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Design and development of three-row improved pull-type rice transplanter for small farmers

M MUTHAMIL SELVAN[1], S J K ANNAMALAI[2], N THAVAPRAKASH[3] and D ANANATHAKRISHNAN[4]

Indian Agricultural Research Institute, New Delhi 110 012

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ABSTRACT

A pull-type transplanter was developed by improvising the functional components of existing six-row manual IRRI rice transplanter. The improved transplanter is capable of planting seedlings in three rows at 250 mm row spacing. Picker mechanism was designed in such a way to perform the planting operation simultaneously as the equipment is being pulled with handle. Thus the push-pull mechanism adopted in the existing transplanter has been eliminated in this improved model, reducing drudgery of operation. While evaluating the unit in different puddling conditions as well as textural conditions, the field capacity was observed as 0.058 ha/h with field efficiency of 85.4% at the draft of 261.7 N. Percentage of missing hills was found as 9.61 with the optimized growing density of seedling of 60 g/mat. The ground wheel diameter was optimized as 500 mm based on intra-row spacing as well as force requirement for pulling the unit. The picker-finger width of 3 mm was optimized as there was high mortality rate observed with other fingers. For the optimized picker-finger width, single seedling was observed in 12.1% hills, double seedlings in 30.4% hills, triple seedlings in 31.7% hills, and 25.8% hills are planted with more than three seedlings. By employing ergonomic consideration in seedling picking mechanism, the energy requirement with improved transplanter was reduced to 19.84 kJ/min from 26.41 as in existing transplanter, and hence there was 24.9% reduction in drudgery. Although energy cost with improved transplanter is graded as 'heavy', the unit can be operated effectively with the recommended rest-pause of 12.5 min for every 45 min. Cost of transplanting with the equipment worked out ₹ 1 150 per ha with a cost-saving of 80.8% in addition to time-saving of 91.3% compared to hand transplanting. The improved transplanter has good scope for introduction in marginal farms.

Key words: Ergonomics, Rice transplanting, Seedlings, Transplanter

Transplanting of paddy is highly labour intensive operation and is still carried out manually in India. The transplanting accounts for 21% of work force required in rice cultivation which works out 320 man-days/ha (Singh *et al.* 1982). Although, some manual transplanters have been developed and evaluated in many research institutions, yet an efficient manual transplanter is to be introduced in India. Large scale field trials on these machines indicated that although the performance of these machines is satisfactory, but is affected due to seedling parameters like mat thickness, seedling age, and type of fingers (Irina 2008). Different mat thicknesses varying from 10 mm to 35 mm and different seedling ages have been used in different machines (Singh *et al.* 1982). However no definite information is available as to how the performance of machines is affected under these variations. This information is critical in manually operated machines as low mat thickness will reduce the overall weight on the machine causing low draft requirement. On the other hand, it may cause entanglement of roots and also higher buckling at higher moisture content. Careful transplanting minimizes trauma in transplanting. Mortality of seedlings is much higher under buckling situations. Similarly, seedlings of lower age may be easy to pick but may cause higher mortality due to thin stem and low height. On the other hand, seedlings of higher age may be difficult to shear from the mat because of more growth of roots causing higher missing. Therefore these aspects need in-depth study.

Keeping the above facts in view, a three-row pull-type transplanter was developed by improvising the functional components of six-row IRRI manual rice transplanter. As the operation with the six-row manual IRRI transplanter was graded as 'heavy' (Vidhu 2001, Fu-Ming 2009, Ben 2013), there is a need to modify the existing IRRI six-row manual transplanter suitably for making the handle down (planting operation) and the pulling operation less drudgerous. This may be possible by adopting appropriate mechanism with cam and follower and by pulling the

[1]Senior Scientist (e mail: m_muthamil@yahoo.co.in), Division of Agricultural Engineering, [2]Principal Scientist (e mail: sjackanna@gmail.com), Central Institute of Agricultural Engineering - Regional Centre, Coimbatore 641 003,[3]Assistant Professor (e mail: agronthava@yahoo.co.in), Department of Farm Management, [4]Professor (Farm Machinery), Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu 641 003

Table 1 Specification of equipment

Parameters	Particulars
Effective working width, m	0.75
Number of rows	3
Weight, kg	35
Handle height, m	1.2
Power transmission	Gears, 2 number
Size of finger, mm	10
Picker-finger width, mm	3
Skid dimension (length×width×thickness), mm	450×150×50
Flot dimension (length×width×thickness), mm	750×750×3
Seedling tray dimension, mm	40x25
Ground wheel diameter, mm	500
Angle of lug in ground wheel, degree	25-30
Speed of machine, km/h	1.0
Distance between hills, cm	25
Depth of planting, cm	2.5
Ground wheel slip,%	8.04
Labour requirement, man-h/ha	14.7
Labour cost, ₹/ha	441
Cost of transplanting, ₹/ha	1530
Draft , N	261.7
Energy requirement, kJ/min	21.2
Field capacity, ha/h	0.058

equipment by providing two ground wheels.

The paper deals with the design criteria, optimization of functional components for the development of improved transplanter, and cost economics of the unit besides describing ergonomics of the equipment.

MATERIALS AND METHODS

Working principle of the unit

The unit is capable of planting seedlings at 250 mm row spacing. The picker mechanism is designed in such a way to perform the planting operation simultaneously as the equipment is being pulled with handle. Thus the push-pull mechanism adopted in the IRRI transplanter has been eliminated in this improved model, reducing drudgery of operation. Drive from two ground wheels actuates the seedling pushing down mechanism through cam. Speed reduction gears are fixed in between ground wheel shaft and seedling picking arms to maintain the intra-row spacing of 250 mm. Seedling tray indexing mechanism was arranged as per the design requirements of the seedling mat. Two skids enhance the ease of floating and pulling.

For standardizing the mat nursery, nursery was raised at wetlands of Tamil Nadu Agricultural University, Coimbatore. Three levels of depth of soil (12, 18, 24 mm), nine levels of density (weight of seeds in a mat of 50×20 cm size) of seeds were taken (20, 30, 40, 50, 60, 70, 80, 90, 100 g/mat). The mats were grown in the field condition and used for transplanter operation. The treatment registered minimum missing hills, and more amount of single seedlings was optimized for the transplanter operation using statistical

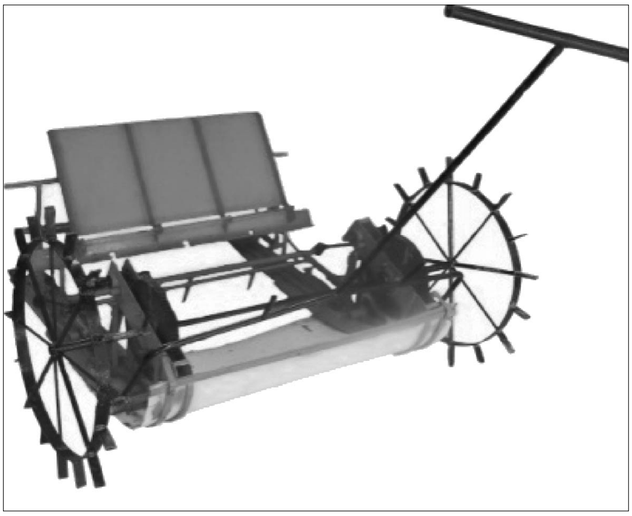

Fig 1 The prototype

analysis (RCBD).

According to a field study, the operation with IRRI six-row manual push-pull transplanter was graded as 'heavy' as the VO2 max (63.6%) was above acceptable work load (AWL) of Indian workers (Vidhu 2001, Guo 2011). Hence ergonomic consideration was given in the design of picker mechanism by eliminating push-pull mechanism in such a way to perform the planting operation simultaneously as the equipment is being pulled with handle. Thus the push-pull mechanism adopted in the IRRI transplanter has been eliminated in this improved model, reducing drudgery of operation.

Ergonomical evaluation of the manual transplanter was conducted for assessing their suitability with the subjects. As transplanting is carried out by women-labourers traditionally as well as the transplanter was designed gender friendly, twelve women labourers were selected for the study. Since maximum strength and power can be expected from the age group of 25 to 35 years (Gite and Singh 1997, Fadi 2010), it was ensured to select the subjects in medium age group. Bio-clinical analysis of the blood of the selected workers was carried out for blood sugar, blood urea, hemoglobin, and serum cholesterol for identifying hypertension ailments and hypothyroid diseases and urine analysis for diabetes. It was also ensured that they are free from respiratory, cardiac, and other ailments. The selected subjects were standardized and calibrated with the help of a bicycle-ergometer to compute the VO_2 max. Anthropometrical data and other basic details of the subjects selected are presented in Table 2. The evaluation was carried out in terms of the following parameters.

Heart rate and oxygen consumption rate are the pertinent parameters for assessing the human energy required for performing various types of operation (Curteon 1947). There is close interaction between circulatory and metabolic processes. For proper functioning, nutrients and oxygen must be brought to the muscle or other metabolizing organs and metabolic by-products removed from it. Therefore, heart rate as a primary indicator of circulatory function and

Table 2 Basic particulars of subjects

Particulars	Subject											
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Age, year	26	35	35	28	25	32	27	28	28	34	35	26
Stature, cm	160	154	158	160	164	169	170	162	165	162	160	159
Weight, kg	58	54	56	54	65	60	65	62	72	66	63	63
Heart rate$_{rest}$, beat/min	71	73	72	70	71	73	73	71	75	72	71	71
Heart rate $_{max}$, beat/min	196	198	202	184	186	190	200	182	192	203	197	194
Blood pressure, mmHg	124/82	120/ 79	118/ 80	122/ 80	120/ 80	118/ 78	118/ 79	120/ 80	122/ 81	119/ 78	120/ 80	121/ 80
BMR, kCal/day	1240	1128	1295	1220	1580	1461	1486	1384	1520	1384	1208	1113
$VO_{2\ rest}$, l/min	0.24	0.19	0.23	0.21	0.17	0.20	0.21	0.22	0.19	0.18	0.24	0.17
$VO_{2\ max}$, l/min	2.04	1.92	1.97	2.21	2.14	2.18	2.02	2.31	2.09	1.91	2.08	2.18
Breath rate, No./min	14	14	17	16	17	14	16	17	16	18	14	15
Experience, year	8	15	13	10	10	12	6	6	7	9	12	11

oxygen consumption, representing the metabolic conversion-taking place in the body, has a linear and reliable relationship. Heart rate measurements have a major advantage over oxygen consumption as an indicator of metabolic process.

From the values of heart rate observed during the trials, the corresponding values of oxygen consumption rate (VO_2) of the subjects for the transplanter were predicted from the calibration chart of the each subject (Aberg 1967). The energy costs of operation of the transplanter were computed by multiplying the oxygen consumed by the subject during the trial period with the calorific value of oxygen as 20.88 kJ/L (Nag *et al.* 1980) for all the subjects.

During any physical activity, there is increase in physiological parameters depending upon the workload, and the maximum values, which could be attained in normal healthy individuals, will be up to VO_2 max. However at this extreme workload, a person can work only for a few seconds. The acceptable workload (AWL) for Indian workers was the work consuming 35% of VO_2 max (Saha *et al.* 1979). To ascertain whether the operation of transplanter is within the acceptable workload (AWL), the VO_2 Max for each treatment was computed and recorded.

For every strenuous work in any field requires adequate rest to have an optimum work output. Proper attention to find the work rest schedule for different operations will produce better performance results. The rest pause requirement was computed by the expression described by Murrel (1965).

$$R = T(K-S)/(K-1.5)$$

where, R= Rest pause required (min), T = Total working time (min), K=Average kCal/min of work, and S=Average kCal/min adopted as standard.

Different designs of fixed type picker-fingers which are simple and easy to fabricate have been used. The shape of these fingers is quite different. One type of finger may perform better under certain nursery conditions, but may not be suitable for other conditions. Proper selection of fingers and nursery parameters may be useful in minimizing the plant/hill mortality and hill missing which is most critical. In these aspects, field evaluations were conducted to study the effect of mat thickness and type of picker-fingers on plant/hill mortality and hill missing with the transplanter developed.

Statistical design: In the present study, the effect of growing density of seedlings, mat thickness, and different types of picker-fingers on plant/hill mortality, and hill missing was studied. For conducting these studies, three levels of various independent variables were taken, viz i) Types of fingers (F1: round edge, F2: small needle, F3: large needle), ii) mat thickness (M1: 12 mm, M2: 18 mm, M3: 24 mm), and iii) growing density of seedlings (D1: 40 g/mat, D2: 60 g/mat, D3: 80 g/mat of 40×25 mm size). The study was planned with a split-split plot design with mat thickness as main factor at 3 levels (T=3), different fingers as sub factor at 3 levels (F=3) and growing density of seedlings as sub factor at 3 levels (D=3). There were in all 27 treatments and 81 sets of observations with three replications.

Six plots each of size 25×15m were selected for evaluation of machine in the field. All the selected plots had the same type of soil namely clay loam. Field was puddled twice by 9-tyne cultivator and cage wheel and then leveled by leveller. After puddling, the soil was allowed for 24 h to settle before transplanting. Each plot was divided into 27 sub-plots. The size of each plot was 5×3 m. The water level at the transplanting time was maintained at 2-3 cm. Seedling mat of 15 days old and different mat thickness, i.e. 12 mm, 18 mm, and 24 mm were uprooted and dressed for uniform edges of mats. These mats were transported to the field. Before starting the operation, the tray was first moved to one side and then three seedlings mats of mat thickness as per experimental requirement, were placed on the seedling tray of the machine (Chiu 2013). Transplanting was started from one end of the field. In this way, 3 plots of 5m×3m size selected randomly were transplanted with each mat thickness. Four runs of the machine were made in plot of 5×3m. These plots were planted by using all the types of fingers studied. Experiments were repeated after interval of five days. Observations recorded for different treatments on hill missing, floating hills, and plant/hill mortality are given in Table 3. Hill is termed as bunch of seedlings transplanterd at a place. When no seedlings are transplanted, it is termed as hill missing. This was measured by actually counting the missed hills in each row for a known area. Hill mortality refers to the cutting of all the seedlings in a hill sheared by a finger form the nursery mat. This was calculated by marking ten hills in each row after transplanting and recounting the number of plants in each hill at the time of transplanting and after 15 days.

The unit was evaluated for its performance in the field. The tests were conducted at Tamil Nadu Agricultural University campus as well as in farmers' fields. The unit was operated at a forward speed optimized during the laboratory tests. The following parameters were observed during the field test.

The draft of the unit was measured by rolling method as given by RNAM test code (Anon 1995) with an angle of pull of 30°. A load-cell of capacity ranging from 0 to 1000 N was attached. Draft was recorded in a measured distance by operating the transplanter at speed optimized in the laboratory tests.

The number of revolutions of the ground wheel of transplanter for a distance of 20 m covered by the unit was recorded for calculating the wheel slip. The slip was calculated using the following expression.

$$\text{Slippage} = [(d_u - d_g) / d_u] \times 100$$

where, d_u, actual distance traveled by unit (m), and d_g, actual distance traveled by ground wheel (m).

The field capacity and field efficiency of the unit were found out by operating the unit in an area of 0.4 ha. The total time taken to cover the area, time lost for running at head lands and other time losses were recorded for the calculation.

Based on the materials used and labour requirement for the fabrication of transplanter, the cost of fabrication and cost of operation per hour of the transplanter was worked out using the procedure recommended by RNAM test codes (Anon. 1995). This cost was compared with the cost of operation of the same by conventional method. The time and cost saved by using the transplanter against conventional method was compared.

RESULTS AND DISCUSSION

Optimization of machine components

Three levels of ground wheel diameter were taken for the study (500, 600, and 700 mm) and the 500 mm ground wheel was optimized based on intra-row spacing as well as force requirement for pulling the equipment. The number of seedlings per hill for the three levels of picker-finger width taken for the study, viz. 2 mm, 3 mm, and 4 mm was observed as 1.9, 3.0, and 4.0 respectively. Although the number of seedlings per hill was minimum with 2 mm finger, the finger width of 3 mm was optimized as there was high mortality rate observed with 2 mm width. For this optimized finger width, single seedling was observed in 12.1% hills, double seedlings in 30.4% hills, triple seedlings in 31.7% hills, and 25.8% hills are planted with more than three seedlings.

Performance evaluation

The unit was evaluated for its performance in the field condition at Tamil Nadu Agricultural University wetlands as well as farmers' fields. The unit was operated at a forward speed optimized during the laboratory tests. The unit was evaluated in different puddling conditions as well as textural conditions and field capacity was observed as 0.058 ha/h with the field efficiency of 85.4%. Percentage of missing hills was found as 9.61 with the optimized growing density of seedling of 60 g/mat. The draft requirement to operate the equipment was 261.7 N with the optimized components. The ground wheel slip of the manual transplanter is found below the allowable limit of 12% (Anon. 1979, Alex 2013) in all the types of soil. The comparison of improved transplanter on specifications and performance with existing six-row manual IRRI transplanter is furnished in Table 3.

Operational performance

Plant mortality and hill mortality: The effect of 3 levels of mat thickness on plant mortality was studied in a manually operated machine. Minimum plant mortality was found to be 2.5% at mat thickness of 18 mm at with round ended fingers at growing density of 60 g. Increase in plant mortality with increase in mat thickness might be due to improper shearing of thicker mats by the picker-fingers. Also weight of the machine increased by 4 to 8 kg when mat thckness increased from 12 mm to 24 mm. Thicker mats might also require higher draft requirement for shearing. As for as finger type concern, higher plant mortality was observed in both small and large needle type fingers (F1 and F2), while the round edge type fingers registered minimum plant mortality (2.2%). This might be due to the reason that the round edge type fingers have better cutting profile to work with the seedling mat due to which proper placement of seedlings are achieved. The same trend was observed for hill mortality. Maximum variation in hill mortality of 3.5 was found at mat thickness of 24 mm for all the fingers studied. Minimum hill mortality of 1.9 was found at mat thickness of 12 mm for finger 1. Statistical analysis presented in Table 4 indicated that the effect of mat thickness on plant mortality was significant at 5% level of significance.

Missing hills: The effect of three levels of mat thickness on missing hills was studied with the machine. Minimum missing hills was found to be 3.5% at mat thickness of 18 mm at with round ended picker-fingers at growing density of 80 g. Increase in missing hills was observed with all the test conditions with decrease in growing density. Increase in missing hills with increase in mat thickness was observed for all the fingers. This might be due to improper shearing of thicker mats by the fingers. As for as picker-finger types concerned, higher missing hills was observed in both small and large needle type fingers (F1 and F2), while the round edge type fingers registered minimum plant mortality

Table 3 Comparison of improved transplanter with existing tranplanter

Parameter	Improved transplanter	IRRI transplanter
Field performance		
Number of rows	3	6
Field capacity, ha/h	0.058	0.050
Quantity of seeds, kg/ha	30	50-60
Hill spacing, cm	25	Depends on operator skill and requirement
Missing hills, %	9.61	4-5
Distribution of seedlings per hill	Single: 12.1% Double: 30.4% Triple : 31.7% Above three : 25.8%	5-7
Machine parameters		
Effective working width, m	0.75	1.20
Source of drive	Ground wheels, 2 number	Manual
Ground wheel slip, %	8.04	NA
Draft, N	261.7	Handle pushing down : 120.5 Handle pushing up : 109.3 Pulling the implement: 156.0
	Energy cost	
Average heart rate, bpm	126.3	139.7
Average VO2, l/min	19.98	26.99
Energy requirement, kJ/min	19.84	26.41
Rest pause (every 45 min)	12.50	16.25
Energy grade of work	Heavy	Heavy
Cost economics		
Cost of transplanting, ₹/ha	1150	1340
Cost saving, %	80.8	77.7
Time saving, %	91.3	90.0

Table 4 Operational performance

Particulars	Test number									
	Institute field					Farmers' field				
	1	2	3	4	5	1	2	3	4	5
Number of seedlings per hill (%)										
One seedling	10.3	12.5	13.4	15.6	10.4	11.9	13.8	11.8	10.5	10.7
Two seedlings	30.5	26.4	29.8	30.9	32.4	30.0	35.1	29.6	27.8	31.5
Three seedlings	36.5	35.4	28.0	26.1	29.8	29.4	31.5	32.5	33.5	34.5
Above 3 seedlings	22.7	25.7	28.8	27.4	27.4	28.7	19.6	26.1	28.2	23.3
Transplanting faults (% of total hills planted)										
Missing hill, %	8.5	8.3	9.2	7.2	6.5	7.5	7.5	10.4	9.4	7.5
Floating hill, %	2.5	2.6	3.5	2.1	1.2	1.5	2.3	1.8	1.8	1.4
Buried seedling, %	0.5	0.4	1.5	0	1.0	0	0	1.2	1.7	0.4
Total	11.5	11.3	12.2	9.3	8.7	9.0	9.8	9.4	10.9	9.3

(2.7%). This might be due to the reason that the round edge type fingers has better cutting profile to work with the seedling mat due to which proper placement of seedlings are achieved.

Ergonomics of the equipment

Ergonomical evaluation of the unit was conducted for assessing their suitability with twelve subjects (Table 5). Energy requirement with improved transplanter and existing 6-row transplanter were 19.84 and 26.41 kJ/min respectively, and hence there was 24.9% reduction in drudgery of the equipment (Baqui 1982). Though the energy cost of operation with improved transplanter is graded as 'heavy', the implement can be operated efficiently with a recommended rest pause of 12.5 min for every 45 min of operation.

Table 5 Physiological response of the subjects

Ergonomic parameter	Machine	Test number										Mean
		1	2	3	4	5	6	7	8	9	10	
Average heart rate, bpm	Improved Model	120.5	128.4	131.5	129.0	118.4	127.8	130.1	128.8	127.4	120.9	126.3
	IRRI Model	138.1	13.7.4	139.4	142.0	139.5	138.4	140.9	143.1	138.2	137.8	139.7
Average VO2, l/min	Improved Model	19.23	20.4	19.81	18.26	17.56	21.41	20.09	20.75	19.76	22.54	19.98
	IRRI Model	26.45	26.75	25.00	25.89	24.89	27.56	29.41	28.79	28.46	26.71	26.99
Energy requirement, kJ/min	Improved Model	21.2	23.5	18.5	20.8	18.4	19.7	17.4	19.60	18.9	20.4	19.84
	IRRI Model	25.6	26.4	27.2	26.5	24.9	28.5	24.9	25.8	26.8	27.5	26.41
Energy grade of work	Improved Model	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy
	IRRI Model	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy
Rest pause for every 45 min	Improved Model	11.9	13.1	13.5	12.6	12.3	12.5	12.8	11.9	12.6	11.8	12.50
	IRRI Model	15.9	15.8	16.1	15.8	16.5	15.9	16.9	16.8	16.4	16.4	16.25

The three-row pull-type rice transplnater performed excellently and it would be very useful for marginal farmers. The cost of the commercial model of the machine was estimated at Rs 15 000. It is economically viable with transplanting cost limited to Rs 1 150 per ha. The equipment performed excellently in different puddling conditions as well as textural conditions with acceptable work rate of 0.058 ha/h, field efficiency of 85.4%, hill-missing of 9.61%, and draft of 261.7 N. By employing ergonomical modifications, energy requirement (24.8%) and hence drudgery have been reduced with the modified transplanter with cost-saving of 80.8% and time-saving of 54.5%. Apart from the encouraging cost economics, the drudgery of operation is greatly reduced when compared to existing methods. The improved transplanter is very effective for addressing the timely planting need of all marginal rice farms.

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