Effect of Puddling on Puddled Soil Characteristics and Performance of Self-propelled Transplanter in Rice Crop

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ABSTRACT

Manual transplanting is tedious and time consuming. Self – propelled rice transplanters are gaining popularity in India because of higher output and less drudgery. But, self – propelled transplanters require an ideal puddled soil condition to avoid sinkage and poor steerability. Hence, a self-propelled rice transplanter (Model: 2ZT – 238 – 8) was evaluated in different puddled soil conditions created by two puddlers (Rotary blade puddler and Peg type puddler) and two levels of puddling (One pass and two passes) to identify a suitable puddled soil condition for effective performance of the transplanter in terms of puddled soil characteristics, transplanter and transplanting parameters and rice yield. Peg type puddler with two passes (P_2) produced highest depth of puddling (10.93 cm) and puddling index (30.13%) compared to rotary puddler with one pass (R_1) (10.09 cm and 24.60 %) and peg type puddler with one pass (P_1) (8.91 cm and 19.40 %). The bulk density of soil increased and hydraulic conductivity decreased 30 and 60 days after puddling (DAP) but puddler and level of puddling had significant ($p<0.5$) effect on hydraulic conductivity only. The cone index of the puddled soil decreased after puddling and gained strength with sedimentation period. But the increase of cone index was more from 24 to 36 h of sedimentation period (S_{24} to S_{36}) than 36 to 48 h of sedimentation period (S_{36} to S_{48}). The hardpan depths, hardness of hardpan and traction wheel sinkage were not so high to create any mobility problem of the transplanter. The buried and floating hill percentage was high at S_{24} and gradually decreased with increase in sedimentation period. Considering the float sinkage and hill mortality, it was found that for P_1 and R_1, 36 h of sedimentation period (S_{36}) was ideal for transplanting whereas P_2 required 48 h of sedimentation period (S_{48}). Maximum grain yield was obtained incase of P_2 at $S_{48.}$ Grain yield was influenced by sedimentation period rather than puddler and level of puddling.

Keywords: Puddler**,** puddled soil characteristics, sedimentation period, self-propelled rice transplanter, yield, India

1. INTRODUCTION

About 50 % of the total irrigated area is under rice cultivation in India and hence, 50 % of irrigation water is used for rice crop whose water requirement is 10^7 l ha $^{-1}$ (Manian and Jivaraj, 1989). Since, rice is the lowest productive crop per unit of water consumed amongst cereals, therefore, optimum water management and cultural practices need to be followed to ensure minimum losses of water. Approximately 75 % of water applied to rice crop is lost through deep percolation during submergence of field (Swaminathan, 1972). Hence, it is cultivated under puddled condition so as to minimize the percolation losses and to enhance the water and nutrient use efficiency of plant. Mostly, in India and other developing countries of Asia, rice is transplanted manually which is labour intensive and requires 250-350 man-hr ha $^{-1}$ that is 25 % of the total labour requirement of the crop (Singh and Hussain, 1983). Manual transplanting also fails to meet the agronomical requirements like plant population m^{-2} and uniform row and hill spacing, thereby limiting the use of agricultural implements and hand tools for intercultural operations. So, transplanting should be done either by manual transplanter or self-propelled transplanter. Manual transplanter consumes more time in transplanting and also involves a lot of human drudgery. Hence, the best alternative is the self propelled rice transplanter. Like all other wetland agricultural machinery, self-propelled rice transplanter also has problems of poor traction, sinkage and steerability. Since, self-propelled rice transplanter works on puddled soil; it encounters a hard surface at plow pan and a soft puddled soil at the top where it must also have sufficient bearing capacity to prevent sinkage of the float. At the same time the plow pan must not be too deep to provide necessary thrust to propel the transplanter. Both traction and bearing capacity are dependent upon shear strength of the soil (Knight and Freitag, 1962). Usually a transplanter would be immobilized either by failure in bearing or traction. Efficient working of a self-propelled rice transplanter requires a suitable puddled soil condition *vis-à-vis* optimum depth of puddling, degree of puddling and soil strength of puddled field. High degree of puddling severely affects the mobility of the transplanter and its performance. It takes longer sedimentation period when the transplanter could be operated. Therefore, in order to identify ideal puddled soil condition with respect to puddling equipment, its level of puddling and sedimentation period, for satisfactory performance of self-propelled rice transplanter as well as the rice crop , the present study was undertaken.

2. MATERIALS AND METHODS

2.1 Soil Characteristics

The soil of the experimental field was weak fine to fine medium granular structure, classified as mollisols. Analysis of a composite soil sample, showed that it was silty clay loam in texture (sand: 32.82%; silt: 42.00%; clay: 25.18%), slightly alkaline in soil reaction, rich in organic carbon, low in available nitrogen, rich in available phosphorous and potassium.

2.2 Puddling Equipment

Two tractor drawn puddling equipment namely rotary puddler (R) and peg type puddler (P) were used for puddling the experimental field. The working widths were 220 and 240 cm respectively with 72 blades (20x7x0.06 cm) in 8 gangs and 20 vertical pegs (22 x 6 cm) in rotary puddler and peg type puddler respectively. Peg type puddler was included in the experiment because of the reason that it was extensively used by local farmers as puddling equipment.

2.3 Self Propelled Rice Transplanter

A Chinese make self-propelled 8-row rice transplanter (Model: 2ZT-238-8), marketed by V.S.T. Agro Inputs, Bangalore, India was used in the experiment. It has a fixed row to row spacing of 23.8 cm and variable plant to plant spacing of 10 and 12 cm with corresponding maximum operating speed of 1.57 and 1.94 km hr^{-1} respectively. The specifications of the transplanter are given at Table 1.

Table 1 Specifications of the self-propelled rice transplanter

Sl. No	Items	Specifications
1.	Model	2ZT-238-8
2.	External dimensions, L x W x H, mm	2410 x 2131x 1300
3.	Weight, kg	320
4.	Engine	Air cooled 2.4 kW Diesel engine
5.	Number of rows	8
6.	Row Spacing, mm	238
7.	Hill to hill spacing, mm	i) 100 ii) 120
8.	Frequency of transplanting	263
9.	Depth of transplanting	Infinitesimal adjustment with screw rod
10.	Operating speed, km h^{-1}	i) 1.57 ii) 1.94
11.	Width of transplanting finger, mm	12.5
12.	Width of seedling gate, mm	16

2.4 Field Experiment

2.4.1 Treatments

The experiment was carried out with peg type puddler with two levels of puddling (one and two passes) and rotary puddler with one pass as main plot treatments. Sedimentation period of 24, 36 and 48 hours were selected as sub-plot treatments. The details of the treatments and nomenclature used are given below:

Table 2 Details of the independent and dependent variables of the experiment

Independent variables		Dependent variables			
Main Plot (Puddling equipment)	Symbols	Puddled soil characteristics	Transplanter parameters	Transplanting parameters	Crop parameters
Peg type puddler (two passes)	P_2	Depth of puddling	Hardpan depth,	Depth of transplanting,	Number of panicles per
Peg type puddler (one pass)	P_1	Puddling index	Hardness of Hardpan,	Hill spacing, Deviation in	hill, Number of
Rotary puddler (one pass)	R_1	Bulk density	Traction wheel	row spacing, Buried hills,	Panicles m^{-2} Grains per
Sub plot (Sedimentation period)		Hydraulic conductivity	sinkage, Traction wheel slip,	Floating hills, Mechanical damage to hills,	panicle, Grain yield
24 hours	S_{24}	Cone index	Float sinkage	Hill mortality,	
36 hours	S_{36}			Missing hills,	
48 hours	S_{48}			Number of	

seedling per
hill, Hill
population

2.4.2 Nursery Raising

The field was harrowed twice by a tractor drawn offset harrow and leveled by planking. Polythene sheet of 50 gauge was spread over the leveled field. Iron frames of size 198.5 x 55 x 2.5 cm having eight compartments (50 x 22 x 2.5 cm) were placed on the polythene sheet. Thereafter, well pulverized soil was filled uniformly in all compartments and gently compacted up to a thickness of 2 cm. Water was sprinkled over it by a hand sprayer and was allowed to soak for sometime. Sprouted seeds (Variety: Govind) was spread uniformly over the mat at the rate of 100-110 g per mat. The seeds were covered with a thin layer of (2-4 mm) of soil. Thereafter frames were removed for further use. To protect the seeds from birds the mats were covered by straw. Water was applied by a hand sprayer thrice in a day till there was complete emergence of seedling. After 4th day, the straw was removed and water was applied by flooding so as to keep the mat soil wet throughout its growth period.

2.4.3 Field Preparation and Transplanting

After harvest of wheat one summer ploughing of the experimental plots was done by a tractor drawn vertical disc plough. Subsequently, it was harrowed twice and was leveled by a scraper. Before puddling, the plots were flooded with water up to 10 cm for 24 hours. Puddling was done by different puddling equipment with a 35 kW Ford tractor (model: 3610). Transplanting was done by the Chinese make self-propelled transplanter at different sedimentation period considered for the experiment. Hill to hill spacing was set at 10 cm.

2.4.4 Fertilizer Application and Plant Protection

Nitrogen, phosphorous and potassium were applied at the rate of 120, 60 and 40 kg ha $^{-1}$. Half of nitrogen and full doses of phosphorous and potassium were applied as basal dose after puddling. Zinc sulphate at the rate of 20 kg ha $^{-1}$ was also applied in the plot. Remaining half dose of nitrogen was applied in two equal splits – first, at tillering and second, at panicle initiation stage. Organophosphatic insecticide, themate 10 G, was applied at the rate of 20 kg/ha after 50 days of transplanting to control stem borer and leaf folder.

2.4.5 Statistical Analysis

The data dependent on puddling equipment like depth of puddling, puddling index, bulk density, hydraulic conductivity, hardpan depth, hardness of hardpan, traction wheel sinkage were analyzed using Randomized Block Design (RBD). The other data dependent both on puddling equipment and sedimentation period were analyzed using split plot technique with puddling equipment as main plot treatment and sedimentation period as sub plot treatment.

2.5 Measurement of Different Parameters

2.5.1 Depth of Puddling

Depth of puddling was measured by a penetrometer as suggested by Taneja and Patnaik (1962).

2.5.2 Puddling Index

Soil water suspension samples were collected during last lap of puddling from different spots behind the puddling equipment with the help of 1.25 cm diameter steel pipe. Samples were taken from each treatment by closing the upper end of the pipe with thumb and collecting in a measuring cylinder till the volume reached 500 ml. The soil water suspension was allowed to settle for 48 hours and the volume of soil settled was recorded. Puddling index was determined by the following relationship (Baboo, 1976)

$$\text{Puddling index (PI)} = \frac{Vs}{V} \text{ x } 100 \qquad \ldots (1)$$

Where,
V_s = Volume of soil, ml
V = Total volume of the sample, ml

2.5.3 Soil Bulk Density

The soil bulk density (d.b) was determined using standard technique of core sampling method (Black, 1971).

2.5.4 Saturated Hydraulic Conductivity

Saturated hydraulic conductivity was determined using a falling head permeameter as suggested by Rane and Varade (1972). The instrument consisted of a glass tube of 75 cm length and 1.25 cm diameter. These were fixed to a depth of 10 cm from surface of the soil just after transplanting. The permeameters were filled with water up to a certain level, h_1, which was kept constant for all treatments. Evaporation loss from the permeameters was checked by adding 3-4 drops of lubricating oil. To prevent rain water entering the permeameter, the top was covered with a polythene sheet. Observations were recorded at 24 hours interval and the height of water column, h_2, was noted. Saturated hydraulic conductivity was determined using the following formula:

$$K = (aL/At)\ 2.302 \log (h_1/h_2) \qquad \ldots(2)$$

Where,
K = Saturated hydraulic conductivity, mm hr^{-1}
a = Cross-sectional area of the pipe, mm^2
L = Length of soil column, mm
A = Cross-sectional area of the soil column, mm^2
t = Time interval during which the head falls from h_1 to h_2, hr
h_1 = Head of water column at the beginning, mm
h_2 = Head of water column after time 't', mm

2.5.5 Cone Index

To determine cone index, a cone penetrometer (model BL, 250 EC, Baker Mercer type C10, LC = 0.002 mm), having 2.618 cm diameter of cone base with cone angle of 20°, was used.

Cone penetrometer was calibrated with known weights and the relationship between applied load and dial gauge deflection was established. Since, puddled soil was having low strength; the cone penetrometer tends to sink without showing any deflection. Hence, the weight of cone penetrometer (3485 g) per unit area of cone base was also taken into account while determining the cone penetrometer resistance (Bhadoria, 1995). The cone penetrometer resistance (CPR) per unit area (sq.-cm) was determined by the following relationship:

$$CPR, = 0.648 + 0.025X, \text{ kg cm}^{-2} \quad \ldots(3)$$

Where,

X = dial gauge deflection, small divisions

The average cone penetrometer resistance over a depth range (0-15 cm) has been termed as cone index. The calculated value of CPR and CI was multiplied by a constant factor 98.067 to get CPR and CI in kPa**.** Cone penetrometer readings at different depths were taken randomly from five different places in each treatment at an increment of 2.5 cm and converted into CPR by the above formula. Cone index values were determined by taking the average of CPR values at different depths (0-15 cm).

2.5.6 Hardpan Depth and Hardness of Hardpan

The hardpan depth and hardness of hardpan was measured using the cone penetrometer used to measure the cone index.

2.5.7 Wheel Slip

Wheel slip was measured by a measuring the distance covered by the transplanter in grassy land and puddled soil in 20 revolutions of the traction wheel using the formula suggested by Meheta et al. (1995).

2.5.8 Sinkage of the Float

The depth of transplanting was measured and the value was subtracted from the preset depth of transplanting (3 cm) to determine the float sinkage.

2.5.9 Buried and Floating Hill

Hills which are completely buried under soil after transplanting are called buried hill (Mori, 1975). Floating hills are those hills where all seedlings in a hill are either floating on the surface or just placed on the surface of the mud (Singh et al., 1985). Buried hills and floating hills were counted in a square meter area after transplanting. Five observations were taken for each treatment. Floating and buried hill were calculated by the following formulae:

$$\text{Buried hill, \%} = (BH/TNH) \times 100 \quad \text{--- (4)}$$

$$\text{Floating hill, \%} = (FL/TNH) \times 100 \quad \text{--- (5)}$$

Where,BH = Number of buried hill m^{-2}

FL = No. of floating hill/m^2

TNH = Total number of hill transplanted m^{-2}

2.5.10 Hill Mortality

One square-meter area was marked after transplanting and the numbers of hills transplanted were counted. After 15th day of transplanting, the numbers of hills survived were counted. Hill mortality was determined by the following formula (Garg et al., 1997):

Hill mortality,% = [1- (HS/ TNH)] x 100

Where, HS = No. of hills survived 15 days after transplanting (DAT) m^{-2}--- (6)

3. RESULT AND DISCUSSION

3.1 Puddle Soil Characteristics

3.1.1 Depth of Puddling

It was observed that depth of puddling was significantly higher in case of P_2 (10.93 cm) and R_1 (10.09 cm) than that of P_1 (8.91 cm). Depth of puddling for P_2 and R_1 were statistically at par. Higher depth of puddling in case of rotary puddler compared to peg type puddler at single pass might be due to its more weight and rotary action of blade that resulted in cutting of soil and mixing with water. Increase in depth of puddling at more number of passes (P_2) might be due to progressive increase in softness of the puddled soil with each operation thereby resulting in greater penetration of ground working parts of the puddlers. This corroborates the observations made by Taneja and Patnaik (1962).

3.1.2 Puddling Index

Puddling index of treatment P_2 (30.13%) was found to be significantly higher than that of P_1 (19.40%) and R_1 (24.60%). During puddling, soil undergoes two types of deformations: first, due to normal stress which is associated with compression and second, because of tangential stress causing shear. Since, puddling is done under saturated condition of soil; it is shear stress which causes dispersion of soil particles in water. Rotary puddler due to rotary motion of its blades matches the weakest fracture plane of soil mass disintegrating it into fine particles (Sharma and De Datta, 1985). This might be the reason for higher puddling index in case of rotary puddler (R_1) over peg type puddler (P_1) in a single pass. Besides that, the angular orientation of blade (30°) in rotary puddler creates a cycloid action of the blade on the soil thereby increases the churning of soil and water mixture which enhances the puddling index (Tewari, 1984). Increase of puddling index in P_2 was due to increase in level of puddling because of more soil manipulation by the implement which is in agreement with the results reported by Salokhe et al. (1993); Behera et al., 2007.

3.1.3 Bulk Density

Initial bulk density of the soil was 1.44 Mg m^{-3} and increased after puddling in all treatments. Highest bulk density of 1.507 Mg m^{-3} was recorded for treatment P_2 followed by treatments R_1 (1.492 Mg m^{-3}) and P_1 (1.472 Mg m^{-3}) at 30 days after puddling (DAP). The bulk density increased marginally to 1.52, 1.50 and 1.49 Mg m^{-3} in case of treatments P_2, R_1 and P_2 respectively at 60 DAP. However, there was no significant difference of bulk density among treatments between 30 and 60 DAP (Table 3). The soil aggregates break into finer particles due to puddling and remain suspended in water. Thereafter, flocculation of particles takes place and there is a stratified settlement of soil particles leading to destruction of macro pores which creates a dense soil. At higher level of puddling, the dispersion of particles in water is more which on settling reduces the porosity thereby resulting in a more compact soil. This might be the reason for increase in bulk density of soil after puddling and further increase of bulk density at higher level of puddling (P_2). Increase of bulk density with respect to time might be due to shrinkage of soil at lower moisture content. Average moisture content of soil was 28.70 and 23.35 % at 30 and 60 DAP. The findings corroborated with the results reported by Bajpai (1994) and Rath (1999).

3.1.4 Hydraulic Conductivity

Minimum hydraulic conductivity of 0.257 mm hr^{-1} was found in case of P_2 which was significantly lower than that of P_1 (0.315 mm hr^{-1}) but statistically at par with R_1 (0.270 mm hr^{-1}) at 30 DAP. At 60 DAP, there was no appreciable variation in hydraulic conductivity over that of 30 DAP. The hydraulic conductivity depends upon the amount and size of coarse pores (transmission pores) in the soil. Considerable reduction of hydraulic conductivity of puddled soil over unpuddled was observed in case of all treatments (Table 3). This might be due to clogging of pore space channels on settling of soil particles after puddling. Clogging of these channels reduced the water transmission pores which resulted in decreasing hydraulic conductivity. Similar results were reported by Rane and Varade (1972) and Sharma et al. (1991).

An empirical relationship was established between bulk density and hydraulic conductivity from the values obtained from different treatments (Fig. 1). It was clear from the figure that as bulk density increased hydraulic conductivity decreased but at higher bulk density the rate of decrease of hydraulic conductivity was low. The correlation coefficient (R^2= 0.7821) was found significant at 5 % level of significance. Behera et al. (2007) also reported a similar relationship between bulk density and hydraulic conductivity at higher level of puddling.

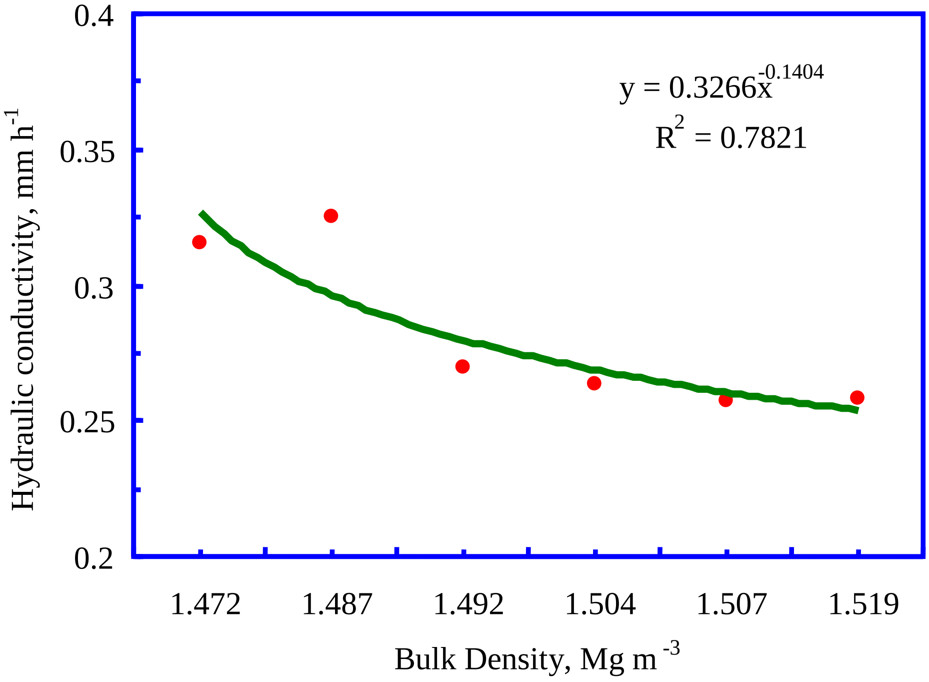

Fig. 1 Effect of bulk density of soil on saturated hydraulic conductivity

Table 3 Effect of puddling on puddling index, bulk density and hydraulic conductivity of puddled soil
Initial bulk density, Mg m^{-3}: 1.44, Initial hydraulic conductivity, mm hr^{-1}:0.648;
Average moisture content of soil, %: 28.70 (30 DAP); 23.35 (60 DAP)

Treatments (Puddling equipment)	Depth of puddling, cm	Puddling index, %	Bulk density, Mg m^{-3}		Hydraulic conductivity, mm hr^{-1}	
			30 DAP	60 DAP	30 DAP	60 DAP
P_1	8.91	19.40	1.472 (2.22)*	1.487 (3.26)	0.315 (51.39)	0.325 (49.85)
P_2	10.93	30.13	1.507 (4.65)	1.519 (5.49)	0.257 (60.34)	0.258 (60.19)
R_1	10.09	24.60	1.492 (3.61)	1.504 (4.44)	0.270 (58.33)	0.263 (59.41)
SEm ±	0.256	0.513	0.008	0.010	0.010	0.003
$CD_{(0.05)}$	1.000	2.00	NS	NS	0.040	0.013

* Values in the parenthesis are percentage change over the initial bulk density and hydraulic conductivity of the soil.

3.1.5 Cone Index

Cone index was measured to study the strength characteristics of puddled soil and its subsequent effect on transplanter performance. It was observed that soil strength reduced considerably after puddling to a depth of 10 cm for all treatments. As sedimentation period increased, the CPR increased at each depth and the increase was at a faster rate from 10 cm and onwards. It was observed that cone index of treatment P_2 was 211.78 kPa at S_{24} which was statistically at par with R_1 (234.39 kPa) but significantly lower than that of P_1 (254.85 kPa). It increased with sedimentation period and behaved in a similar manner as that of S_{24}. However, the increase was more when sedimentation increased from 24 to 36 h than 36 to 48 h. The strength of soil is made up of two properties viz. (i) internal friction or resistance due to inter-locking of particles and (ii) cohesion or the resistance due to inter-particle forces which tends to hold the particles together in a soil mass. During the process of puddling, soil is thoroughly churned under flooded condition. Due to this, the internal friction becomes negligible and it depends solely on cohesion which is progressively reduced as puddling intensity is increased. Because of this, the cone index of puddled soil decreased considerably over that of saturated soil and it further decreased with level of puddling. These findings on cone index corroborated with that of Salokhe et al. (1993). Decrease of cone index was comparatively higher in case of rotary puddler (R_1) than peg type puddler (P_1) at a same level of puddling. This might be due to better puddling by rotary action of the blades whereas there was combing action in case of peg type puddler which gave poor quality of puddling at same level of puddling. Increase of cone index with sedimentation period might be due to the fact that the dispersed soil particles settled with time and water level of field also receded which resulted in a compact and firm medium which subsequently increased the strength of the soil. This phenomenon is called thixotropy (Awadhwal and Singh, 1985). Higher the level of puddling, slower would be the settlement of dispersed particles and hence, lower would be the cone index. This was the reason for low cone index in case of R_1 at S_{48} compared to P_1. This observation was in agreement with Khan and Gunkel (1989).

Table 4 Effect of puddling on cone index of puddled soil at different sedimentation period
Initial cone index of saturated soil: 393.35 kPa

Treatments (Puddling equipment)	Sedimentation period, h 24	 36	 48	Mean
P_1	254.85 (35.21)*	320.39 (18.55)	342.48 (12.93)	305.91
P_2	211.78 (46.16)	261.60 (33.49)	282.30 (28.23)	251.77
R_1	234.39 (40.41)	272.74 (30.66)	308.95 (21.46)	274.89
Mean	233.69	287.62	311.24	277.52
Factors	S Em ±	$CD_{(0.05)}$		
Puddling equipment (a)	7.00	27.38		
Sedimentation period (b)	2.70	8.31		
Interaction (a x b)	7.98	29.67		

* Values in parenthesis shows percentage reduction in cone index over saturated soil cone index

3.2 Transplanter Parameters

3.2.1 Hardpan Depth, Hardness of Hardpan and Traction Wheel Sinkage

Hardpan depth and its hardness varied from 19.50 to 20.67 cm and 1033 to 1074 kPa respectively, which were statistically similar. There were no appreciable variations in traction wheel sinkage under different sedimentation period; hence these were pooled together to represent the average sinkage in each main plot treatment. The traction wheel sinkage varied from 21 to 22 cm. Mobility of the transplanter depends upon the depth of puddling, hardpan depth and sinkage of float (Singh and Garg, 1976). The sinkage of the float was not to that extent which might warrant a bearing failure (Table 5). Since, the traction wheel touched the hardpan as the sinkage of the traction wheel was more than the hardpan (Table 5), it could produce necessary traction, and hence, there was no traction failure. This was the reason for encountering no mobility problem. From this, it could be inferred that up to 11 cm depth of puddling, mobility would not be a problem for the transplanter. Behera et al. (2003) reported that there was no traction failure of the transplanter up to a puddling depth of 15 cm.

3.2.2 Traction Wheel Slip

Minimum traction wheel slip of 2.13 % was recorded in case of P_2 followed by R_1 (3.96%) and P_1 (4.94%) at S_{24}. Thereafter, traction wheel slip increased with sedimentation period; however, the increase was non-significant. At S_{48}, it was 6.51, 7.63 and 8.92 % in case of treatments P_2, R_1 and P_1, respectively. The interaction effect of puddling equipment and sedimentation period on traction wheel slip was also found non-significant. Low traction wheel slip at S_{24} might be due to less drag force because of better lubrication at the interface of float and puddled soil. At this level of sedimentation, the water level in the field for all treatments was more than 2 cm which enhanced the process of lubrication. As sedimentation period increased, soil became harder and water level gradually receded which increased the drag force and subsequently the wheel slip. Greater wheel slip for treatments at S_{48} might be due to more drag force because of higher soil-float adhesion. Mori (1975) also reported an increase of wheel slip of transplanter at hard soil surface.

3.2.3 Float Sinkage

Maximum float sinkage of 2.69 cm was obtained for P_2 at S_{24} which was significantly higher than that of P_1 (2.38 cm) but statistically at par with R_1 (2.58 cm) (Table 5). Float sinkage between P_1 and R_1 was observed to be non-significant. At S_{36}, float sinkage decreased and behaved identically to that of S_{24} but at S_{48}, it was statistically at par with values of 1.19, 0.92 and 1.10 cm for treatments P_2, P_1 and R_1 respectively. More sinkage at S_{24} might be due to softness of puddled soil resulting in low sinkage resistance. With increase of sedimentation period, the soil gained strength which supported the weight of the float thereby reducing the sinkage. Garg (1999) suggested that transplanting should not be done either on too soft and or on hard soil. They further reported that float sinkage less than 1 cm signified hard field condition which might pose problem in penetration of transplanting fingers into puddled soil. Assuming that float sinkage greater than 2 cm is indicative of soft soil, therefore, transplanting may be done at a float sinkage in between 1 to 2 cm. In the present study, the float sinkage was found more than 2 cm at S_{24} for all the treatments. Whereas, it was in between 1 to 2 cm in case of P_1, P_2, R_1 at S_{36} and P_2 and R_1 at S_{48} respectively. If, float sinkage with respect to sedimentation period is considered as a yardstick for optimum time of transplanting after puddling, it may be said that for all treatments 36 hours of sedimentation period is required for transplanting. Goel et al. (2008) also reported float sinkage within 1-2 cm after 48 h of sedimentation period.

Table 5 Effect on puddling on hardpan depth, hardness of hardpan and traction wheel sinkage

Treatments (Puddling equipment)	Hardpan depth, cm	Hardness of hardpan, kPa	Traction wheel sinkage, cm	Traction wheel slip, %			Float sinkage, cm		
				S_{24}	S_{36}	S_{48}	S_{24}	S_{36}	S_{48}
Peg type puddler one pass (P_1)	19.50	1033.49	21.46	4.94	6.02	8.92	2.38	1.20	0.92
Peg type puddler two passes (P_2)	20.67	1074.24	22.53	2.13	4.00	6.51	2.69	1.50	1.19
Rotary puddler one pass (R_1)	20.00	1070.16	21.92	3.96	5.91	7.63	2.58	1.33	1.10
SEm±	0.860	30.00	1.104	a: 0.324 b: 0.343			-		
$CD_{(0.5)}$	NS	NS	NS	a: 0.183, b: 0.175 a x b: NS			-		

3.3 Transplanting Parameters

3.3.1 Depth of Transplanting

Maximum depth of transplanting was recorded as 5.69 cm in case of P_2 at S_{24}, which was statistically at par with R_1 (5.58 cm) but significantly higher than P_1 (5.38 cm). Depth of transplanting was found to decrease with sedimentation period. However, at S_{48}, there was no significant difference in depth of transplanting among treatments. It was noticed that depth of transplanting depended upon the float sinkage. Higher the float sinkage more was the depth of transplanting. In the present study, the depth of transplanting was set at 3 cm. But it was found considerably high at S_{24}. This might be due to more sinkage of the float at that stage because of softer puddled soil. With increase in sedimentation period, puddled soil gained strength reducing the float sinkage, which in turn resulted in lesser depth of transplanting. Higher depth of transplanting under the soft puddled condition was also reported by Mori (1975) and Goel et al. (2008).

3.3.2 Hill Spacing

Hill spacing was observed more than the prefixed spacing of 10 cm for all the treatments at S_{24} and thereafter, it decreased with increase in sedimentation period. However, it was more than the preset spacing at S_{48}. Sedimentation period had significant effect on hill spacing (Table 6), but the interaction effect of puddling equipment and sedimentation period was found non-significant. Hill spacing depends on the traction wheel slip. Higher hill spacing at S_{24} might be due to low wheel slip than the designed slip for the transplanter. As sedimentation period increased the wheel slip increased resulting in a decrease in hill spacing. Similar observations were made by Mori (1975).

3.3.3 Deviation in Row Spacing

Deviation in row spacing ranged from 5.46 to 5.81 % at S_{24}. It decreased with sedimentation period and the variation was 2.64 to 3.64 % at S_{48}. However, the interaction effect of puddling equipment and sedimentation period was non-significant although both puddling equipment and sedimentation period had significant effect on deviation in row spacing. Higher deviation in row spacing from the theoretical preset value (23.8 cm) at S_{24} might be due to movement of puddled soil along with the float which disturbed the row spacing. More variation in case of P_2 compared to P_1 and R_1 might be due to inadequate settling of soil because of higher puddling in P_2 leading to more sinkage of float which displaced more mud. With increase in sedimentation period, puddled soil settled and its flow reduced which in turn reduced the deviation in row spacing.

3.3.4 Buried Hills, Floating Hill, Mechanical Damage to Seedling and Hill Mortality

Maximum buried hill was obtained in case of P_2 (5.87%) at S_{24} followed by P_1 (3.33%) and R_1 (3.27%) which were statistically at par but significantly lower than that of P_2 (Table 6). Thereafter, buried hill decreased with sedimentation period and at S_{36}, there was no significant difference among all treatments. At S_{48}, it was 1.32 % for P_2 whereas it was only 0.53 and zero for treatments P_1 and R_1 respectively.

Highest floating hill of 4.05 % was observed in case of P_2 at S_{24} (Table 6). Floating hill also decreased with increase in sedimentation period for all treatments. However, the interaction effect of puddling equipment and sedimentation period was found non-significant which indicated that there was no statistical difference of floating hill under different treatments with respect to sedimentation period. Higher percentage of buried and floating hills at S_{24} might be due to poor anchorage of seedling in soft soil and movement of puddled mass along with the float due to its higher sinkage (Table 5). Puddled soil because of inadequate settling remained in a flowable state where the strength of the soil (cone index) was very low resulting in poor gripping capacity of seedlings which was also evident from the results of seedling withdrawal force Behera (2000). Due to more float sinkage, the depth of transplanting increased which might have also contributed towards the buried hill. Besides above reasons, high water level at low sedimentation created a wave action thereby washing away the seedlings which in turn might have increased the floating hill. It was observed that due to flow of mud and water at least two rows of the previously transplanted pass were normally affected. As sedimentation period increased, soil gained strength and the flow of soil along with the float reduced. This was the reason for reduction in buried and floating hills with increase in sedimentation period. These findings were in agreement with Singh and Garg (1976); Kanoksak et al. (1988) and Khan and Gunkel (1988). There existed a linear relationship between cone index and buried & floating hill which showed a good negative correlation ($R^2 = 0.831$) between them (Fig. 2). The correlation coefficient was significant at 5 % level of significance.

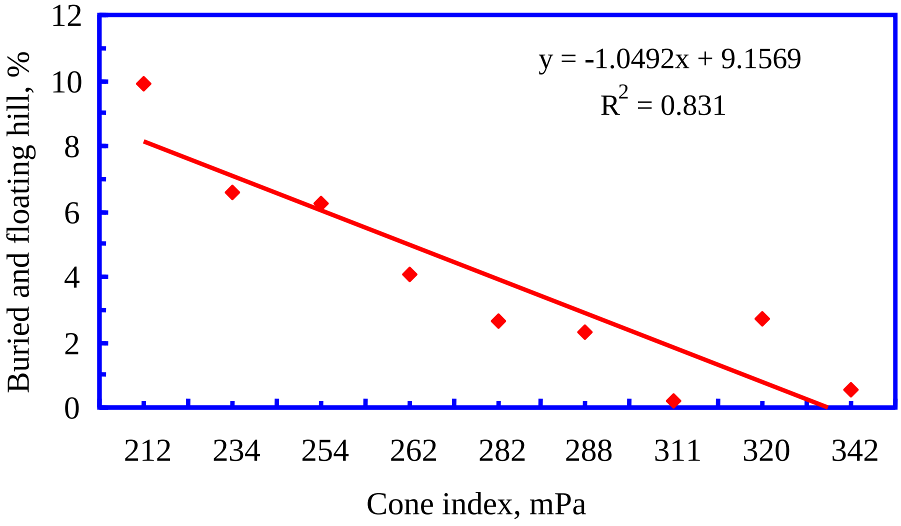

Fig. 2 Relationship between cone index and buried and floating hill

The average mechanical damage was found as 0.26 % with standard deviation of 0.44 which showed inconsistency in the data. Maximum mechanical damage of 1.40 % was found in case of treatment R_1 at S_{48}. Mechanical damage to seedlings mainly depends upon the transplanting speed (1.38 km/h) and tenderness of the seedling.

Highest hill mortality of 8.28 % was recorded in case of treatment P_2 at S_{24} which was significantly higher than R_1 (5.37%) and P_1 (4.88%). At S_{36}, mortality was 4.23 % for P_2 followed by P_1 (1.97%) and R_1 (1.77%). There was no hill mortality in case of P_1 at S_{48} whereas a marginal increase in hill mortality from 1.77 to 2.78 % was observed for treatment R_1 (Table 6). Relationships between buried hill, floating & mechanically damaged hill and mortality were established and shown in Fig.3. From the above figure, it was noticed that mortality in most of cases were less than total buried, floating and mechanically damaged hills with few exception where mortality was higher. It may be due to survival of some of the floating hills. It was observed that mortality decreased with increase in sedimentation period.

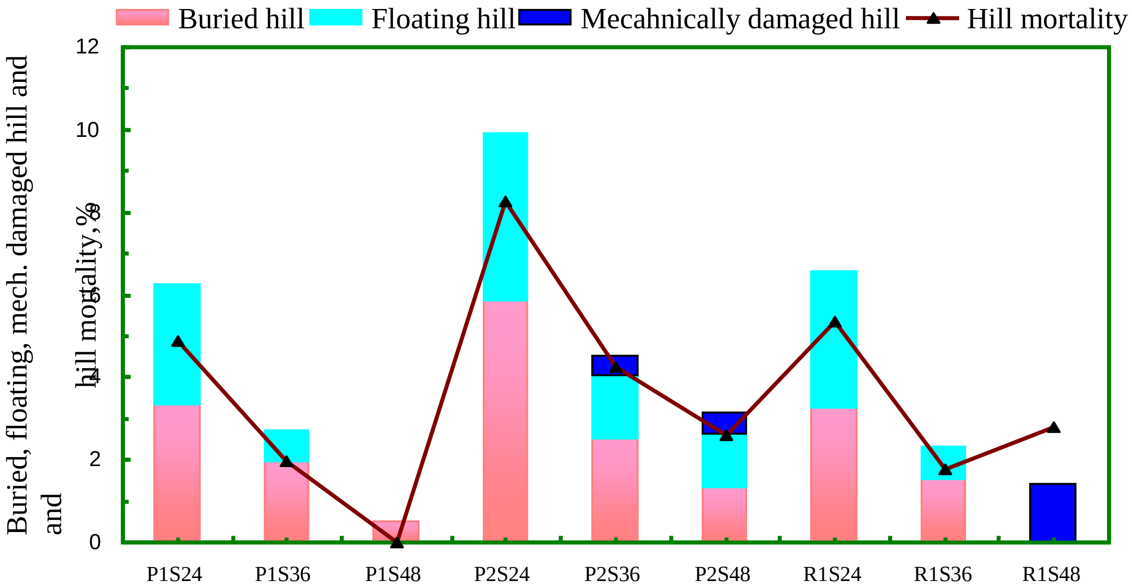

Fig. 3 Effect of puddling on hill mortality

A linear relationship between cone index and mortality was found with a negative correlation (R^2 =0.873) which was significant at 5 % level of significance (Fig. 4). Decrease of mortality with increase of sedimentation period might be due to reduction of buried and floating hill which generally contributed towards hill mortality. Goel et al. (2008) reported a hill mortality of 4.74 % after 48 h of sedimentation period in a higher intensity of puddling by rotavator.

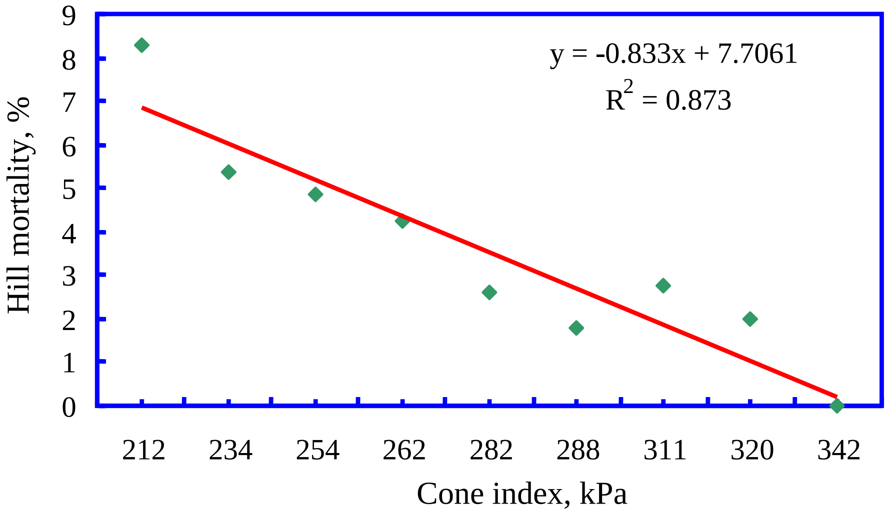

Fig. 4 Relationship between cone index and hill mortality

3.3.7 Missing Hills

Missing hill varied between 5.83 to 11.81 % with an average of 8.96 % with standard deviation of 1.23. Missing hill mostly depends upon the seedling density and its uniformity in the mat (Mufti and Khan, 1995). Higher missing of hills in the present study was due to non-uniformity of seedling distribution in the mat. Besides that, silty clay loam soil of the seedling mat being sticky in nature might have caused problem in sliding of mat on the tray resulting in more missing of hills. Similar observations were made by Singh et al. (1985). Missing hill was found more than the allowable limit of 5 % (Mori, 1975). Hence, it needs to be careful to maintain proper density of seedling as well as its uniformity in the mat.

3.3.8 Seedling per Hill

Seedling per hill varied from 2.51 to 2.94. The corresponding mean value of seedling per hill was 2.70 with standard deviation 0.13. From this, it was found that the agronomical requirement of 2-3 seedlings per hill was achieved in the study.

3.3.9 Hill Population

It was found that hill population increased with sedimentation period. However, there was no significant effect of puddling equipment and sedimentation period on hill population. Least hill population was obtained in case of P_2 (31.80) compared to that of P_1 (32.47) and R_1 (32.20) at S_{24} (Table 6). In general, hill population depends upon mortality, hill spacing and finally on missing hills. Least hill population in case of P_2 at S_{24} might be due to more hill mortality (8.28%). Increase of hill population with respect to sedimentation period might be due to reduction in mortality and hill spacing (Table 6). At higher sedimentation period, traction wheel slip was found to increase leading to a decrease of hill spacing which in turn increased the hill population. This might be the reason for non-significant variation in hill population among treatments P_2, P_1 and R_1 at S_{24} and S_{36}, even if hill mortality in case of P_2 (8.28 & 4.23%) was significantly higher compared to that of P_1 (4.88 & 1.97%) and R_1 (5.37 & 1.77%). As missing hill showed lack of consistency in the data (8.96 % ± 1.23), the hill population failed to follow a particular trend although hill mortality and spacing decreased with increase in sedimentation period. However, missing hill being controllable and a function of seedling mat uniformity and density, hill population depended on hill mortality and spacing which in turn depended on the puddled condition. So, in order to have an optimum plant population, the mortality of hill resulting due to buried, floating and mechanically damaged hills should be controlled.

Table 6 Effect of puddling and sedimentation period on transplanting parameters

Treatments	Sedimentation period, h	DT, cm	HS, cm	DRS, %	BH, %	FL, %	MDH, %	HM, %	HP, No.
P_1	S_{24}	5.38	10.45	5.54	3.33	2.93	0.00	9.88	32.47
	S_{36}	4.20	10.36	3.67	1.97	0.75	0.00	1.98	34.93
	S_{48}	3.92	10.09	2.81	0.53	0.00	0.00	0.00	36.80
P_2	S_{24}	5.69	10.94	5.81	5.87	4.05	0.00	8.28	31.80
	S_{36}	4.50	10.49	4.43	2.50	1.55	0.46	4.23	33.13
	S_{48}	4.19	10.32	3.64	1.32	1.30	0.51	2.59	34.27
R_1	S_{24}	5.58	10.57	5.47	3.27	3.30	0.00	5.37	32.26
	S_{36}	4.33	10.56	2.45	1.55	0.78	0.00	1.77	33.73
	S_{48}	4.10	10.32	2.64	0.00	0.00	1.40	2.78	35.53
C. D $_{(0.05)}$	Factor (a)	0.19	NS	0.61	0.56	0.16	NS	1.20	-
	Factor (b)	0.15	0.327	0.52	0.52	0.30	NS	0.68	-
	Interaction	0.28	NS	NS	0.92	NS	NS	1.52	-

DT: Depth of transplanting; **HS:** Hill spacing; **DRS:** Deviation in row spacing; **BH:** Buried hill; **FL:** Floating hill; **MDH:** Mechanically damaged hill; **HM:** Hill mortality; **HP:** Hill population.

3.4 Crop Parameters and Yield

Maximum panicles per hill was obtained in case of P_2 (11.03) which was statistically similar to that of R_1 (10.75) but higher than P_1 (10.11). However, number of panicles/hill for treatments R_1 and P_1 were statistically at par. The effect of puddling equipment and sedimentation period was found non-significant on number of panicles/hill. Maximum panicles/m^2 was obtained in case of P_2 (365) followed by R_1 (364) and P_1 (353). However, there was no significant difference of panicles/m^2 among the treatments. Only the main factor (puddling equipment) had significant effect on grains/panicle whereas the interaction was found non-significant. Maximum grains/panicle were observed in case of P_2 (116) followed by R_1 (112) and P_1 (107). Treatments P_2 and R_1 were statistically at par but differed significantly from P_1. Maximum grain yield of 5.33 t/ha was obtained in case of P_2 at S_{48} followed by R_1 (5.17 t/ha) also at S_{48}. Only sedimentation period was observed to have significant effect on grain yield. The interaction effect of puddling equipment and sedimentation period was found non significant ($P<0.05$). However, maximum grain yield of 5.08 t/ha in case of treatment P_1 was recorded at S_{36}. It was observed that even with low level of puddling the grain yield was remarkably higher than that obtained with higher level of puddling (Behera et al., 2007). Grain yield is affected by physico-chemical status of soil and optimum plant population taking into account others parameters constant for all treatments. Increase in grain yield with respect to sedimentation period might be because of better plant population due to less mortality.

Table 7 Effect of puddling and sedimentation period on transplanting parameters

Treatments	Sedimentation period, h	No. of Panicles/hill	No. of panicles/m^2	Grains /panicle	Yield, t/ha
P_1	S_{24}	9.87	324	107	4.31
	S_{36}	10.44	365	105	5.08
	S_{48}	10.10	371	108	5.06
P_2	S_{24}	10.75	342	115	4.92
	S_{36}	11.00	366	113	4.73
	S_{48}	11.31	388	119	5.33
R_1	S_{24}	10.68	344	114	4.87
	S_{36}	10.66	360	108	4.75
	S_{48}	10.93	388	116	5.17
C. D $_{(0.05)}$	Factor (a)	0.98	NS	4.24	NS
	Factor (b)	NS	20.71	7.31	0.31
	Interaction	NS	NS	NS	NS

4. CONCLUSION

From the study it could be concluded that puddling increased bulk density of the soil and decreased hydraulic conductivity. The puddler and level of puddling had significant effect on hydraulic conductivity which decreased at a decreasing rate at higher bulk density of soil.

The cone index of the puddled soil decreased significantly from the initial cone index of the saturated soil and gained strength as sedimentation period increased. The increase of cone index was more pronounced between sedimentation period of 24 and 36 h than between 36 to 48 h. No mobility problem of the transplanter was encountered which indicated that the puddling equipment and level of puddling was acceptable for puddling. Ideal condition for transplanting was found to 48 hour after puddling in case of rotary puddler with single pass (R_1) and peg type puddler with two passes (P_2). However, in case of peg type puddler with one pass (P_1) it was found to be 36 hours after puddling. The puddling equipment had no significant effect on grain yield indicating that any one of them could be used in the silty clay loam soil. Only the sedimentation period was having a significant effect on the grain yield. Maximum yield of 5.33 t/ha was achieved in case of P_2 after 48 hours of sedimentation period.

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