to 4.25 percent and 1.4 to 3.27 percent respectively in manual transplanting for 10 to 30 days after transplanting (**Table 2**). The small increment in percent seedling mortality in mechanical transplanting was due to increase in damage to the seedlings in comparison to manual transplanting. The damage was attributed to mechanical damage as well as damage and missing caused by birds.

### Cost Economics of Transplanting

In traditional method, the labor requirement at observed average manual transplanting rate of 9 to 11 seedlings.min<sup>-1</sup>.person<sup>-1</sup> was 400 man-h/ha. Whereas, due to increase in feeding rate in mechanical transplanting, the average transplanting rate also increased up to 54 seedlings.min<sup>-1</sup>.person<sup>-1</sup> which leads to decrease in labor requirement to 115 man-h/ha. The cost of operation for manual transplanting was 90 to 118 Rs./h against 628 Rs./h for mechanical transplanting. But, due to increased field capacity of mechanical transplanting cost was reduced to 8,042 Rs./ha as compared to Rs. 12,000/ha for manual transplanting resulting in net saving of 33% over traditional method. The average payback period was found to be 177.13 h for owning the transplanter by onion grower. The breakeven point (BEP) was found to be 29.23 h which was 11.69% of the annual utility of 250 hours of onion seedling transplanter.

### Crop Yield

After harvesting of the crop, the yield of onion for N-53 and Pusa Riddhi variety was 12.20 and 12.65 tonnes/ha in mechanical transplant-

**Table 2** Seedling mortality in manual and mechanical transplanting

Seedling mortality, percent	N-53		Pusa Riddhi	
	Manual	Mechanical	Manual	Mechanical
After 10 days	1.28	2.93	1.40	3.59
After 20 days	2.55	3.38	2.59	3.93
After 30 days	4.25	4.17	3.27	5.52

ing as compared to 12.95 and 13.43 tonnes/ha in manual transplanting. The yield was found close to the recommended yield of 15-20 tonnes/ha (Mohanty *et al.*, 2001) for kharif season planting. At plant geometry of 0.20 × 0.10 m, the required plant population should be 500,000 plants per hectare. However, in machine transplanting, the plant population obtained was 390,625 (78.13 per cent) of required plant population.

The weight and diameter of ten randomly selected harvested samples from mechanically and manually transplanted plots were determined. The weight and diameter of onion bulbs of N-53 variety ranged from 55.74 to 66.65 g and 62 to 111 mm in mechanical whereas 47.63 to 62.43 g and 52 to 93 mm in manual transplanting respectively for N-53 variety. However, in Pusa Riddhi the weight and diameter of onion bulbs ranged from 49.67 to 66.65 g and 52 to 111 mm in mechanical whereas 50.16 to 58.68 g and 48 to 84 mm in manual transplanting respectively. Weight and diameter of harvested onion bulbs were higher in mechanically transplanted seedlings over manual transplanted seedlings. This may be due to uniform plant spacing and depth of placement of onion seedling in mechanical transplanting. But, the yield of onion bulbs was higher in manually transplanted plot than mechanically transplanted plot. The negligible variation in yield was due to miss transplanting (4.66 and 5.39%) in mechanical method as against zero percent miss transplanting in manual method.

## Conclusions

The six row onion seedling transplanter having overall dimensions 1650 (L) × 1410 (W) × 650 (H) mm and weight 315 kg was evaluated for transplanting 60 days old onion seedlings. The field capacity and field efficiency of transplanter was 0.078 ha/h and 76.53% respectively.

There was no significant difference in mortality between mechanically and manually transplanted seedlings. A labor requirement in mechanical transplanting was 115 man-h/ha as against 400 man-h/ha in manual transplanting. Average cost for transplanting 1000 onion seedlings with developed onion seedling transplanter was Rs. 33/- as against Rs. 76/- when done manually. Net saving in mechanical transplanting over traditional method of transplanting was 3,958 Rs./ha. The overall performance parameters of prototype onion seedling transplanter are considered to be satisfactory.

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