OPEN ACCESS
Pakistan Journal of Agricultural Research

Research Article

# Puddled Soil Settling Period and Seedling Age Affect Growth, Productivity and Economic Benefits of Mechanically Transplanted Rice

**Ali Zohaib[1]*, Muzzammil Hussain[2], Ishtiaq Hassan[3], Muhammad Tahir Latif[2], Tahira Tabassum[1] and Naeem Faisal[2]**

*[1]Cereals and Pulses Section, Agronomic Research Institute, Ayub Agricultural Research Institute, Faisalabad 38850, Pakistan; [2]Adaptive Research Farm, Gujranwala 52200, Pakistan; [3]Directorate General Agriculture (Extension and Adaptive Research) Punjab, Lahore 54000, Pakistan.*

**Abstract** | Seedling age and soil condition after puddling affects stand establishment, growth and productivity of mechanically transplanted rice (MTR). Study was performed to evaluate different puddled soil settling periods (24, 48 and 72 hours) and seedling age (20, 25 and 30 days) for decreasing the missing hills while improving plant and root growth, and consequently grain yield of MTR. Experiment was conducted using randomized complete block design (RCBD) with split-plot arrangement and three replications during 2020 and 2021. Shoot and root length as well as dry mass of rice seedlings sown in trays were significantly increased with increase in seedling age. Increase in puddled soil settling period and seedling age significantly interacted in increasing filled hills and decreasing missing hills after transplanting the nursery. Root length, plant height and root/shoot ratio was significantly higher at 72 hours puddled soil setting period; however, seedling age didn't affect plant growth. The productive tillers, total dry matter (TDM) and grain yield of MTR was improved interactively by 72 hours puddled soil settling period and 25 days old nursery. The 1000-grain weight was increased by increase in puddled soil setting period while didn't affect significantly by seedling age. Benefit cost ratio (BCR) and net returns were substantially improved by 72 hours puddled soil settling period and 25 days seedling age. In conclusion, 72 hours puddled soil settling period and 25 days seedling age improved the yield and economic returns by decreasing missing hills; hence could be employed to enhance yield and economic benefits of MTR.

**Received** | May 26, 2023; **Accepted** | December 31, 2023; **Published** | January 17, 2024
***Correspondence** | Ali Zohaib, Cereals and Pulses Section, Agronomic Research Institute, Ayub Agricultural Research Institute, Faisalabad 38850, Pakistan; **Email:** alizohaib208@gmail.com
**Citation** | Zohaib, A., M. Hussain, I. Hassan, M.T. Latif, T. Tabassum and N. Faisal. 2024. Puddled soil settling period and seedling age affect growth, productivity and economic benefits of mechanically transplanted rice. *Pakistan Journal of Agricultural Research,* 37(1): 29-38.
**DOI** | https://dx.doi.org/10.17582/journal.pjar/2024/37.1.29.38
**Keywords** | Economic benefits, Grain yield, Puddled soil settling period, Root growth, Seedling age, Stand establishment



## Introduction

Rice (*Oryza sativa* L.) is cultivated and utilized as staple food in a large number of countries over the world. Traditionally, rice is planted by transplanting nursery manually in the puddled soil that is quite strenuous and time consuming (Thomas, 2002; Farooq *et al*., 2007). In recent years, a marked increase in labor scarcity and cost has occurred demanding a shift of transplanting method from manual to mechanical (Wassmann *et al*., 2004; Shinde *et al*., 2018; Zohaib *et al*., 2022). Mechanical transplanting is the best alternate to overcome the problems of labor shortage, high cost, less yield and economic losses which are faced in manual transplanting method (Mann and Ashraf, 2001; Rani and Jayakiran, 2010; Malik *et al*., 2011; Liu *et al*., 2017). Mechanical transplanting ensures optimum plant spacing and plant density which regulates the tiller production, radiation use efficiency, photosynthesis, dry mass production and crop productivity (Huang *et al*., 2013; Liu *et al*., 2017; Chen *et al*., 2019).

Although the mechanical transplanting technology has been successfully induced in rice-wheat cropping system of Pakistan (Zohaib *et al*., 2022) but still there is a need for research to eliminate various problems associated with it e.g. missing hills, early transplanting shock, poor early stand establishment, inadequate root growth and plant competition etc. These associated problems are deemed to be eliminated through further investigations by keeping different agronomic factors in mind in order to improve the grain yield and sustainability. Although previous research has presented the yield benefits of MTR but only a few studies are present which address the site specific problems such as adequate soil conditions, seeding rate, stand establishment and plant density, seedling age, seedling competition and nursery growing conditions, and their interactions etc. (He *et al*., 2018; Rashid *et al*., 2018; Mamun *et al*., 2020; Dou *et al*., 2021; Zohaib *et al*., 2022). Early and better stand establishment along with less transplanting shock is essential for avoiding missing hills and acquiring optimum plant density to improve plant and root growth, tillering capacity, early acquisition of TDM accumulation and better productivity (Liu *et al*., 2015; Zohaib *et al*., 2022). Among various factors responsible for better stand establishment, extended vegetative growth period for dry matter production, and higher crop yield of MTR the proper puddled soil condition and seedling age at the time of nursery transplanting are crucial (Shen *et al*., 2006; Mamun *et al*., 2020).

In rice, puddling is practiced in south Asian countries to transplant nursery, reduce water and nutrient leaching by breaking the non-capillary pore spaces and avoid weeds (Fang *et al*., 2019; Hossain *et al*., 2020; Nazir *et al*., 2022). Puddling refers to the process of working of tillage implements in saturated or near saturated soil to pulverize and destroy soil structure, and create soil layer impervious to water (Kirchhof *et al*., 2011). In MTR, young nursery is transplanted hence puddled soil characteristics such as soil type, puddling depth, sinkage of soil particles, soil bonding and strength, and porosity affect the early seedling establishment, root growth and productivity of crop plants (Kirchhof *et al*., 2000; Fang *et al*., 2019). Soil settling after puddling depends on the settling period which varies with soil texture. For instance, sandy soils take less time while clayey soils take more time for soil settling after puddling (Mamun *et al*., 2020). Hence, it is crucial to optimize puddled soil settling period to obtain puddled soil condition suitable for better and early stand establishment, optimum plant density, and enhanced rice growth and productivity.

In MTR, optimal aged rice nursery is essential to achieve proper early seedling establishment, extended crop growth period, photosynthesis and dry matter accumulation, and crop yield (Liu *et al*., 2015, 2017). Among various agronomic factors contributing towards the crop yield of MTR the seedling age is the most crucial factor even preceding the sowing density and fertilization in seedbed (Shen *et al*., 2006). In rice-wheat cropping system of Gujranwala, Pakistan transplanting of sub or supra-optimal aged nursery occurs due to less availability of mechanical transplanters and/or weather conditions. Transplantation of young nursery seedlings is often prone to more transplanting shock and even seedling death leading to missing hills, low plant density and crop yield (Kewat *et al*., 2002). On the other hand, transplantation of older seedling results in poor tillering, shortened growth period, decreased dry matter accumulation and productivity of rice (Pasuquin *et al*., 2008; Huo *et al*., 2012; Lee *et al*., 2021). Nevertheless, previous research has considered 25 days or less old seedlings suitable for MTR due to better stand establishment, improved production of dry matter and tillers following transplanting (Yu *et al*., 2006; Zhang *et al*., 2008; Li *et al*., 2020).

Puddled soil settling period and seedling age affects early seedling establishment, crop growth and yield of MTR. In present study, we hypothesized that crop yield could be improved by reducing missing hills, while improving root growth and dry matter accumulation through optimized puddled soil settling period and seedling age for MTR. This two-year study was accomplished with objectives to evaluate different puddled soil settling periods and seedling age for reducing missing hills, and enhancing plant and root growth, and TDM accumulation for improving the grain yield and economic benefits of MTR.

## Materials and Methods

### *Treatments and experimental design*

Study was carried out at Adaptive Research Farm, Gujranwala, Pakistan (32°12′21″N 74°13′49″E, 226 m above sea level) during 2020 and 2021. Before transplanting the nursery, soil physico-chemical properties were assessed by collecting and analyzing the samples (0-30 cm depth) from experimental field. Soil was heavy clay loam with 0.87% organic matter, 8.0 pH, 2.1 mS/cm EC (electrical conductivity), 0.05% total N, 11.1 ppm available P and 172 ppm available K. Experimentation was performed by utilizing the RCBD with split-plot arrangement and three replications. In order to minimize experimental error, blocks were made within experimental field and complete set of treatments was randomized within each block. Net plot area was 17.5 m × 7.6 m. The treatments were consisted of three puddled soil settling periods and three nursery seedling ages. Treatments detail is given in Table 1. Meteorological conditions occurring during experimentation are given in Table 2.

### *Crop husbandry*

The experiment was conducted by using the fine rice cultivar Super basmati. The nursery sowing was carried out in trays (length 60 cm × width 30 cm × depth 2.5 cm) with five days interval to achieve the desired nursery age according to the treatments starting on 17$^{th}$ and 7$^{th}$ June during 2020 and 2021, respectively. The seed rate of 90 g per tray was used as optimized in our previous study (Zohaib *et al*., 2022) using seeding machine and 250 trays ha$^{-1}$ were used for transplanting nursery. The field was divided in three main plots and puddling was performed in each main plot with 24 hours difference according to the treatments. Transplanting was performed with 4-rows walk after type rice transplanter on 17$^{th}$ and 7$^{th}$ July in 2020 and 2021, respectively. The spacing between rows and plants within rows was kept 25 cm and 20 cm, respectively. Fertilizers (NPK) were applied @ 120-88-62 kg/ha. The K and P were employed as basal dose using muriate of potash and diammonium phosphate, respectively. The N was employed in three splits using urea i.e. basal dose, 30 days after transplanting (DAT) and 45 DAT. Zinc sulfate (33%) @ 15 kg ha$^{-1}$ was employed at 10 DAT. Irrigation was applied to keep water standing (5 cm depth) and later up to field capacity level. Irrigation was stopped 12-15 days before harvesting. Plant protection was ensured by local recommendations. Crop was harvested and threshed in 1$^{st}$ week of November during both years.

**Table 1:** *Treatments details of experiment.*

| Treatments | |
|---|---|
| **Puddled soil settling period** | **Seedling age** |
| 24 hours | 20 days |
| 24 hours | 25 days |
| 24 hours | 30 days |
| 48 hours | 20 days |
| 48 hours | 25 days |
| 48 hours | 30 days |
| 72 hours | 20 days |
| 72 hours | 25 days |
| 72 hours | 30 days |

**Table 2:** *Meteorological conditions during rice growing seasons.*

| Month | Temperature (°C) | | | | | | Total rainfall (mm) | | Relative humidity (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Monthly maximum | | Monthly minimum | | Daily mean | | | | | |
| | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 |
| June | 37.5 | 39.1 | 23.9 | 21.9 | 30.7 | 30.5 | 97.6 | 26.6 | 75.1 | 71.3 |
| July | 35.9 | 35.0 | 26.5 | 26.4 | 31.2 | 30.7 | 79.6 | 301.2 | 80.3 | 83.2 |
| August | 35.1 | 36.5 | 26.5 | 27.0 | 30.4 | 31.8 | 333.3 | 60.5 | 89.5 | 85.1 |
| September | 36.1 | 33.7 | 25.0 | 24.5 | 30.6 | 29.1 | 49.2 | 80.1 | 85.4 | 85.9 |
| October | 33.6 | 31.8 | 17.7 | 18.6 | 25.6 | 25.2 | 0.0 | 54.2 | 82.2 | 81.6 |
| November | 24.8 | 26.3 | 10.8 | 10.8 | 17.8 | 18.5 | 15.5 | 1 | 84.3 | 83.4 |

**Source:** *Meteorological Department, Punjab*

*Measurements*

On completion of emergence the number of plants per tray was counted from selected three nursery trays from each treatment. The seedling shoot and root length was determined by carefully uprooting the five seedlings from selected trays, measuring with scale, and averaging. Afterwards, the shoots and roots of seedlings were separated, dried in oven and their weight was determined with weighing balance. The number of filled and missing hills $m^{-2}$ was determined at harvesting from each replication. Transplanting efficiency was calculated by using the formula [Transplanting efficiency = (number of filled hills $m^{-2}$/ total number of hills $m^{-2}$) × 100]. At maturity, plant height was measured from randomly selected plants using a meter rod. The root length was measured with meter rod by digging and uprooting selected plants. Afterwards, root length was divided by plant height to determine the root/shoot ratio. The productive tillers $m^{-2}$ was counted from randomly selected area from each replication. The grains per panicle were counted from panicles of selected plants from each replication and averaging. Thousand grains were counted and weighed using a weighing balance for determination of 1000-grain weight. Plants from selected one $m^2$ area were manually harvested and weighed before threshing to determine TDM. Afterwards, harvested plants were threshed and weighed to determine the grain yield.

*Economic analysis*

Total cost, net returns and BCR was determined by following CIMMYT (1988). Local market prices of all inputs (seed and treatments, land preparation and transplanting, fertilizers, irrigation, pesticides, labor etc.) used in the experiment was calculated to determine fixed cost. The variable cost included harvesting cost on produce share basis. Fixed and variable costs were summed to determine the total cost. Net returns were determined by subtracting total cost from gross income. The BCR was computed by dividing gross income with total cost.

*Statistical analysis*

Normality of data was checked using scatter plot. The year effect was found significant as a result of paired T-test, and therefore analyzed and presented separately. Further analysis was performed with 2-way analysis of variance (ANOVA) (Steel *et al.*, 1997). The treatments means were compared by using least significant difference (LSD) as post-hoc test at 5% probability. The treatments' means of main effects are presented in tables while the treatments' means of significant interaction effects are presented in figures.

## Results and Discussion

*Nursery seedling traits*

Seedling age of rice nursery significantly affected all studied traits pertaining to seedling shoot and root, during both years. However, there was no significant influence of seedling age on number of plants per tray. There was an increase in seedling length and dry weight traits of rice nursery with increase in nursery age. Maximum length and dry weight of shoots and roots of rice nursery seedlings was produced in 30 days old nursery (Table 3). Results revealed that old aged seedlings had higher growth and dry weight as compared to young seedlings. The increase in seedling growth with seedling age was associated with more time for growth and dry matter production. Li *et al.* (2020) described that older plants of rice had higher growth and dry matter due to more time for storage of photo-assimilates.

*Plant density and transplanting efficiency*

Puddled soil settling period and nursery age significantly affected the number of filled and missing hills $m^{-2}$, and transplanting efficiency after transplanting of rice. Number of filled hills $m^{-2}$ and transplanting efficiency were increased while missing hills $m^{-2}$ were decreased with increase in puddled soil settling period. Across seedling age, maximum increase in filled hills (12-13%) and transplanting

**Table 3:** *Effect of seedling age on seedling traits of rice nursery.*

| Seedling age | No. of plants tray$^{-1}$ | | Seedling shoot length (cm) | | Seedling root length (cm) | | Seedling shoot dry weight (mg) | | Seedling root dry weight (mg) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 |
| 20 d | 2127 a | 1912 a | 18.3 c | 18.9 c | 9.9 c | 10.7 c | 47.24 c | 45.25 c | 18.95 c | 21.22 c |
| 25 d | 2146 a | 1940 a | 23.3 b | 24.0 b | 12.8 b | 12.5 b | 56.38 b | 57.74 b | 24.37 b | 26.25 b |
| 30 d | 2134 a | 1927 a | 26.3 a | 27.2 a | 15.1 a | 14.6 a | 63.16 a | 64.55 a | 27.95 a | 29.11 a |
| P < 0.05 | 0.8636 | 0.9072 | 0.0211 | 0.0032 | 0.0018 | 0.0090 | 0.0030 | 0.0032 | 0.0018 | 0.0090 |

*Means in a column having same letters don't differ significantly at P < 0.05* efficiency (12-13%), and decrease in missing hills m$^{-2}$ (5-6%) of rice crop was caused by 72 hours puddled soil settling period, as compared to 24 hours puddled soil settling period, during both years. Likewise, increase in seedling age improved the number of filled hills and transplanting efficiency, while decreased the missing hill m$^{-2}$ in rice crop. Across puddled soil settling period, maximum increase in number of filled hills and transplanting efficiency (6-13%), and decrease in missing hills m$^{-2}$ (3-6%) was recorded by transplanting 30 and 25 days old nursery during 2020 and 2021, respectively, as compared to 20 days old nursery, during both years (Table 4). Furthermore, the interaction of puddled soil settling period and seedling age was significant for filled and missing hills m$^{-2}$, and transplanting efficiency as well, during both years (Table 4). The greatest increase in number of filled hills and transplanting efficiency, and decrease in missing hills m$^{-2}$ in rice was found by transplanting 25 days old nursery after 72 hours puddled soil settling period during both years; however, transplanting 30 days old nursery after 48 hours puddled soil settling period produced similar results during 2020 (Figure 1).

**Table 4:** *Effect of puddled soil settling period and seedling age on number of filled hills, missing hills and transplanting efficiency of mechanically transplanted rice.*

| Treat-ments | No. of filled hills m$^{-2}$ | | No. of missing hills m$^{-2}$ | | Transplanting efficiency (%) | |
|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 |
| **Puddled soil settling period (P)** | | | | | | |
| 24 hours | 15.7 b | 15.3 b | 3.3 a | 3.7 a | 82.5 | 83.6 |
| 48 hours | 16.9 a | 16.1 b | 2.1 b | 2.9 a | 88.9 | 84.8 |
| 72 hours | 17.7 a | 17.1 a | 1.3 b | 1.9 b | 93.0 | 61.4 |
| **Seedling age (S)** | | | | | | |
| 20 d | 15.6 b | 15.8 b | 3.4 a | 3.2 a | 81.9 | 87.7 |
| 25 d | 17.0 a | 16.7 a | 2.0 b | 2.3 b | 89.5 | 84.8 |
| 30 d | 17.7 a | 16.1 ab | 1.3 b | 2.9 ab | 93.0 | 57.3 |
| **Source of variation (Pr > F)** | | | | | | |
| P | 0.0056 | 0.0088 | 0.0056 | 0.0088 | 0.0057 | 0.0087 |
| S | 0.0022 | 0.0147 | 0.0022 | 0.0147 | 0.0021 | 0.0148 |
| P × S | 0.0231 | 0.0409 | 0.0231 | 0.0409 | 0.0227 | 0.0404 |

*Means in a column having same letters don't differ significantly at P < 0.05*

The increase in puddled soil settling period increased the number of filled hills while the number of missing hills was decreased which increased the transplanting efficiency (Table 4) and it might be attributed to soil texture. In present study, the soil of experimental area was heavy clay; therefore, took more time for settling (Uzoegbo, 2016). After puddling, sandy soils take less time while clayey soils take more time for settling (Uzoegbo, 2016; Mamun *et al*., 2020). Furthermore, the results revealed that well settled soil created more grip to hold the seedlings due to which seedling establishment after transplanting was improved leading to less missing hills (Mamun *et al*., 2020). Previous research has reported results similar to our present study (Paul *et al*., 2016; Mamun *et al*., 2020). In present study, transplantation of 25 days old seedlings substantially increased the filled hills and reduced the missing hills, as compared to 20 and 30 days old nursery (Table 4). This might be because the too young or old seedlings are more susceptible to transplanting shock leading to poor stand establishment and plant growth after transplanting (Li *et al*., 2020; Lee *et al*., 2021). Virk *et al*. (2020) reported that transplanting of older seedlings (i.e. 35 days) showed higher mortality as compared to younger seedlings in hand transplanted rice under system of alternate wetting and drying. However, our study results are supported by previous reports (Zhang *et al*., 2008; Liu *et al*., 2017).

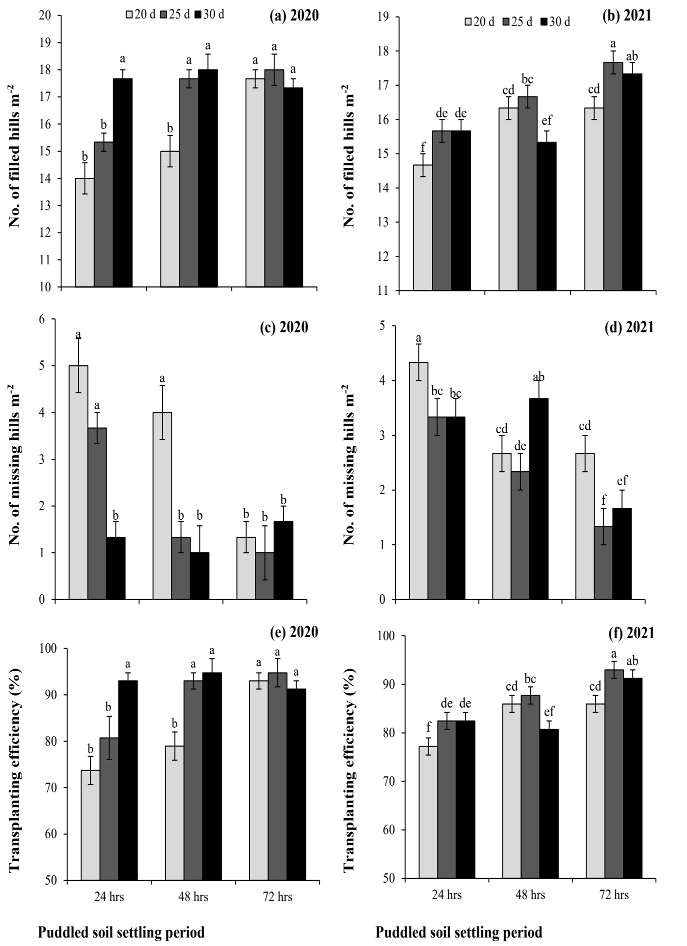


**Figure 1:** *Effect of puddled soil settling period and seedling age on number of filled hills (a-b), missing hills (c-d) and transplanting efficiency (e-f) of mechanically transplanted rice. Bars are means ± SE (n=3). Bars having same letters don't differ significantly at P < 0.05.*

**Table 5:** *Effect of puddled soil settling period and seedling age on growth and yield related attributes of mechanically transplanted rice.*

| Treatments | Plant height (cm) | | Root length (cm) | | Root/Shoot ratio | | No. of productive tillers $m^{-2}$ | |
|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 |
| **Puddled soil settling period (P)** | | | | | | | | |
| 24 hours | 116.7 b | 119.8 c | 35.0 b | 36.0 b | 0.30 b | 0.30 b | 302 b | 320 b |
| 48 hours | 118.7 b | 123.1 b | 36.1 a | 37.5 b | 0.30 b | 0.30 b | 335 a | 329 b |
| 72 hours | 121.3 a | 124.7 a | 38.6 a | 39.6 a | 0.32 a | 0.32 a | 338 a | 339 a |
| **Seedling age (S)** | | | | | | | | |
| 20 d | 118.6 a | 121.9 a | 36.3 a | 37.0 a | 0.31 a | 0.30 a | 317 b | 320 c |
| 25 d | 119.1 a | 122.8 a | 36.8 a | 38.2 a | 0.31 a | 0.31 a | 337 a | 336 a |
| 30 d | 119.0 a | 122.9 a | 36.7 a | 37.8 a | 0.31 a | 0.31 a | 322 b | 332 b |
| **Source of variation (Pr > F)** | | | | | | | | |
| P | 0.0176 | 0.0000 | 0.0313 | 0.0173 | 0.0450 | 0.0178 | 0.0097 | 0.0106 |
| S | 0.8547 | 0.5099 | 0.3785 | 0.4454 | 0.6929 | 0.3628 | 0.0310 | 0.0000 |
| P × S | 0.7784 | 0.9138 | 0.9962 | 0.8189 | 0.9243 | 0.5789 | 0.0117 | 0.0448 |

*Means in a column having same letters don't differ significantly at P < 0.05*

*Plant and root growth*

Plant growth of rice was significantly affected by puddled soil settling period; however, seedling age didn't affect significantly (Table 5). Similarly, the interaction effect of puddled soil settling period and seedling age on rice growth was non-significant (Table 5). An increase in plant growth of rice occurred by increasing the puddled soil settling period after puddling for transplanting of rice nursery. Across seedling age, the highest increase in plant height (4%), root length (10%) and root/shoot ratio (7%) was recorded by transplanting rice nursery after 72 hours of puddled soil settling period as compared to 24 hours puddled soil settling time, during both years (Table 5).

Puddling affects the soil structure by increasing or decreasing the bulk density, changing macro-pores to micro-pores and decreasing soil strength which affects the root growth (Rezaei *et al*., 2012; Deng *et al*., 2014; Fang *et al*., 2019). In present study, increase in puddled soil settling period improved the root growth and plant height of MTR (Table 5) which might be associated with optimum soil bulk density and soil strength required to support the transplanted seedlings. Previous research has found that puddling causes maximum decrease in bulk density and soil strength (Rezaei *et al*., 2012; Zhang *et al*., 2016) which regains for supporting seedlings with soil settling (Mamun *et al*., 2020). However, later on the continuous cycles of wetting and drying increase soil bulk density and strength until crop harvest which could severely limit the root growth (Lima *et al*., 2009; Deng *et al*., 2014; Fang *et al*., 2019).

*Grain yield and related attributes*

Puddled soil settling period and seedling age of nursery significantly affected production of productive tillers, TDM and grain yield, during both years. However, 1000-grain weight was significantly affected by puddled soil settling period while grains panicle$^{-1}$ were not affected significantly by either puddled soil settling period or seedling age, during both years (Table 6). Increase in puddled soil settling period enhanced the yield related attributes and yield of rice. Across seedling age, the highest increase in productive tillers (6-12%), 1000-grain weight (2-6%), TDM (9-11%) and grain yield (11-14%) was produced by 72 hours puddled soil settling period, as compared to 24 hours puddled soil settling period. Similarly, increase in seedling age improved the yield related attributes and yield of rice. Across puddled soil settling period, transplanting of 25 days old seedlings caused highest increase in productive tillers $m^{-2}$ (5-6%), TDM (6-8%) and grain yield (5-9%) of rice, as compared to 20 days old seedlings, during both years (Table 6). Interaction of puddled soil settling period and seedling age significantly affected the productive tillers and grain yield of MTR (Table 6). Highest number of productive tillers was produced by transplanting 30 days old nursery at 48 hours puddled soil settling period and 25 days old nursery at 72 hours puddled soil settling period during 2020 and 2021, respectively. Grain yield of MTR was increased the most by transplanting 25 days old nursery at 72 hours puddled soil settling period (Figure 2).

**Table 6:** *Effect of puddled soil settling period and seedling age on grain yield and related attributes of mechanically transplanted rice.*

| Treatments | No. of grains panicle$^{-1}$ | | 1000-grain weight (g) | | Total dry mass (t ha$^{-1}$) | | Grain yield (kg ha$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 |
| **Puddled soil settling period (P)** | | | | | | | | |
| 24 hours | 110.3 a | 105.7 a | 22.56 ab | 21.11 b | 16.70 c | 14.24 c | 4170 c | 3589 b |
| 48 hours | 112.4 a | 106.9 a | 22.22 b | 21.56 b | 17.84 b | 14.74 b | 4462 b | 3722 b |
| 72 hours | 113.1 a | 108.0 a | 23.06 a | 22.33 a | 18.62 a | 15.49 a | 4770 a | 3971 a |
| **Seedling age (S)** | | | | | | | | |
| 20 d | 112.4 a | 106.2 a | 22.56 a | 21.44 a | 17.33 b | 14.22 b | 4370 b | 3574 c |
| 25 d | 111.1 a | 107.2 a | 22.83 a | 22.00 a | 18.29 a | 15.30 a | 4605 a | 3912 a |
| 30 d | 112.3 a | 107.1 a | 22.44 a | 21.56 a | 17.54 b | 14.94 ab | 4427 b | 3796 b |
| **Source of variation (Pr > F)** | | | | | | | | |
| P | 0.4036 | 0.3829 | 0.0389 | 0.0177 | 0.0044 | 0.0003 | 0.0010 | 0.0063 |
| S | 0.4282 | 0.7528 | 0.4451 | 0.2450 | 0.0326 | 0.0479 | 0.0121 | 0.0001 |
| P × S | 0.9083 | 0.9375 | 0.8938 | 0.7110 | 0.2409 | 0.9423 | 0.0257 | 0.0368 |

*Means in a column having same letters don't differ significantly at P < 0.05*

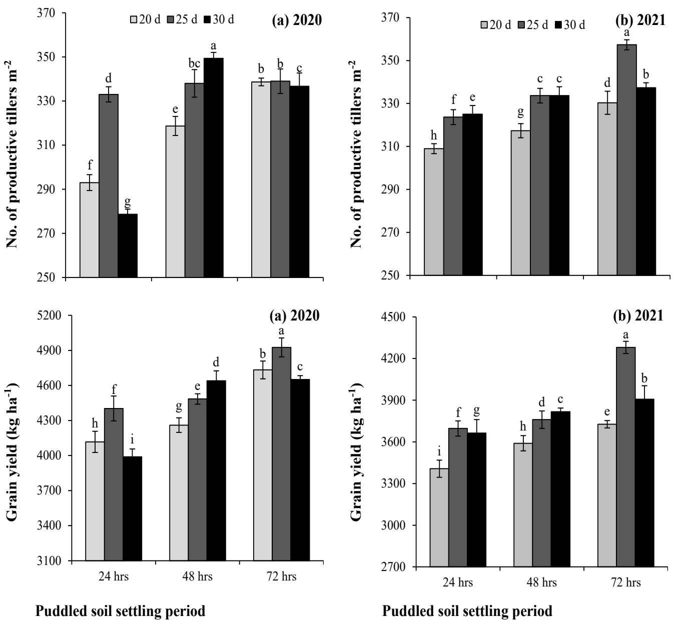


**Figure 2:** *Effect of puddled soil settling period and seedling age on number of productive tillers m$^{-2}$ (a-b) and grain yield (c-d) of mechanically transplanted rice. Bars are means ± SE (n=3). Bars having same letters don't differ significantly at P < 0.05.*

In present study, grain yield was improved with increase in puddled soil settling period (Table 6, Figure 2) which was associated with increase in dry matter accumulation, productive tillers (Table 5, Figure 2) and grain weight (Table 6). The MTR with 72 hours puddled soil settling period had less missing hills (Table 4) and better root growth (Table 5) which resulted in higher productive tillers and better grain weight due to improved plant water and nutrient uptake ability. Similarly, Mamun *et al.* (2020) has reported improved grain yield of MTR with increased puddled soil settling period. In present study, the seedling age also affected the grain yield of MTR and maximum grain yield was recorded by transplanting 25 days old seedlings (Table 6, Figure 2). This increase in grain yield was due to better dry matter production and production of more productive tillers than 20 or 30 days seedlings (Tables 4-5; Figure 2). Previous research has also considered 25 days or less old seedlings suitable for MTR due to better dry matter and tillers production after transplanting (Yu *et al.*, 2006; Zhang *et al.*, 2008; Li *et al.*, 2020).

### *Economic analysis*

Variable cost, gross income, net returns and BCR varied with puddled soil settling period and seedling age. The economic benefits and BCR were increased with an increase in puddled soil settling period and seedling age of rice nursery. Highest average variable cost (Rs. 33013), gross income (Rs. 279101), net returns (Rs. 129368) and BCR (1.86) was recorded by transplanting 25 days old nursery at 72 hours puddled soil settling period and it was followed by 30 days old nursery at 72 hours puddled soil settling period (Table 7). In present study increase in grain yield by increasing the puddled soil settling period along with 25 days old nursery seedlings caused an increase in the gross income and net returns which ensued in higher BCR (Table 7). Previous studies have reported that better management of MTR causes an increase in yield and reduces the yield losses which consequence in better net returns and BCR (Dongarwar *et al.*, 2018; Zohaib *et al.*, 2022).

**Table 7:** *Effect of puddled soil settling period and seedling age on economic efficiency of mechanically transplanted rice.*

| Puddled soil settling period | Seedling age | Adjusted Grain yield (t ha$^{-1}$) | Gross income (Rs. ha$^{-1}$) | Variable cost (Rs. ha$^{-1}$) | Total cost (Rs. ha$^{-1}$) | Net returns (Rs. ha$^{-1}$) | Benefit cost ratio |
|---|---|---|---|---|---|---|---|
| 24 hours | 20 d | 3.39 | 230826 | 26978 | 143698 | 87127 | 1.61 |
| | 25 d | 3.65 | 247369 | 29046 | 145766 | 101603 | 1.70 |
| | 30 d | 3.44 | 234555 | 27444 | 144164 | 90391 | 1.63 |
| 48 hours | 20 d | 3.53 | 240205 | 28151 | 144871 | 95335 | 1.66 |
| | 25 d | 3.71 | 251520 | 29565 | 146285 | 105235 | 1.72 |
| | 30 d | 3.81 | 257595 | 30324 | 147044 | 110551 | 1.75 |
| 72 hours | 20 d | 3.81 | 257698 | 30337 | 147057 | 110641 | 1.75 |
| | 25 d | 4.14 | 279101 | 33013 | 149733 | 129368 | 1.86 |
| | 30 d | 3.85 | 260519 | 30690 | 147410 | 113109 | 1.77 |

*Adjusted grain yield: 10% less than actual grain yield; Cost and income was estimated by using the prevailing market prices for inputs and paddy, respectively, in Pakistan.*

## Conclusions and Recommendations

Puddled soil settling period and seedling age significantly affected the missing and filled hills, growth and yield of MTR. Grain yield and economic returns of MTR were improved by 72 hours puddled soil settling period and 25 days seedling age by enhancing the root growth, TDM production, productive tillers and grains per panicle of MTR; and hence could be adopted for profitable crop production.

## Acknowledgement

Agriculture (Ext&AR) Department, Govt. of the Punjab, Pakistan is acknowledged for providing the support and funding to conduct this study.

## Novelty Statement

Determination of optimum seedling age and puddled soil settling period could improve the root growth, yield and economic benefits of MTR. Present study was performed to evaluate different puddled soil settling periods and seedling age for reducing missing hills and improving stand establishment, plant and root growth and yield of MTR for enhancing the economic benefits.

## Author's Contribution

**Ali Zohaib:** Carried out planning of study, experimentation, data collection and analysis, and write-up of article.
**Muzzammil Hussain:** Supervised study and reviewed paper.
**Ishtiaq Hassan:** Gave technical input during planning of study.
**Muhammad Tahir Latif:** Helped in economic analysis.
**Tahira Tabassum:** Helped in data analysis and revision.
**Naeem Faisal:** Helped in review.

*Conflict of interest*

The authors have declared no conflict of interest.

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