# Effects of inundation period and tillage option on field performance of self-propelled rice transplanter

Md. Anwar Hossen[1*], Md. Mosharraf Hossain[2], Richard W. Bell[3], Md. Enamul Haque[4]

(1. *Senior Scientific Officer, Farm Machinery and Postharvest Technology Division, Bangladesh Rice Research Institute, Gazipur-1701, Bangladesh*; 2. *Professor, Department of Farm Powerand Machinery, Mymensingh, Bangladesh*; 3. *Professor, School of Veterinary and Life Sciences, Murdoch University, Murdoch, WA 6150 Australia*; 4. *Adjunct Associate Professor, Murdoch University, Australia*)

**Abstract:** Mechanized transplanting of rice could decrease costs and use of labor in the peak of transplanting periods. Self-propelled rice transplanter requires an ideal field condition as well as optimal inundation of non-puddled soil before transplanting. Hence, self-propelled rice transplanters (four rows walking type, model DP480 except clay loam soil during the Boro season in 2013-2014 where six rows riding type rice transplanter, model S3-680) was evaluated in clay loam, loam and sandy loam soil during the irrigated dry season (Boro) in 2012-2013 and 2013-2014. Tillage treatments in a strip plot design were stripped, zero and conventional tillage and irrigation treatments as inundation periods before transplanting as sub-plots were 12, 18 and 24 hours (hrs). Soil penetration resistance decreased with the increased of inundation period in both the seasons and three soil types. Field capacity of both the walking (0.11 to 0.14 ha $hr^{-1}$) and the riding type rice transplanter (0.21 to 0.22 ha $hr^{-1}$) had not varied significantly with the tillage options. Averaged of two seasons, strip tillage gave higher field capacity for 12 hrs inundation period in clay loam soil and 18 hrs inundation period in loam and sandy loam soil whereas zero and conventional tillage gave higher for 24, 18 and 24 hrs inundation period and 18, 12 and 18 hrs inundation period in clay loam, loam and sandy loam soil, respectively. The non-puddled strip and zero tillage reduced fuel consumption by 22% to 13% and 8% to 13% for transplanting in clay loam and sandy loam soil compared to conventional tillage, respectively. However, strip tillage reduced the percentage of missing hills (9.7%) compared to zero (13.0%) and conventional tillage (10.7%) while percentage of missing hills, averaged of two seasons and three soil types, decreased 13.7% to 9.2% with the increased of inundation periods 12 to 24 hrs. The highest percentage of picker missing hills was observed in zero tillage irrespective of seasons and soil types. However, zero tillage also gave higher percentage of damage hills compared to conventional and strip tillage. Floating hills decreased with the increased of inundation periods in non-puddled strip and zero tillage. Conventional tillage increased the buried hills significantly in both the seasons. Strip tillage gave higher grain yield compared to zero and conventional tillage in both the seasons except clay loam soil during the Boro season in 2012-13 where zero tillage gave a higher grain yield. However, 18 hrs inundation periods for strip (6.1 t $ha^{-1}$), 24 hrs for zero (6.0 t $ha^{-1}$) and conventional (5.9 t $ha^{-1}$) tillage gave the highest grain yields. Finally, it can be stated that non-puddled minimum tillage (strip and zero) is a resource saving technique while 18 hrs inundation prior to transplant for strip and 24 hrs inundation for zero tillage showed more benefited for rice production.

**Keywords:** Tillage option, inundation period, field performance of the transplanter, field capacity, soil type and grain yield

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## 1 Introduction

Rice (*Oryza sativa* L.) is an important cereal crop in the world and nearly more than half of the population subsists on it. Rice can either be transplanted or directly sown. In Bangladesh, rice seedlings are transplanted manually by hired labor that resulted in a labor shortage throughout the peak period of transplanting. To solve the problem of labor shortage, alternate methods of rice seedling establishment are expected. Manual transplanting of rice consumes a large amount of labor

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*** Corresponding author:** Md. Anwar Hossen, Ph.D., Senior Scientific Officer, Farm Machinery and Postharvest Technology Division, Bangladesh Rice Research Institute, Bangladesh. Email: ahossenbrri@gmail.com. Tel: +88-02-49272005-14 ext. 414, Fax: +88-02-49272000.

forces. The manual transplanting of rice seedling is both time consuming and tiring. The total labor requirement for rice production in 1.0 hectare of land is about 156 man-days of which 45 man-days is consumed by seedling raising and transplanting which is about 29% of the total labor requirements (Rahman, 1997). Soil attached seedling is necessary in most of the cases for mechanical transplanting. The attached soil with seedling works as bonding elements which helps to maintain uniformity and stand-up state of seedlings, a crucial pre-requisite for mechanical transplanter operation in the field. The smooth operation of the rotary picker and successful isolation of a hill of seedling from its mate is largely determined by whether the seedlings were properly bounded by the soil and evenly distributed (CAME, 2007).

Mechanization is now essential for rice production and processing. The principal objective of agricultural mechanization is the notion of reduction in production cost and labor requirements. Agricultural mechanization using small scale machinery to agricultural production has been one of the outstanding developments in the developed countries (Osunbitana et al., 2005). In Bangladesh and other developing countries in Asia, manual transplanting of rice in puddled is conventional practice but relies on access to cheap readily-available labor. Besides being costly, cumbersome, and time consuming, puddling results in degradation of soil (Chauhan, 2012). The use of continuous puddling results in the formation of a hard pan with a consequent increase in bulk density and lowering of hydraulic conductivity below the plow layer (Singh et al., 2009). Although, tillage for rice establishment has significantly mechanized in Bangladesh, 16% -18% of the total production cost is involved in tillage and followed by leveling operation (BRRI, 2013). Puddling is done by repeated intensive tillage and leveling operation under ponded-water conditions, which help in controlling weeds by water stagnation in rice fields. Puddling is a rather extreme form of tillage because it results in aggregate breakdown and destruction of macrospores (Voase-Ringrose, 2000). Gupta et al. (2003) also stated that puddling destroys soil aggregates, breaks capillary pores, and disperses the soils leading to increased bulk density of surface layers. Puddling to a greater extent creates a detrimental effect on soil physical condition for the following crop in rice based cropping system (Hobbs and Morris, 1996). Puddling should be avoided to overcome the delayed practice for the following crops in rice based cropping system. Minimum tillage showed an advantage over puddling in a clay loam soil for maintaining physical condition and saving field preparation time (Brown and Quantrill, 1973).

Due to shortage of human labor, farmers are compelled to practice delayed transplanting which causes rice yield loss at the rate of 60.0, 55.4 and 9.6 kg per ha per day during the Boro (after January), Aus (after May) and Aman (after mid of August) seasons, respectively in Bangladesh (Satter, 1999). It is therefore essential to adopt the mechanical transplanter to ensure the timeliness in transplanting. Labor shortages for rice transplanting across Asia are stimulating interest in mechanical transplanting. Mechanical rice transplanting is being introduced in Bangladesh and gaining popularity through the different intervention of some Governmental and Non-governmental organization. While the transplanters have been evaluated in puddled soils, there is little understanding of their efficacy with transplanting into soils following minimum tillage such as zero tillage and strip tillage. Mechanical rice transplanter has problems of poor traction, sinkage and steerability in the wet field like all other wetland agricultural machinery. Since, mechanical 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 (skid). At the same time, the plow pan must not be too deep to provide necessary traction to propel the transplanter. Both traction and bearing capacity are dependent upon shear strength of the soil (Knight and Freitag, 1962). The non-puddled soil produced more traction and bearing capacity compared to puddled soil. Farmers of Bangladesh prepared to puddle the soil by 2 to 4 tillage operations followed by leveling which destroy the soil strength as well as plough pan. Weak soil strength and deeper plough pan hindered the speed of the rice transplanter, reduced the periphery of the driving wheel and also reduced the plant to plant distance from a set of spacing because of slippage. Excessive degree of puddling reduced the field performance of rice transplanter. On the other hand, excessive puddling takes longer sedimentation period to recover the soil strength.

Recently, the scarcity of, and competition for, water has been increasing worldwide. By 2025, the per capita available water resources in Asia are expected to decline by 15-54 percent compared with 1990's availability (Guerra et al., 1998). Despite the constraints of water scarcity, rice production and productivity must rise in order to address the growing demand for rice driven largely by population growth and rapid economic development in Asia. Producing more rice with less water is therefore a formidable challenge for achieving food, economic, social, and water security for the region (Facon, 2000). In fact, the majority of the world's rice is being produced under flooded, so-called lowland conditions. Rice grown under traditional practices in the Asian tropics and subtropics requires between 700-1500 mm of water per cropping season depending on soil texture (Bhuiyan, 1992). However, this conventional water management method leads to a high amount of surface runoff, seepage, and percolation that can account for between 50%-80% of the total water input (Sharma, 1989). Because of the combined increasing demand for food with the increasing scarcity of water, rice producers face three major challenges: (i) to save water; (ii) to increase productivity; and (iii) to produce more rice with less water (Bouman and Tuong, 2001). Technological progress in rice cultivation is crucial for sustaining food security in Bangladesh. This paper presents the results of different inundation periods under minimum tillage for mechanized cultivation.

To overcome the labor and water shortages that have emerged in recent years, mechanical transplanting of rice under minimum tillage is of considerable interest but little is known about the optimal inundation period for soils before transplanting. Therefore, in this study both farmers' participatory and research station-based experiments evaluated the performance of a mechanical rice transplanter (four rows walk-behind type rice transplanter, model DP480 and six rows riding type rice transplanter, model S3-680) at Bangladesh Rice Research Institute research farm, Gazipur and on a farmer's field at Kushtia and Rangpur, Bangladesh under minimum tillage options and varied inundation period during the irrigated season (Boro season) in 2012-2013 and 2013-14 with the following objectives.

**Objectives**

- To discover the best inundation period for non-puddled mechanized transplanting under different tillage options
- To evaluate the field performance of the rice transplanters under different tillage and inundation periods

## 2 Materials and methods

This study, both farmers' participatory and research station-based, was conducted to evaluate the performance of the mechanical rice transplanters at Bangladesh Rice Research Institute (BRRI) research farm, Gazipur (Latitude: 23°59'34.08" and Longitude: 90°24'27.55") and on a farmers' field at Kushtia (Latitude: 23°51'15.12" and Longitude: 89°14'30.12") and Rangpur (Latitude: 25°44'41.4960"N and Longitude: 89°16'32.1204"E), Bangladesh under minimum tillage option and varied inundation period during the Boro season in 2012-2013 and 2013-2014. Walking type rice transplanter (four rows, model DP480) was used except BRRI research farm, Gazipur during the Boro season in 2013-2014 where riding type rice transplanter (six rows, model S3-680) was used for seedling transplanting.

### 2.1 Experimental designs and treatments

Tillage treatments in a strip plot design were strip tillage (ST), zero tillage (ZT) and conventional tillage (CT) to main plots arranged in a randomized complete block design (RCBD) with three replications and the irrigation treatments as inundation periods (IP) before transplanting as sub-plots within each main plot were 12 ($IP_1$), 18 ($IP_2$) and 24 ($IP_3$) hrs.

### 2.2 Soil sample collections and analysis

A metal core (50 mm height and 49.8 mm diameter) was used to collect soil samples from 0-50 mm, 50-100 mm and 100-150 mm from three different places in the field to measure bulk density using the method described (Blake and Hartge, 1986). Soil samples were also collected from three different places at the depth of 0-150 mm to identify soil textural class, pH and organic matter. Soil of Gazipur, Kushtia and Rangpur experimental field is found as clay loam, loam and sandy loam textured with nearly neutral pH respectively (Table 1). Porosity and particle density were calculated using the formula described by Lowery et al. (1996). Textural class was determined by the USDA Soil Texture Triangle (Black, 1965).

**Table 1 Soil conditions of the experimental field (0-150 mm)**

| Characteristics | Gazipur | Kushtia | Rangpur |
|---|---|---|---|
| % of sand | 44.20 | 42.60 | 52.12 |
| % of clay | 28.75 | 24.84 | 19.52 |
| % of silt | 27.05 | 32.56 | 28.36 |
| Soil texture | Clay loam | Loam | Sandy loam |
| pH | 6.2 | 8.1 | 5.23 |
| Organic matter content, g $kg^{-1}$ | 19.4 | 17.5 | 16.8 |
| Bulk density, g $cc^{-1}$ | 1.22 | 1.32 | 1.40 |
| Particle density, g $cc^{-1}$ | 2.56 | 2.49 | 2.40 |
| Soil porosity, % | 0.48 | 0.53 | 0.58 |

## 2.3 General Information of the experiment

Each sub-plot size was 112.2 $m^2$ (22 m long and 5.1 m width) in Gazipur whereas it was 100.8 $m^2$ (21 m long and 4.8 m width) in Kushtia and 102.0 $m^2$ (20.4 m long and 5.0 m width) in the Rangpur. Variety of BRRI dhan28 was transplanted both the Boro seasons in 2012-13 and 2013-14. Experimental operations were conducted based on guideline of the selected variety (Table 2).

**Table 2 General information regarding experimental characteristics**

| Location | Variety | Date of seed sowing | Date of Transplanting | Date of harvesting |
|---|---|---|---|---|
| Boro/2012-13 | | | | |
| Gazipur | BRRI dhan28 | 10 Dec 2012 | 09 Jan 2013 | 05 May 2013 |
| Kushtia | BRRI dhan28 | 04 Dec 2012 | 30 Dec 2012 | 03 May 2013 |
| Rangpur | BRRI dhan29 | 05 Jan 2013 | 09 Feb 2013 | 14 June 2013 |
| Boro/2013-14 | | | | |
| Gazipur | BRRI dhan28 | 08 Dec 2013 | 30 Jan 2014 | 06 May 2014 |
| Kushtia | BRRI dhan28 | 26 Nov 2013 | 30 Dec 2013 | 29 April 2014 |
| Rangpur | BRRI dhan28 | 24 Dec 3013 | 17 Feb 2014 | 23 May 2014 |

## 2.4 Land preparation

Conventional tillage: Two rotary tillage passes by 2-wheal tractor (WT) in non-saturated soil were followed by saturation of the soil then one further wet rotary tillage pass (i.e. the puddling operation) and a final leveling.

Strip tillage: The Versatile Multi-crop Planter (VMP) machine was used to make strips by rotating blades prior to pre0irrigation for transplanting. Average dimensions of the tilled strips were: 80 mm width × 40 mm depth.

Zero tillage: Transplanting was done directly into undisturbed soil after 12, 18 and 24 hrs of inundation. In both seasons, 75-100 mm height of previous rice crop straw was maintained.

## 2.5 Soil resistance

A hand Penetrometer (Model: Ejkelkemo, Serial no. 27180909, Netherlands) was used to measure the soil penetration resistance of both the puddled and non-puddled soil before transplanting. The force was recorded in newton (N) from the gauge reading for 0-50 mm and 50-100 mm depths. Penetrometer readings were taken randomly at three places in each plot. Soil penetration resistance was calculated as MPa (1 Mpa = 100 N $cm^{-2}$) based on the surface area of the cone fitted.

## 2.6 Fuel consumption

Fuel consumption of the rice transplanter for transplanting operation was assessed during both the seasons. The fuel tank of the transplanter was filled before and after operations to determine the fuel use and duration of each operation was recorded. Fuel consumption was calculated as liter per hour (l $h^{-1}$) based on the volume of fuel required to refill the tank after operation (l) and time of operation (h).

## 2.7 Specifications of the rice transplanters

Walking type rice transplanter (WRT) was used except BRRI research farm, Gazipur during the Boro season in 2013-2014 where riding type rice transplanter (RRT) was used to conduct the study. Specification of the transplanters is presented in Table 3.

## 2.8 Transplanter setting during operation

There are three options to adjust plant to plant spacing in the rice transplanter (DP 480 and S3 680). The transplanter was set to maintain 150 mm distance between each hill and hill spacing between rows (line to line spacing) was 300 mm which a fixed for the rice transplanter. In the puddled field, the transplanting depth control lever was adjusted to the shallow mode whereas it was adjusted to the deeper mode in the non-puddled field to maintain 20-30 mm depth of seedling placement. The picker was set at point 5 (DP-480) and point 3 (S3-680) to maintain similar numbers of seedlings per hill in all tillage types.

**Table 3 Specifications of the walking and riding type rice transplanters (RT)**

| Description of items | | | | |
|---|---|---|---|---|
| Country of origin, model and type | | | South Korea (DP480) and walk behind | South Korea (S3-680) and ride on |
| | Type | | Walking type (WRT) | Riding type (RRT) |
| Dimensions | Overall length, width & height, mm | | 2385×1530×870 | 3120×2140×1655 |
| | Overall weight, kg | | 160 | 620 |
| | Type | | 4-strocke and air-cooled | 4-stroke and air-cooled |
| | Displacement (CC) | | 147 | 437 |
| | Maximum output kW/rpm | | 3/1800 | 10.5/3600 |
| | Fuel tank capacity, L | | 3.4 | 15-20 |
| | Starting method | | Recoil | Electric motor |
| Traveling Section | Steering | | Hydraulic power steering mode | Hydraulic power steering mode |
| | | Rear | Rubber lug wheel | Solid rubber |
| | Gearshift | Forward | 2 speeds | 2 speeds |
| | | Reverse | 1 speed | 1 speed |
| Transplanting Section | Transplanting mechanism | | Rotary | Rotary type |
| | Number of rows | | 4 | 6 |
| | Row to row distance, mm | | 300 | 300 |
| | Plant to plant distance, mm | | 110, 130, 150 | 140, 160, 180, 200 |
| | Planting pitch control | | Adjustable | Adjustable |
| | Planting depth control | | Adjustable | Adjustable |
| | Planting depth, cm | | 0.8-4.4 | 0.8-4.4 |
| | No. of seedling rack (No.) | | 4 | 6 |
| | Transplanting speed, m $s^{-1}$ | | 0.6 to 1.0 | 0 to 1.36 |

### 2.9 Transplanter performances

Field capacity of the rice transplanter was calculated as hectors per hour (ha $h^{-1}$) based on the area covered per unit time. Rice transplanter turning time during field operation, seedling feeding time, operator's personal time, adjustment time etc. were summed to calculate the actual field capacity of rice transplanter, which is transplanting area covered (ha) divided by the time of operation (h). Transplanting data regarding missing, damaged, floating and buried hills were counted from 1.2 $m^2$ (1.2 × 1.04 m) per plot in both the Boro seasons.

### 2.10 Statistical Analysis

Data were analyzed as a two-way factorial design (three tillage × three inundation periods) according to Gomez and Gomez (1984) using Crop Stat 7.2 software (IRRI, 2007). Means were compared with the least significant difference (LSD) test using Statistix 10 program (Statistix 10 software, 2013). Simple correlation analysis was carried out with Excel to determine the relationship of grain yield to yield attributes.

## 3 Results

### 3.1 Soil resistance before transplanting

Soil penetration resistance before transplanting responded to the interaction of tillage × inundation period in 0 to 50 mm depth in CLS and LS and 50 to 100 mm depth in SLS during the Boro/2012-2013 seasons (Table 4). Tillage showed significant effect on soil penetration resistance irrespective of depth and soil types except LS and CLS in 50-100 mm depth during the Boro/2012-2013 and 2013-2014 seasons, respectively. However, inundation period showed a significant effect on soil penetration resistance only in SLS and LS in 50-100 mm depth during the Boro/2012-2013 and 2013-2014 seasons, respectively while it was decreased with the increased of inundation period irrespective of seasons and soil types except CT and ST in CLS and LS during the Boro/2012-2013 seasons, respectively. It might be the causes of soil type, texture, amount of clay and soil settlement. Soil penetration resistance varied largely with moisture content, texture, type and amount of clay and the arrangements of particles in the soil matrix (Bhagat, 2003). Minimum tillage (ST and ZT) gave higher soil penetration resistance to 0-50 mm depth compared to CT irrespective of soil types and seasons whereas it was inconsistent in 50-100 mm depth. This result is coincided with the finding of Carman (1997) and Martinez et al. (2008) where minimum tillage gave higher soil resistance compared to CT at the soil surface. Among three soil types, LS gave lower soil resistance compared to CLS and SLS under different tillage and inundation period because of particle arrangement and less compacted soil. Traction development by the rice transplanter is directly related to soil resistance and depth of the hard surface of plough pan (Behera et al., 2009).

**Table 4 Soil penetration resistance (MPa) during transplanting as affected under different tillage options and inundation period**

| Soil | Treat | 50 mm depth | | | | 100 mm depth | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $IP_{12}$ | $IP_{18}$ | $IP_{24}$ | Mean | $IP_{12}$ | $IP_{18}$ | $IP_{24}$ | Mean |
| **Boro/2012-13** | | | | | | | | | |
| CLS | ST | 0.16 | 0.13 | 0.10 | 0.13 | 0.20 | 0.15 | 0.16 | 0.17 |
| | ZT | 0.19 | 0.16 | 0.14 | 0.16 | 0.23 | 0.22 | 0.20 | 0.21 |
| | CT | 0.07 | 0.09 | 0.12 | 0.09 | 0.16 | 0.16 | 0.18 | 0.17 |
| | Mean | 0.14 | 0.13 | 0.12 | - | 0.20 | 0.18 | 0.18 | - |
| | $LSD_{0.05}$ | T=0.016 and T × IP=0.03 | | | | T=0.02 | | | |
| LS | ST | 0.04 | 0.07 | 0.08 | 0.06 | 0.35 | 0.41 | 0.31 | 0.35 |
| | ZT | 0.07 | 0.05 | 0.04 | 0.05 | 0.21 | 0.17 | 0.33 | 0.24 |
| | CT | 0.06 | 0.04 | 0.06 | 0.05 | 0.32 | 0.28 | 0.22 | 0.27 |
| | Mean | 0.05 | 0.05 | 0.06 | - | 0.29 | 0.28 | 0.29 | - |
| | $LSD_{0.05}$ | T × IP=0.03 | | | | - | | | |
| | CV | 27.48 | | | | 73.08 | | | |
| SLS | ST | 0.16 | 0.16 | 0.21 | 0.18 | 0.45 | 0.33 | 0.36 | 0.38 |
| | ZT | 0.20 | 0.15 | 0.10 | 0.15 | 0.42 | 0.26 | 0.25 | 0.31 |
| | CT | 0.05 | 0.05 | 0.04 | 0.05 | 0.08 | 0.04 | 0.02 | 0.05 |
| | Mean | 0.14 | 0.12 | 0.12 | - | 0.32 | 0.21 | 0.21 | - |
| | $LSD_{0.05}$ | T=0.06 | | | | T=0.85 and IP=0.085 | | | |
| **Boro/2013-14** | | | | | | | | | |
| CLS | ST | 0.22 | 0.24 | 0.21 | 0.22 | 0.25 | 0.26 | 0.22 | 0.24 |
| | ZT | 0.23 | 0.23 | 0.21 | 0.22 | 0.24 | 0.22 | 0.21 | 0.23 |
| | CT | 0.20 | 0.14 | 0.15 | 0.17 | 0.30 | 0.24 | 0.24 | 0.26 |
| | Mean | 0.22 | 0.20 | 0.19 | - | 0.26 | 0.24 | 0.22 | - |
| | $LSD_{0.05}$ | T=0.04 | | | | - | | | |
| LS | ST | 0.09 | 0.08 | 0.05 | 0.07 | 0.17 | 0.14 | 0.17 | 0.16 |
| | ZT | 0.04 | 0.04 | 0.05 | 0.04 | 0.10 | 0.15 | 0.17 | 0.14 |
| | CT | 0.03 | 0.04 | 0.04 | 0.04 | 0.18 | 0.16 | 0.12 | 0.15 |
| | Mean | 0.05 | 0.05 | 0.04 | - | 0.15 | 0.15 | 0.15 | - |
| | $LSD_{0.05}$ | T=0.02 | | | | T=0.11, IP=0.04 | | | |
| SLS | ST | 0.17 | 0.10 | 0.13 | 0.13 | 0.42 | 0.39 | 0.40 | 0.41 |
| | ZT | 0.08 | 0.10 | 0.08 | 0.09 | 0.33 | 0.32 | 0.27 | 0.31 |
| | CT | 0.04 | 0.04 | 0.03 | 0.04 | 0.30 | 0.23 | 0.26 | 0.26 |
| | Mean | 0.10 | 0.08 | 0.08 | - | 0.35 | 0.31 | 0.31 | - |
| | $LSD_{0.05}$ | T=0.034 | | | | T=0.10 | | | |

Note: CLS-Clay loam soil, LS-Loam soil, SLS-Sandy loam soil, T-Tillage options, ST-Strip tillage, ZT-Zero tillage, CT-Conventional tillage, $IP_{12}$-12 hrs inundation period, $IP_{18}$-18 hrs inundation period and $IP_{24}$-24 hrs inundation period.

## 3.2 Field capacity of the rice transplanter

Field capacity of the rice transplanter responded significantly to the two-way interaction of tillage and inundation period and to the single effect of inundation period only in SLS during Boro/2013-2014 season (Table 5). In CLS, walking type rice transplanter (WRT) gave 20% to 21% higher field capacity under minimum tillage conditions compared to CT while field capacity of riding type rice transplanter (RRT) was similar irrespective of tillage options. In LS, CT gave higher field capacity compared to ZT and ST during Boro/2012-13 season whereas ST gave 7.5% higher field capacity compared to CT during Boro/2013-14 season. On the contrary, CT provided less field capacity in CLS compared to LS and SLS because rice transplanter frequently overloaded during field operation due to the absence of plough pan and less soil resistance in SLS. Averaged for two seasons, ST gave higher field capacity for 18 hrs inundation periods irrespective of soil types whereas ZT gave more for 24, 18 and 24 hrs inundation periods in CLS, LS and SLS respectively. Contrary to, CT gave higher field capacity for 24, 12 and 18 hrs inundation periods in CLS, LS and SLS, respectively. However, minimum tillage (ST and ZT) showed higher field capacity only in CLS whereas CT demonstrated more in LS and SLS. It might be the causes of a hard plow pan and a soft puddled surface soil which increased the mobility of rice transplanter float.

**Table 5 Field capacity (ha $h^{-1}$) of rice transplanter as affected by tillage options and inundation period**

| Soil | Treat | Boro/2012-13 | | | | Boro/2013-14 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $IP_{12}$ | $IP_{18}$ | $IP_{24}$ | Mean | $IP_{12}$ | $IP_{18}$ | $IP_{24}$ | Mean |
| CLS | ST | 0.160 | 0.105 | 0.120 | 0.128 | 0.203 | 0.228 | 0.210 | 0.214 |
| | ZT | 0.143 | 0.106 | 0.133 | 0.127 | 0.195 | 0.241 | 0.234 | 0.223 |
| | CT | 0.106 | 0.112 | 0.099 | 0.106 | 0.185 | 0.246 | 0.211 | 0.214 |
| | Mean | 0.136 | 0.107 | 0.117 | - | 0.194 | 0.238 | 0.218 | - |
| | $LSD_{0.05}$ | -. | | | | - | | | |
| LS | ST | 0.112 | 0.110 | 0.102 | 0.108 | 0.122 | 0.142 | 0.122 | 0.129 |
| | ZT | 0.125 | 0.114 | 0.097 | 0.112 | 0.121 | 0.137 | 0.109 | 0.122 |
| | CT | 0.160 | 0.124 | 0.121 | 0.135 | 0.118 | 0.130 | 0.112 | 0.120 |
| | Mean | 0.132 | 0.116 | 0.107 | - | 0.120 | 0.136 | 0.114 | - |
| | $LSD_{0.05}$ | - | | | | - | | | |
| SLS | ST | 0.107 | 0.133 | 0.098 | 0.112 | 0.117 | 0.138 | 0.124 | 0.126 |
| | ZT | 0.100 | 0.131 | 0.137 | 0.123 | 0.115 | 0.125 | 0.134 | 0.125 |
| | CT | 0.123 | 0.138 | 0.131 | 0.131 | 0.123 | 0.142 | 0.126 | 0.131 |
| | Mean | 0.110 | 0.134 | 0.122 | - | 0.119 | 0.135 | 0.128 | - |
| | $LSD_{0.05}$ | - | | | | IP=0.006 and T ×IP=0.011 | | | |

Note: CLS-Clay loam soil, LS-Loam soil, SLS-Sandy loam soil, T-Tillage options, ST-Strip tillage, ZT-Zero tillage, CT-Conventional tillage, $IP_{12}$-12 hrs inundation period, $IP_{18}$-18 hrs inundation period and $IP_{24}$-24 hrs inundation period. Field capacity of RRT is presented under CLS during Boro/2013-14.

Average of two seasons and three soil types, ST, ZT and CT tillage gave higher field capacity at 18 hrs inundation period followed by 12 hrs. Averaged of three tillage options, 18 hrs inundation periods gave higher field capacity during Boro/2013-14 season whereas 12 hrs inundations were not enough to make the soil softer enough in SLS. As a result, rice transplanter vibrated during field operation. Contrary to, 24 hrs inundations made the soil too soft in the same soil type. It was also observed that the field capacity of the rice transplanter related inversely with the soil penetration resistance up to 50 mm depth in CLS, LS and SLS. Kumar et al., (2012) reported that the soil penetration resistance is directly related to the inundation period and 12-24 hrs of inundation is necessary for successful non-puddled mechanical transplanting. Behera and Varshney (2003) also studied the correlation between puddling and mobility of the transplanter and found they are inversely proportional.

### 3.3 Fuel consumption for mechanical transplanting of rice

Fuel consumption of the rice transplanter varied significantly with the interaction of tillage × inundation period only in SLS during both the seasons (Table 6). In SLS, significantly higher volume of fuel (4.9 to 5.4 L ha$^{-1}$) was required in CT for 12 hrs inundation whereas significantly lower in ZT (3.1 to 3.7 L ha$^{-1}$) for 24 hrs inundation irrespective of seasons. Averaged of two seasons, minimum tillage saved 8% to 13% fuel requirement compared to CT whereas it was decreased with the increased of inundation periods. In CLS, tillage showed a significant effect on fuel consumption during Boro/2012-13 season and CT consumed 21% to 29% compared to ZT and ST during Boro/2012-13 season. Fuel consumption of RRT in CLS was varied significantly only with the inundation periods and 12 hrs inundation consumed significantly higher volume of fuel (11.7 L ha$^{-1}$) compared to the 18 hrs inundations (8.7 L ha$^{-1}$). In LS, fuel consumption did not response significantly to the interaction of tillage × inundation period as well as to the single effect of tillage and inundation period.

Rate of fuel consumption is inversely related with the field capacity of the same machine if other factors remain same. Fuel consumption of the rice transplanter in ST and ZT was found less compared to CT because of minimum load association, more traction development and ease of mobility during operation in CLS and SLS. In LS, it was reversed because of hard plough pan and soft surface soil that help the mobility of the transplanter operation under CT. Inundation period was found inconsistency in fuel consumption during the two seasons under three soil types. Kumar et al. (2012) noted that mechanical transplanting of rice in non-puddled conditions saved 72& transplanting cost including all related cost of machine operations. Raper et al. (1994) also stated that minimum tillage decreased the input costs for labor, fuel, tractors, and other equipment.

**Table 6 Fuel consumption (L ha$^{-1}$) for rice transplanter operation as affected by tillage options and inundation period**

| Soil | Treat | Boro/2012-13 | | | | Boro/2013-14 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $IP_{12}$ | $IP_{18}$ | $IP_{24}$ | Mean | $IP_{12}$ | $IP_{18}$ | $IP_{24}$ | Mean |
| CLS | ST | 3.6 | 5.1 | 4.4 | 4.4 | 10.1 | 8.7 | 9.4 | 9.4 |
| | ZT | 4.5 | 5.4 | 4.9 | 4.9 | 12.1 | 9.1 | 9.8 | 10.3 |
| | CT | 6.3 | 5.8 | 6.5 | 6.2 | 12.9 | 8.4 | 11.8 | 11.0 |
| | Mean | 4.8 | 5.4 | 5.3 | - | 11.7 | 8.7 | 10.3 | - |
| | $LSD_{0.05}$ | T=1.16 | | | | IP=2.3 | | | |
| LS | ST | 5.0 | 5.7 | 4.9 | 5.2 | 5.0 | 5.0 | 6.0 | 5.3 |
| | ZT | 4.9 | 5.9 | 6.1 | 5.7 | 3.6 | 4.0 | 4.7 | 4.1 |
| | CT | 4.2 | 4.4 | 4.1 | 4.2 | 6.1 | 5.9 | 5.6 | 5.9 |
| | Mean | 4.7 | 5.3 | 5.0 | - | 4.9 | 5.0 | 5.4 | - |
| | $LSD_{0.05}$ | - | | | | - | | | |
| SLS | ST | 4.2 | 4.7 | 4.4 | 4.4 | 4.3 | 3.9 | 3.9 | 4.1 |
| | ZT | 4.4 | 3.8 | 3.1 | 3.8 | 4.5 | 4.4 | 3.7 | 4.2 |
| | CT | 4.9 | 4.1 | 4.3 | 4.4 | 5.4 | 4.3 | 4.6 | 4.8 |
| | Mean | 4.5 | 4.2 | 3.9 | - | 4.8 | 4.2 | 4.1 | - |
| | $LSD_{0.05}$ | T=1.9, IP=1.4 and T×IP=2.5 | | | | T=0.22, IP=0.22 and T×IP=0.38 | | | |

Note: CLS-Clay loam soil, LS-Loam soil, SLS-Sandy loam soil, T-Tillage options, ST-Strip tillage, ZT-Zero tillage, CT-Conventional tillage, $IP_{12}$-12 hrs inundation period, $IP_{18}$-18 hrs inundation period and $IP_{24}$-24 hrs inundation period. Fuel consumption of RRT is presented under CLS during Boro/2013-14 only.

### 3.4 Transplanting performance

Transplanting performance of the mechanical rice transplanter was measured in terms of percentage of total missing hills, missing parameters as picker missing hills, floating hills, buried hills and mechanical damage hills.

### 3.5 Total percentage of missing hills

The total numbers of missing hills depend on transplanter failure to pick and place the seedling in all hills, damaged hills, floated hills and buried hills. Number of hills per unit area varied significantly with the interaction of tillage × inundation period only in SLS during the season of Boro/2013-14 while ZT for 12 hrs and 18 hrs, ST for 12 hrs and CT for 18 hrs inundation periods gave significantly higher percentage of missing hills (Table 7). However, significantly lower percentage of missing hills was observed for 18, 24 and 12 hrs inundation periods in ST, ZT and CT, respectively. On the contrary, tillage and inundation periods showed significant effect irrespective of soil types and seasons. Averaged of the two seasons and three soil types, minimum percentage of missing hills was observed in ST (9.7%) compared to ZT (13.0%) and CT (10.7%) while percentage of missing hills decreased from 13.7% to 9.2% with the increased of inundation period from 12 to 24 hrs because surface soil of ZT and ST field became soft and soil of CT plot became settlement down enough to reduce floating and buried hills and to reduce the damage and picker missing hills. Munnaf et al. (2014) observed 10.33% of total missing hills for the Kukje self-propelled rice transplanter under conventional tillage. Alizadeh et al. (2011) reported that the missing hills decreased from 13% to 8% with increasing seeding rate from 60 to 100 g per tray (tray size: 280×580×25 mm). Hossen et al. (2014) found that 140 g of seed/tray for bold grain, 130 g/tray for medium and slender grain and 120 g $tray^{-1}$ for extra-long and slender paddy were suitable for minimizing the missing hills and for optimum number of seedlings per hill under different seedling adjustment options for the present transplanter.

**Table 7 Percentage of missing hills as affected by tillage options and inundation period**

| Soil | Treat | Boro/2012-13 | | | | Boro/2013-14 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $IP_{12}$ | $IP_{18}$ | $IP_{24}$ | Mean | $IP_{12}$ | $IP_{18}$ | $IP_{24}$ | Mean |
| CLS | ST | 12.5 | 11.5 | 6.3 | 10.1 | 11.1 | 5.6 | 6.7 | 7.8 |
| | ZT | 16.7 | 10.4 | 9.4 | 12.2 | 14.4 | 11.1 | 10.0 | 11.9 |
| | CT | 13.5 | 8.3 | 7.3 | 9.7 | 11.1 | 10.0 | 7.8 | 9.6 |
| | Mean | 14.2 | 10.1 | 7.6 | - | 12.2 | 8.9 | 8.2 | - |
| | $LSD_{0.05}$ | T=2.25 and IP=3.00 | | | | T=2.31 and IP=2.31 | | | |
| LS | ST | 13.1 | 5.9 | 11.9 | 10.3 | 11.9 | 7.1 | 10.7 | 9.9 |
| | ZT | 20.2 | 15.5 | 11.9 | 15.9 | 15.5 | 13.1 | 10.7 | 13.1 |
| | CT | 16.7 | 15.5 | 11.9 | 14.7 | 11.9 | 10.7 | 9.5 | 10.7 |
| | Mean | 16.7 | 12.3 | 11.9 | - | 13.1 | 10.3 | 10.3 | - |
| | $LSD_{0.05}$ | T=3.06 and IP=3.06 | | | | T=1.97 and IP=1.97 | | | |
| SLS | ST | 13.1 | 10.7 | 7.1 | 10.3 | 14.3 | 4.8 | 9.5 | 9.5 |
| | ZT | 15.5 | 14.3 | 9.5 | 13.1 | 15.5 | 13.1 | 7.1 | 11.9 |
| | CT | 11.9 | 10.7 | 8.3 | 10.3 | 7.1 | 10.7 | 9.5 | 9.1 |
| | Mean | 13.5 | 11.9 | 8.3 | - | 12.3 | 9.5 | 8.7 | - |
| | $LSD_{0.05}$ | T=1.61 and IP=1.61 | | | | T=2.15, IP=2.37 and T×IP=4.10 | | | |

Note: CLS-Clay loam soil, LS-Loam soil, SLS-Sandy loam soil, T-Tillage options, ST-Strip tillage, ZT-Zero tillage, CT-Conventional tillage, $IP_{12}$-12 hrs inundation period, $IP_{18}$-18 hrs inundation period and $IP_{24}$-24 hrs inundation period.

## 3.6 Missing parameters

Missing hill parameters as picker missing hills, damage hills, floating hills and buried hills affected under different tillage options and inundation periods are presented in Table 8 and Table 9 for Boro/2012-13 and Boro/2013-14 seasons, respectively.

### 3.6.1 Picker missing hills

Picker missing responded significantly only with the inundation periods in SLS and CLS during the Boro season of 2012-13 and 2013-14, respectively (Table 8). Averaged of the two seasons and three soil types, percentage of picker missing hills was counted 3.2%, 4.3% and 3.1% for ST, ZT and CT whereas it was 4.1%, 3.6% and 2.9% for 12, 18 and 24 hrs inundation periods, respectively. The highest percentage of picker missing hills was observed for 12 hrs inundation periods irrespective of soil types and seasons except LS during Boro/2013-14 season. However, 24 hrs for CLS, 18 hrs for LS and 24 hrs for SLS gave minimum percentage of picker missing hills.

**Table 8 Effect of tillage and inundation period on percentage of missing parameters during Boro/2012-13 season**

| Treat | CLS | | | | LS | | | | SLS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $IP_{12}$ | $IP_{18}$ | $IP_{24}$ | Mean | $IP_{12}$ | $IP_{18}$ | $IP_{24}$ | Mean | $IP_{12}$ | $IP_{18}$ | $IP_{24}$ | Mean |
| **Percentage of picker missing** | | | | | | | | | | | | |
| ST | 3.1 | 3.1 | 2.1 | 2.8 | 3.6 | 2.4 | 4.8 | 3.6 | 4.8 | 3.6 | 2.4 | 3.6 |
| ZT | 4.2 | 2.1 | 3.1 | 3.1 | 7.1 | 6.0 | 4.8 | 6.0 | 7.1 | 4.8 | 1.2 | 4.4 |
| CT | 3.1 | 2.1 | 3.1 | 2.8 | 4.8 | 4.8 | 3.6 | 4.4 | 1.2 | 4.8 | 1.2 | 2.4 |
| Mean | 3.5 | 2.4 | 2.8 | - | 5.2 | 4.4 | 4.4 | - | 4.4 | 4.4 | 1.6 | - |
| $LSD_{0.05}$ | - | | | | - | | | | IP=1.8 | | | |
| **Percentage of damage hills** | | | | | | | | | | | | |
| ST | 4.2 | 2.1 | 3.1 | 3.1 | 2.4 | 0.0 | 1.2 | 1.2 | 2.4 | 3.6 | 2.4 | 2.8 |
| ZT | 4.2 | 2.1 | 3.1 | 3.1 | 3.6 | 4.8 | 1.2 | 3.2 | 2.4 | 3.6 | 4.8 | 3.6 |
| CT | 2.1 | 3.1 | 2.1 | 2.4 | 3.6 | 0.0 | 1.2 | 1.6 | 2.4 | 1.2 | 1.2 | 1.6 |
| Mean | 3.5 | 2.4 | 2.8 | 2.9 | 3.2 | 1.6 | 1.2 | 2.0 | 2.4 | 2.8 | 2.8 | 2.6 |
| $LSD_{0.05}$ | - | | | | - | | | | - | | | |
| **Percentage of floating hills** | | | | | | | | | | | | |
| ST | 4.2 | 5.2 | 1.0 | 3.5 | 7.1 | 3.6 | 4.8 | 5.2 | 4.8 | 3.6 | 2.4 | 3.6 |
| ZT | 8.3 | 5.2 | 3.1 | 5.6 | 7.1 | 4.8 | 6.0 | 6.0 | 6.0 | 6.0 | 3.6 | 5.2 |
| CT | 1.0 | 0.0 | 0.0 | 0.3 | 3.6 | 4.8 | 1.2 | 3.2 | 2.4 | 2.4 | 0.0 | 1.6 |
| Mean | 4.5 | 3.5 | 1.4 | 3.1 | 6.0 | 4.4 | 4.0 | 4.8 | 4.4 | 4.0 | 2.0 | 3.4 |
| $LSD_{0.05}$ | T=2.7 and IP=1.4 | | | | T=2.2 and IP=2.2 | | | | T=1.4 and IP=1.8 | | | |
| **Percentage of buried hills** | | | | | | | | | | | | |
| ST | 1.0 | 1.0 | 0.0 | 0.7 | 0.0 | 0.0 | 1.2 | 0.4 | 1.2 | 0.0 | 0.0 | 0.4 |
| ZT | 0.0 | 1.0 | 0.0 | 0.3 | 2.4 | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| CT | 7.3 | 3.1 | 2.1 | 4.2 | 4.8 | 6.0 | 6.0 | 5.6 | 6.0 | 6.0 | 2.4 | 4.8 |
| Mean | 2.8 | 1.7 | 0.7 | 1.7 | 2.4 | 2.0 | 2.4 | 2.2 | 2.4 | 2.0 | 0.8 | 1.7 |
| $LSD_{0.05}$ | T=1.0 and IP=1.4 | | | | T=3.9 and T×IP=4.6 | | | | T=2.6, IP=0.9, T×IP=2.9 | | | |

Note: CLS-Clay loam soil, LS-Loam soil, SLS-Sandy loam soil, T-Tillage options, ST-Strip tillage, ZT-Zero tillage, CT-Conventional tillage, $IP_{12}$-12 hrs inundation period, $IP_{18}$-18 hrs inundation period and $IP_{24}$-24 hrs inundation period.

### 3.6.2 Damage hills

Damage hills varied significantly only with the tillage options in CLS and SLS during the Boro/2013-14 season where ZT demonstrated significantly higher percentage of damage hills (Table 9). Averaged of the two seasons and three soil types, ST, ZT and CT reported 1.8%, 2.8% and 1.3% of damage hills, respectively. However, 12 hrs inundation periods demonstrated a higher percentage of damage hills (2.4%) followed by 24 hrs (1.8%) while it was lower for 18 hrs inundation period (1.7%).

**Table 9 Effect of tillage and inundation period on percentage of missing parameters during Boro/2013-14 season**

| Treat | CLS | | | | LS | | | | SLS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $IP_{12}$ | $IP_{18}$ | $IP_{24}$ | Mean | $IP_{12}$ | $IP_{18}$ | $IP_{24}$ | Mean | $IP_{12}$ | $IP_{18}$ | $IP_{24}$ | Mean |
| Percentage of picker missing | | | | | | | | | | | | |
| ST | 5.6 | 3.3 | 1.1 | 3.3 | 2.4 | 1.2 | 3.6 | 2.4 | 4.8 | 1.2 | 3.6 | 3.2 |
| ZT | 4.4 | 4.4 | 2.2 | 3.7 | 2.4 | 3.6 | 4.8 | 3.6 | 4.8 | 6.0 | 3.6 | 4.8 |
| CT | 3.3 | 2.2 | 2.2 | 2.6 | 2.4 | 3.6 | 2.4 | 2.8 | 3.6 | 4.8 | 2.4 | 3.6 |
| Mean | 4.4 | 3.3 | 1.9 | - | 2.4 | 2.8 | 3.6 | - | 4.4 | 4.0 | 3.2 | - |
| $LSD_{0.05}$ | IP=1.7 | | | | - | | | | - | | | |
| Percentage of damage hills | | | | | | | | | | | | |
| ST | 1.1 | 0.0 | 2.2 | 1.1 | 2.4 | 1.2 | 2.4 | 2.0 | 1.2 | 0.0 | 0.0 | 0.4 |
| ZT | 3.3 | 2.2 | 1.1 | 2.2 | 3.6 | 2.4 | 2.4 | 2.8 | 2.4 | 2.4 | 0.0 | 1.6 |
| CT | 2.2 | 0.0 | 0.0 | 0.7 | 0.0 | 1.2 | 2.4 | 1.2 | 0.0 | 0.0 | 1.2 | 0.4 |
| Mean | 2.2 | 0.7 | 1.1 | - | 2.0 | 1.6 | 2.4 | - | 1.2 | 0.8 | 0.4 | - |
| $LSD_{0.05}$ | T=0.8 | | | | - | | | | T=0.01 | | | |
| Percentage of floating hills | | | | | | | | | | | | |
| ST | 4.4 | 2.2 | 1.1 | 2.6 | 6.0 | 3.6 | 4.8 | 4.8 | 7.1 | 3.6 | 4.8 | 5.2 |
| ZT | 5.6 | 4.4 | 6.7 | 5.6 | 7.1 | 6.0 | 3.6 | 5.6 | 8.3 | 4.8 | 3.6 | 5.6 |
| CT | 0.0 | 2.2 | 1.1 | 1.1 | 1.2 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 2.4 | 0.8 |
| Mean | 3.3 | 3.0 | 3.0 | - | 4.8 | 3.2 | 2.8 | - | 5.2 | 2.8 | 3.6 | - |
| $LSD_{0.05}$ | T=1.3 | | | | T=3.1 and IP=1.6 | | | | T=4.2 and T×IP=2.9 | | | |
| Percentage of buried hills | | | | | | | | | | | | |
| ST | 0.0 | 0.0 | 2.2 | 0.7 | 1.2 | 1.2 | 0.0 | 0.8 | 1.2 | 0.0 | 1.2 | 0.8 |
| ZT | 1.1 | 0.0 | 0.0 | 0.4 | 2.4 | 1.2 | 0.0 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| CT | 5.6 | 5.6 | 4.4 | 5.2 | 8.3 | 6.0 | 4.8 | 6.3 | 3.6 | 6.0 | 3.6 | 4.4 |
| Mean | 2.2 | 1.9 | 2.2 | - | 4.0 | 2.8 | 1.6 | - | 1.6 | 2.0 | 1.6 | - |
| $LSD_{0.05}$ | T=2.5 | | | | T=1.6 | | | | T=1.8 | | | |

Note: CLS-Clay loam soil, LS-Loam soil, SLS-Sandy loam soil, T-Tillage options, ST-Strip tillage, ZT-Zero tillage, CT-Conventional tillage, $IP_{12}$-12 hrs inundation period, $IP_{18}$-18 hrs inundation period and $IP_{24}$-24 hrs inundation period.

### 3.6.3 Floating hills

The two-way interaction of tillage × inundation period demonstrated significant effect on percentage of floating hills only in SLS during Boro/2013-14 season where significantly higher percentage of floating hills was observed for 12 hrs inundation periods in ZT (8.3%) and ST (7.1%). Floating hills was not observed for 12 and 18 hrs inundation periods in CT. Floating hills responded significantly with the tillage options irrespective of seasons and soil types where significantly higher percentage was observed in ZT followed by ST. Inundation period also showed a significant effect on floating hills irrespective of seasons and soil types except CLS during Boro/2013-14 season. Floating hills decreased with the increased of inundation period irrespective of soil types and seasons. Significantly higher percentage of floating hills was observed for 12 hrs and lower for 24 hrs inundation periods. Indeed, average of two seasons and three soil types ST, ZT and CT reported 4.2%, 5.6% and 1.2% of floating hills, respectively. However, 12, 18 and 24 hrs inundation periods reported 4.7%, 3.4% and 2.8% of floating hills, respectively.

### 3.6.4 Buried hills

Buried hills responded significantly to the two-way interaction of tillage × inundation period in LS and SLS during the Boro/2012-13 seasons whereas tillage demonstrated significant effect irrespective of seasons and soil types. However, it was varied significantly with the inundation periods in CLS and SLS during Boro/2012-13 season. The highest percentage of missing hills was observed in CT irrespective of seasons and soil types. Averaged of the two seasons and three soil types, ST, ZT and CT tillage reported 0.6%, 0.5% and 5.1% of buried hills, respectively. The highest percentages of buried hills were also observed for 12 hrs inundation periods (2.6%) while the lowest for 24 hrs inundation period (1.6%) over two seasons and three soil types.

Missing hills are the sum of rotary picker missing, buried, floating and damaged hills missing. Irrespective of soil types, ZT demonstrated more missing hills during both the seasons because of more floating hills. Contrary to, less missing hills were observed in ST. In ZT, hole created by the rotary picker of the transplanter was not re-filled by mud or loosed soil after seedling placement resulting more floating hills due to un-griped seedling in the field. Optimum inundation period might be the provable solution to reduce floating hills under minimum tillage. ST demonstrated less buried and floating hills compared to CT and ZT as a result minimum missing hills in ST. However, seedling placement hole re-filled by soil-mud resulting less floating hills and water-soil mud pool is not created by the skid of transplanter resulting less buried hills. In CT, water-soil mud pool created by the skid of transplanter during transplanter operation consequently hills of the adjacent transplanted lines buried into the soil. Depth of transplanting in CT due to sinkage of float might be another cause of buried hills. Buried hills might be reduced by sufficient settlement of soil after final preparation of the land. Mufti and Khan (1995) reported that missing hill mostly depends upon the seedling density and its uniformity in the mat.

### 3.7 Yield performance

Yield performance was measured in terms of grain and straw yield described as follows.

#### 3.7.1 Grain yield

Grain yield varied significantly with the two-way interaction of tillage × inundation period in SLS during the both seasons where ST for 18 hrs and ZT for 24 hrs inundation period gave significantly higher grain yield (Table 10). Inundation periods showed a significant effect on grain yield irrespective of soil types and seasons while 24 hrs inundation periods gave significantly higher yield which was statistically similar with 18 hrs inundation period except SLS during Boro/2013-14 season. However, tillage showed a significant effect in LS and SLS during Boro/2012-13 season. In LS, ST and CT gave significantly higher yield compared to ZT during Boro/2012-13 season. On the contrary, ST gave significantly higher yield compared to ZT and CT during the same season in SLS. Indeed, ST, ZT and CT gave higher yield for 18 (6.1 t $ha^{-1}$), 24 (6.0 t $ha^{-1}$) and 24 hrs (5.9 t $ha^{-1}$) inundation periods respectively over the soil types and seasons.

ST gave higher grain yield of rice compared to ZT and CT in irrespective of seasons and soil types except CLS during Boro 2012-13 seasons where ZT gave higher yield. De Datta et. al. (1979), Rodriguez and Lal (1979) reported that ZT and minimum tillage systems produced rice grain yield similar to the conventional tillage. It has also been reported that in clay soil, minimum tillage produced the similar grain yield as through conventional tillage (Sharma et al 1988). Haque et al. (2014) noticed significantly higher rice grain yield (6.00 t/ha) attained from ST compared to CT during the Boro 2012-13 season in 29 on-farm demonstration sites in different locations of Bangladesh. Bajpai et al. (2000) found equally effective for grain yield of rice in both puddling and non-puddling condition. However, non-puddling of rice produced significantly higher wheat grain yield than that of wheat followed by puddled rice. There have been no significant differences between 18 and 24 hrs inundation periods. ZT and ST showed better performance under 24 and 18 hrs inundation periods, respectively where CT showed inconsistent performance in both 18 and 24 hrs inundations. This result is directly related with the transplanter performance because transplanter mostly showed better performance in ST, ZT and CT for 18, 24 and 18/24 hrs inundation periods in terms of hills per unit area, plant to plant distance, number of plants per hill and missing parameters (all data are not shown in the text).

**Table 10 Field grain yield (t $ha^{-1}$ at 14% mc) as affected under different tillage options and inundation period**

| Soil | Treat | Boro/2012-13 | | | | Boro/2013-14 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $IP_{12}$ | $IP_{18}$ | $IP_{24}$ | Mean | $IP_{12}$ | $IP_{18}$ | $IP_{24}$ | Mean |
| CLS | ST | 4.7 | 5.1 | 5.3 | 5.0 | 5.4 | 5.9 | 5.7 | 5.7 |
| | ZT | 5.2 | 5.2 | 5.6 | 5.3 | 5.1 | 5.3 | 5.8 | 5.4 |
| | CT | 4.8 | 5.4 | 5.7 | 5.3 | 5.3 | 5.8 | 5.6 | 5.6 |
| | Mean | 4.9 | 5.2 | 5.5 | - | 5.3 | 5.6 | 5.7 | - |
| | $LSD_{0.05}$ | IP=0.40 | | | | IP=0.29 | | | |
| LS | ST | 4.7 | 5.5 | 5.4 | 5.2 | 7.1 | 7.5 | 7.3 | 7.3 |
| | ZT | 4.3 | 4.5 | 4.8 | 4.5 | 6.8 | 7.3 | 7.5 | 7.2 |
| | CT | 4.7 | 4.8 | 5.3 | 4.9 | 6.9 | 7.2 | 7.1 | 7.1 |
| | Mean | 4.6 | 4.9 | 5.2 | - | 7.0 | 7.3 | 7.3 | - |
| | $LSD_{0.05}$ | T=0.23 and IP=0.23 | | | | IP=0.28 | | | |
| SLS | ST | 6.0 | 6.9 | 6.3 | 6.4 | 5.3 | 5.8 | 5.3 | 5.5 |
| | ZT | 5.2 | 5.8 | 6.5 | 5.8 | 4.8 | 5.3 | 5.8 | 5.3 |
| | CT | 5.5 | 5.6 | 6.3 | 5.8 | 5.5 | 5.1 | 5.2 | 5.3 |
| | Mean | 5.6 | 6.1 | 6.4 | - | 5.2 | 5.4 | 5.4 | - |
| | $LSD_{0.05}$ | T=0.25, IP=0.25 and T×IP=0.42 | | | | T×IP=0.64 | | | |

Note: CLS-Clay loam soil, LS-Loam soil, SLS-Sandy loam soil, T-Tillage options, ST-Strip tillage, ZT-Zero tillage, CT-Conventional tillage, $IP_{12}$-12 hrs inundation period, $IP_{18}$-18 hrs inundation period and $IP_{24}$-24 hrs inundation period.

## 4 Conclusion

The mechanical transplanting of rice has been considered the most promising option, as it saves labor and fuel consumption for transplanting and attains high productivity. However, the mechanical rice transplanter operation and rice production under minimum tillage were found satisfactory irrespective of soil types especially under strip tillage. Average across the three soil types, 18 hrs inundations for strip and 24 hrs inundations for zero and conventional tillage showed better performance of the rice transplanter as well as rice production.

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