# Evaluating the impact of rice establishment methods, zinc application and rice residue retention on growth and development in rice


## ABSTRACT

**Aims:** To investigatethe effect of different rice establishment methods, zinc application and residue retention on the rice plant growth metrics.
**Study design:**Split-plot design with three replications.
**Place and Duration of Study:**Rice and Wheat Research Centre-CSK HPKV, Malan, Kangra, Himachal Pradesh, India. Study was conducted during *kharif* season of 2021 and 2022.
**Methodology:**The treatments under observation included six main plot treatments *viz.,* $M_1$: transplanting, $M_2$: wet seeding (line sowing under puddle condition),$M_3$: aerobic rice (dry rice cultivation),$M_4$: transplanting + soil application of $ZnSO_4$ @12.5 kg $ha^{-1}$ + 0.5% $ZnSO_4$ spray at flowering and early milk stages, $M_5$: wet seeding + soil application of $ZnSO_4$ @12.5 kg $ha^{-1}$ + 0.5% $ZnSO_4$ spray at flowering and early milk stages,$M_6$: aerobic rice + soil application of $ZnSO_4$ @12.5 kg $ha^{-1}$ + 0.5% $ZnSO_4$ spray at flowering and early milk stages, and three sub plot treatments *viz.,* $S_1$: no residue, $S_2$: 15 cm height of rice straw from ground and incorporation in soil and $S_{3:}$ 30 cm height of rice straw from ground and incorporation. The variety used in the investigation was HPR 1068 of rice.
**Results:**The treatment where zinc was applied resulted in significantly better rice plant height, leaf area index, crop growth rate and net assimilation rate when coupled with transplanting establishment method. Conversely, aerobic method of rice establishment without zinc application resulted in significantly lower rice growth attributes. The days to flowering and physiological maturity were not significantly influenced by the treatments during the study.
**Conclusion:**The study revealed that transplanting method in conjunction with soil application of $ZnSO_4$ @ 12.5 kg $ha^{-1}$ and foliar application of $ZnSO_4$ @ 0.5% at flowering and early milk stages resulted in significantly higher and better rice plant growth and hence is encouraged.


*Keywords: absolute growth rate, aerobic rice, crop growth rate rice,direct seeded rice, leaf area index, net assimilation rate, transplanting*

## 1. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the world's most important staple crops, feeding a large section of the population. As demand for rice increases owing to swelling populations and changing dietary habits, improving rice yield and sustainability has become critical (Kingra et al., 2019). In this context, optimizing rice establishment techniques, zinc application, and rice residue management are identified as essential aspects for creating sustainable rice production systems. Rice establishment techniques such as direct seeding and transplanting have a substantial impact on rice plant growth and development (Rao et al., 2007). Direct sowing, while less labour-intensive, necessitates precise water and weed management. Transplanting, on the other hand, includes the labour-intensive procedure of seedling transplantation but frequently results in more uniform plant stands and less competition from weeds. The method of establishment can have an impact on a variety of growth metrics, including plant height, root architecture, and, ultimately, grain output.

Zinc (Zn) is a critical element for rice plants, influencing a variety of physiological processes including enzyme activation, photosynthesis, and hormone regulation (Solanki, 2021). Zinc insufficiency is a prevalent limitation in rice-growing locations worldwide, resulting in slower growth, delayed maturity, and poorer grain yield. Zinc fertilizers have been demonstrated to reduce deficient symptoms and improve rice growth and development (Wissuwa et al., 2006). However, the efficacy of zinc application varies according on soil type, pH, organic matter level, and other environmental parameters. Rice residue retention, which includes integrating crop leftovers into the soil or leaving them on the top as mulch, has received attention for its ability to increase soil health and nutrient cycling. Rice residues can alter soil structure, moisture retention, and nutrient availability, impacting rice growth and development. Furthermore, residue retention can influence weed control, disease incidence, and greenhouse gas emissions in rice fields, highlighting its importance in sustainable rice production systems (Kaur et al., 2021). Given the intricacies of these interacting elements, further research is required to assess their combined effects on rice growth and development. The purpose of this study is to investigate the impact of different rice establishing methods (direct seeding, transplanting and wet direct seeding), zinc application rates, and rice residue management strategies on important rice plant growth metrics.

## 2. MATERIAL AND METHODS

The field experiment was conducted during *kharif* season of 2021 and2022 under the mid-hill conditions of Himachal Pradesh at Experimental farm of Rice and Wheat Research Centre, Malan of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh. The experimental farm is located at an altitude of 950 meters above mean sea level with latitude $32^{o}$06’55.4” N and longitude $76^{o}$25’00.4” E. According to agroclimatic zones of Himachal Pradesh, the site falls under sub-humid mid-hill zone of the North-Western Himalayas in the Palam valley of District Kangra, Himachal Pradesh, India. A composite soil sample from a depth of 0-15 cm was collected before the start of the field study. The sample was air-dried, grounded and passed through 2 mm sieve. The processed soil sample was analysed for different physio-chemical properties of the soil. The soil at the experimental site was silty clay loam in texture and acidic in reaction. It was medium in organic carbon, medium in available nitrogen, phosphorus and potassium.

The experiment was laid out in split-plot design and comprised of six main plot treatments *viz.,* $M_1$: transplanting, $M_2$: wet seeding (line sowing under puddle condition),$M_3$: aerobic rice (dry rice cultivation),$M_4$: transplanting + soil application of $ZnSO_4$ @12.5 kg $ha^{-1}$ + 0.5% $ZnSO_4$ spray at flowering and early milk stages, $M_5$: wet seeding + soil application of $ZnSO_4$ @12.5 kg $ha^{-1}$ + 0.5% $ZnSO_4$ spray at flowering and early milk stages,$M_6$: aerobic rice + soil application of $ZnSO_4$ @12.5 kg $ha^{-1}$ + 0.5% $ZnSO_4$ spray at flowering and early milk stages, and three sub plot treatments *viz.,* $S_1$: no residue, $S_2$: 15 cm height of rice straw from ground and incorporation in soil and $S_{3:}$ 30 cm height of rice straw from ground and incorporation with three replications. The variety used in the investigation was HPR 1068 of rice. The soil at the experimental site was silty clay loam in texture, acidic in reaction, medium in available nitrogen, available phosphorus and available potassium. The data was subjected to statistical analysis using RStudio 2023.12.1+402 "Ocean Storm" (R Core Team, 2023). The post hoc mean separation test employed was Least Significant Difference (LSD).

## 3. RESULTS AND DISCUSSION

### *Growth attributes*

***Plant height:*** Plant height of rice was significantly influenced by varied rice establishment methods with or without zinc application during both years of study (Table 1). The transplanted method of rice establishment consistently resulted in taller plants, especially

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when combined with soil and foliar applications of zinc ($M_4$). Conversely, the aerobic system of rice cultivation without zinc ($M_3$) led to reduced plant height. Residue incorporation showed no significant effect initially but resulted in taller plants during the subsequent year (*kharif* 2022), with 15 cm of residue incorporation ($S_2$) yielding the best outcomes. At harvest, the transplanted method with zinc application produced the tallest plants, emphasizing the positive impact of zinc on rice growth and the importance of establishment methods. Residue management also played a role, with moderate residue incorporation proving beneficial.

The height of rice plants is a crucial morphological trait influenced by genetic factors, soil conditions, nutrient availability, and environmental factors. Aerobic cultivation methods often result in reduced plant height primarily due to slower initial growth stages compared to transplanting methods (Maniraj et al., 2022). Transplanting from nurseries provides rice with a head start, leading to increased plant height compared to direct seeding (Dou et al., 2021). The reduced plant height under aerobic conditions may result from restricted cell elongation due to increased plant density, intensifying competition for nutrients (Patel et al., 2010). Aerobically grown rice plants may allocate more photosynthates to roots, impacting shoot growth. Zinc plays a vital role in rice production, particularly in flooded conditions, with deficiency leading to reduced yield and growth. Zinc enhances plant height by promoting shoot elongation through increased auxin levels. Studies have reported significant increases in plant height with soil zinc applications, indicating its importance in rice cultivation (Saikh et al., 2022; Ghoneim, 2016).

**Table 1: Effect of different treatments on plant height (cm) in rice crop**

| | **30 DAS** | | **60 DAS** | | **90 DAS** | | **At harvest** | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **2021** | **2022** | **2021** | **2022** | **2021** | **2022** | **2021** | **2022** |
| **Rice establishment methods** | | | | | | | | |
| **M1** | 49.44 | 38.83 | 80.10 | 67.39 | 101.60 | 92.88 | 104.10 | 97.13 |
| **M2** | 41.50 | 38.17 | 71.27 | 64.11 | 92.30 | 92.00 | 103.27 | 86.78 |
| **M3** | 40.33 | 34.22 | 67.30 | 59.78 | 92.83 | 89.40 | 98.10 | 83.82 |
| **M4** | 47.76 | 40.28 | 85.10 | 70.00 | 101.67 | 94.08 | 105.60 | 97.83 |
| **M5** | 41.03 | 38.17 | 73.07 | 66.83 | 95.20 | 91.58 | 101.20 | 95.06 |
| **M6** | 43.20 | 36.83 | 69.57 | 59.89 | 95.10 | 92.70 | 100.30 | 93.28 |
| **SEm±** | 0.56 | 0.49 | 0.75 | 0.97 | 1.07 | 0.91 | 1.23 | 0.97 |
| **LSD** | 1.76 | 1.54 | 2.35 | 3.06 | 3.37 | 2.87 | 3.88 | 3.05 |
| **Rice residue retention in rabi season** | | | | | | | | |
| **S1** | 43.70 | 36.17 | 73.93 | 63.44 | 95.95 | 90.79 | 100.19 | 92.78 |
| **S2** | 44.02 | 38.86 | 75.00 | 65.61 | 96.72 | 94.31 | 103.08 | 96.24 |

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| **S3** | 43.90 | 38.22 | 74.27 | 64.94 | 96.68 | 91.22 | 103.02 | 92.92 |
| **SEm±** | 0.37 | 0.43 | 0.53 | 0.54 | 0.76 | 0.72 | 0.98 | 0.85 |
| **LSD** | NS | 1.27 | NS | 1.57 | NS | 2.09 | NS | 2.49 |

***Leaf Area Index (LAI):*** Significant variations in leaf area index due to varied establishment methods in rice were observed during rice growing period (Table 2). Transplanting rice with soil application of $ZnSO_4$ @ 12.5 kg $ha^{-1}$ and foliar spray of $ZnSO_4$ @ 0.5% during flowering and early milk stages ($M_4$) resulted in a significantly higher LAI compared to other methods. Conversely, the aerobic rice system without zinc showed a lower LAI, similar to aerobic rice with zinc application. Incorporating 15 cm of rice residue led to a significantly increased LAI compared to conventional tillage without residue, though LAI was at parity with 30 cm residue incorporation.

The lower leaf area index (LAI) observed under the aerobic method of rice cultivation is likely due to reduced leaf water content and increased electrolyte leakage, indicative of compromised cell membrane stability. This contrasts with the transplanted method, where the inundation of water helps maintain optimal leaf water content, thereby promoting higher LAI during rice establishment, as noted by Zayed et al. (2023). This finding aligns with the results of Kadiyala et al. (2012), who similarly reported higher LAI under the transplanted method. Furthermore, studies by Singh et al. (2011, 2012) demonstrated that the application of zinc resulted in increased LAI, suggesting a potential avenue for enhancing leaf area in rice cultivation.

**Table 2: Effect of different treatments on Leaf Area Index (LAI) in rice crop**

| | **30 DAS** | | **60 DAS** | | **90 DAS** | | **At harvest** | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **2021** | **2022** | **2021** | **2022** | **2021** | **2022** | **2021** | **2022** |
| **Rice establishment methods** | | | | | | | | |
| **M1** | 2.36 | 2.50 | 4.10 | 4.50 | 3.90 | 4.34 | 3.73 | 4.07 |
| **M2** | 1.98 | 2.07 | 4.12 | 4.41 | 3.92 | 4.12 | 3.69 | 3.95 |
| **M3** | 1.79 | 1.88 | 3.90 | 4.11 | 3.44 | 3.59 | 3.30 | 3.43 |
| **M4** | 2.46 | 2.65 | 4.24 | 4.65 | 4.14 | 4.39 | 3.85 | 4.03 |
| **M5** | 2.24 | 2.34 | 4.22 | 4.45 | 4.10 | 4.35 | 3.77 | 3.51 |
| **M6** | 1.79 | 1.90 | 4.03 | 4.26 | 3.58 | 3.61 | 3.32 | 3.06 |
| **SEm±** | 0.02 | 0.02 | 0.04 | 0.05 | 0.05 | 0.03 | 0.04 | 0.04 |
| **LSD** | 0.08 | 0.07 | 0.14 | 0.17 | 0.16 | 0.08 | 0.13 | 0.13 |

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| **Rice residue retention in rabi season** | | | | | | | | |
| **S1** | 2.09 | 2.10 | 4.09 | 4.23 | 3.82 | 3.90 | 3.58 | 3.47 |
| **S2** | 2.10 | 2.44 | 4.12 | 4.51 | 3.87 | 4.25 | 3.65 | 3.86 |
| **S3** | 2.12 | 2.13 | 4.10 | 4.44 | 3.85 | 4.06 | 3.61 | 3.70 |
| **SEm±** | 0.02 | 0.02 | 0.04 | 0.04 | 0.03 | 0.03 | 0.03 | 0.04 |
| **LSD** | NS | 0.07 | NS | 0.12 | NS | 0.09 | NS | 0.11 |

***Growth indices:*** The study investigated the impact of different rice cultivation methods and zinc application on crop growth rates (AGR) and net assimilation rates (NAR) at various stages of growth (Table 3 and 5). Puddled transplanted rice, when combined with soil and foliar zinc applications, exhibited significantly higher AGR at 30 days after sowing (DAS), highlighting the positive effect of zinc on early growth. Conversely, aerobic rice cultivation without zinc resulted in lower AGR, emphasizing the importance of zinc supplementation. The incorporation of rice residue did not initially affect AGR but showed benefits in subsequent years, indicating a longer-term impact of residue management. Towards harvest, AGR declined notably in transplanted rice without zinc initially and in aerobic rice without zinc later in the growth cycle, emphasizing the critical role of zinc in sustaining growth throughout the cropping season. At crop growth stages (CGR), wet direct-seeding of rice combined with soil zinc application and foliar zinc spray resulted in notably higher growth rates both at the early stage (30 DAS) and at harvest, highlighting the efficacy of zinc application in promoting sustained growth. Aerobic rice establishment with zinc also exhibited enhanced growth rates compared to methods without zinc, emphasizing the positive impact of zinc across different rice cultivation systems (Table 4). Analysis of net assimilation rates (NAR) revealed similar trends, with wet direct-seeding combined with zinc application showing significantly higher NAR compared to treatments without zinc. Aerobic rice cultivation without zinc consistently exhibited the lowest NAR throughout the study period, underlining the necessity of zinc supplementation for optimal assimilation rates. The study also noted the effects of rice residue incorporation, with positive trends observed with increased residue levels in some instances. Retention of rice straw residue in the kharif season significantly increased NAR, demonstrating the potential benefits of residue management on crop assimilation rates.

Transplanting rice led to higher plant height and leaf area index compared to other establishment methods. This increase in leaf area index suggests a larger surface area available for photosynthesis, while taller plants ensure greater light interception. Additionally, wider spacing and lower plant density associated with transplanting facilitate enhanced photosynthate production and accumulation of dry matter. Furthermore, the process of water pounding during transplanting serves to suppress weed growth and mitigate the stress of transplanting, promoting rapid seedling growth. Bhandari et al. (2020) and Midya et al. (2021) also observed significantly higher dry matter accumulation under conventional puddling and transplanting methods. The application of zinc, both to the soil and as foliar spray, was found to enhance rice dry matter accumulation. Zinc plays a crucial role in plant metabolism, regulating enzymes like carbonic anhydrase involved in carbon dioxide fixation and antioxidant enzymes like superoxide dismutase and catalase, which protect against oxidative stress in plant cells. This regulation aids in nutrient distribution towards generative

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plant organs, ultimately contributing to increased dry matter accumulation. This finding aligns with previous studies by Amanullah and Inamullah (2016), Ghoneim (2016), and Saikh et al. (2022), which also reported increased dry matter accumulation in rice following zinc application via soil and foliar methods.

**Table 3: Effect of different treatments on Absolute Growth Rate (cm day$^{-1}$) in rice crop**

| Treatment | 0-30 DAS | | 30-60 DAS | | 60-90 DAS | | 90 DAS-At harvest | |
|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 |
| **Rice establishment methods** | | | | | | | | |
| **M1** | 1.65 | 1.29 | 1.02 | 0.95 | 0.72 | 0.85 | 0.07 | 0.12 |
| **M2** | 1.38 | 1.27 | 0.99 | 0.86 | 0.70 | 0.93 | 0.30 | 0.05 |
| **M3** | 1.34 | 1.14 | 0.90 | 0.85 | 0.85 | 0.99 | 0.14 | 0.07 |
| **M4** | 1.59 | 1.34 | 1.24 | 0.99 | 0.55 | 0.80 | 0.11 | 0.10 |
| **M5** | 1.37 | 1.27 | 1.07 | 0.96 | 0.74 | 0.82 | 0.16 | 0.10 |
| **M6** | 1.44 | 1.23 | 0.88 | 0.77 | 0.85 | 1.09 | 0.14 | 0.02 |
| **SEm±** | 0.02 | 0.02 | 0.02 | 0.04 | 0.05 | 0.05 | 0.05 | 0.02 |
| **LSD** | 0.06 | 0.05 | 0.07 | 0.14 | 0.14 | 0.15 | 0.16 | 0.06 |
| **Rice residue retention in rabi season** | | | | | | | | |
| **S1** | 1.46 | 1.21 | 1.01 | 0.91 | 0.73 | 0.91 | 0.11 | 0.06 |
| **S2** | 1.47 | 1.27 | 1.03 | 0.91 | 0.72 | 0.96 | 0.17 | 0.05 |
| **S3** | 1.46 | 1.30 | 1.01 | 0.87 | 0.75 | 0.88 | 0.17 | 0.05 |
| **SEm±** | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.04 | 0.04 | 0.03 |
| **LSD** | NS | 0.04 | NS | NS | NS | NS | NS | NS |

**Table 4: Effect of different treatments on Crop Growth Rate (g m$^{-2}$ day$^{-1}$) in rice crop**

| Treatment | 0-30 DAS | | 30-60 DAS | | 60-90 DAS | | 90 DAS-At harvest | |
|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 |
| **Rice establishment methods** | | | | | | | | |
| **M1** | 2.04 | 2.02 | 12.50 | 12.46 | 14.91 | 14.86 | 3.27 | 3.30 |

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|---|---|---|---|---|---|---|---|---|
| **M2** | 2.44 | 2.41 | 11.44 | 11.41 | 9.49 | 9.39 | 4.91 | 5.05 |
| **M3** | 1.76 | 1.72 | 11.77 | 11.73 | 9.75 | 9.73 | 5.03 | 5.16 |
| **M4** | 2.19 | 2.14 | 13.07 | 13.03 | 15.25 | 15.25 | 3.63 | 3.69 |
| **M5** | 2.73 | 2.66 | 11.83 | 11.80 | 10.03 | 10.06 | 5.12 | 5.26 |
| **M6** | 2.01 | 1.98 | 11.85 | 11.80 | 10.61 | 10.58 | 5.26 | 5.43 |
| **SEm±** | 0.03 | 0.03 | 0.18 | 0.13 | 0.41 | 0.27 | 0.39 | 0.35 |
| **LSD** | 0.10 | 0.09 | 0.58 | 0.41 | 1.29 | 0.86 | 1.22 | 1.09 |
| **Rice residue retention in rabi season** | | | | | | | | |
| **S1** | 2.17 | 2.15 | 12.08 | 12.02 | 11.60 | 11.35 | 4.53 | 4.51 |
| **S2** | 2.18 | 2.17 | 12.12 | 12.30 | 11.74 | 11.56 | 4.56 | 4.77 |
| **S3** | 2.24 | 2.15 | 12.03 | 11.81 | 11.69 | 12.02 | 4.52 | 4.67 |
| **SEm±** | 0.02 | 0.02 | 0.11 | 0.11 | 0.27 | 0.17 | 0.25 | 0.28 |
| **LSD** | NS | NS | NS | 0.33 | NS | 0.51 | NS | NS |

**Table 5: Effect of different treatments on Net Assimilation Rate (g $g^{-1}$ $day^{-1}$) in rice crop**

| **Treatment** | **0-30 DAS** | | **30-60 DAS** | | **60-90 DAS** | | **90 DAS-At harvest** | |
|---|---|---|---|---|---|---|---|---|
| | **2021** | **2022** | **2021** | **2022** | **2021** | **2022** | **2021** | **2022** |
| **Rice establishment methods** | | | | | | | | |
| **M1** | 0.74 | 0.74 | 4.00 | 3.72 | 3.80 | 3.41 | 0.87 | 0.81 |
| **M2** | 0.76 | 0.73 | 3.98 | 3.85 | 2.39 | 2.23 | 1.30 | 1.26 |
| **M3** | 0.57 | 0.57 | 4.37 | 4.15 | 2.67 | 2.56 | 1.50 | 1.46 |
| **M4** | 0.80 | 0.78 | 4.04 | 3.67 | 3.68 | 3.40 | 0.92 | 0.88 |
| **M5** | 0.98 | 0.96 | 3.80 | 3.61 | 2.42 | 2.29 | 1.31 | 1.34 |
| **M6** | 0.65 | 0.66 | 4.38 | 4.13 | 2.83 | 2.73 | 1.53 | 1.64 |
| **SEm±** | 0.01 | 0.01 | 0.06 | 0.04 | 0.11 | 0.07 | 0.10 | 0.10 |
| **LSD** | 0.04 | 0.04 | 0.20 | 0.13 | 0.36 | 0.23 | 0.30 | 0.32 |

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| **Rice residue retention in rabi season** | | | | | | | | |
| **S1** | 0.73 | 0.75 | 4.13 | 3.70 | 2.99 | 2.63 | 1.24 | 1.22 |
| **S2** | 0.76 | 0.79 | 4.08 | 3.99 | 2.94 | 2.84 | 1.24 | 1.24 |
| **S3** | 0.76 | 0.68 | 4.07 | 3.87 | 2.96 | 2.84 | 1.23 | 1.24 |
| **SEm±** | 0.01 | 0.01 | 0.05 | 0.05 | 0.07 | 0.05 | 0.07 | 0.07 |
| **LSD** | NS | 0.02 | NS | 0.13 | NS | 0.14 | NS | NS |

***Developmental studies:*** The number of days required by a crop to achieve flowering and physiological maturity is a varietal character and depends on weather conditions, mainly temperature varying slightly due to the cultivation practices. Hence, it is clear from Table 6 that different establishment method with or without zinc interventions as well as residue retention treatments failed to significantly influence days to physiological maturity of rice crop.

**Table 6: Effect of different treatments on developmental studies in rice crop**

| | **Days to 50% flowering** | | **Days to physiological maturity** | |
|---|---|---|---|---|
| **Treatment** | **2021** | **2022** | **2021** | **2022** |
| **Rice establishment methods** | | | | |
| **M1** | 82.79 | 81.79 | 112.79 | 111.79 |
| **M2** | 83.12 | 82.12 | 113.12 | 112.12 |
| **M3** | 82.89 | 81.89 | 112.89 | 111.89 |
| **M4** | 83.10 | 82.10 | 113.10 | 112.10 |
| **M5** | 82.79 | 81.79 | 112.79 | 111.79 |
| **M6** | 82.99 | 81.99 | 112.99 | 111.99 |
| **SEm±** | 2.53 | 1.62 | 2.53 | 1.62 |
| **LSD** | NS | NS | NS | NS |
| **Rice residue retention in rabi season** | | | | |
| **S1** | 82.98 | 81.98 | 112.98 | 111.98 |
| **S2** | 82.93 | 81.93 | 112.93 | 111.93 |
| **S3** | 82.92 | 81.92 | 112.92 | 111.92 |

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|---|---|---|---|---|
| **SEm±** | 1.42 | 1.44 | 1.42 | 1.44 |
| **LSD** | NS | NS | NS | NS |

## 4. CONCLUSION

Presentinvestigation-based outcomes revealed that integrating transplanting method of rice establishment with soil application of $ZnSO_4$ @ 12.5 kg $ha^{-1}$ and foliar spray of $ZnSO_4$ @ 0.5% at flowering and early milk stages resulted in significantly higher plant height, leaf area index, absolute crop growth rate and net assimilation rate. Therefore, this investigation concluded that transplanting method of rice establishment with soil application of $ZnSO_4$ @ 12.5 kg $ha^{-1}$ and foliar spray of $ZnSO_4$ @ 0.5% at flowering and early milk stages can be encouraged to the stakeholders in order to promote better growth and development of rice crop plants under the conditions of North-Western Himalayan region of India.

## REFERENCES

Amanullah I and Inamullah X. 2016. Dry matter partitioning and harvest index differ in rice genotypes with variable rates of phosphorus and zinc nutrition. *Rice Science* 23(2): 78-87

Bhandari S, Sapkota S and Gyawali C. 2020. Effect of different methods of crop establishment on growth and yield of a spring rice at Janakpurdham-17, Dhanusha. *Malaysian Journal of Sustainable Agriculture* 4(1): 10-15

Dou Z, Li Y, Guo H, Chen L, Jiang J, Zhou Y, Xu Q, Xing Z, Gao H and Zhang H. 2021. Effects of mechanically transplanting methods and planting densities on yield and quality of Nanjing 2728 under Rice-Crayfish continuous production system. *Agronomy* 11: 488

Ghoneim AM. 2016. Effect of different methods of zinc application on rice growth, yield and nutrients dynamics in plant and soil. *Journal of Agriculture and Ecology Research International* 6(2): 1-9

Kadiyala MDM, Mylavarapu RS, Li YC, Reddy GB and Reddy MD. 2012. Impact of aerobic rice cultivation on growth, yield and water productivity of rice-maize rotation in semiarid tropics. *Agronomy* 104(6): 1757

Kaur R, Kaur S, Deol JS, Sharma R, Kaur T, Brar AS and Choudhary OP. 2021. Soil Properties and weed dynamics in wheat as affected by rice residue management in the rice–wheat cropping system in south Asia: a Review. *Plants*, 10(5): 953

Kingra PK, Kaur R and Kaur S. 2019. Climate change impacts on rice (*Oryza sativa*) productivity and strategies for its sustainable management. *The Indian Journal of Agricultural Sciences* 89(2): 171-180

Maniraj N, Revathi P, Suneetha Devi KB and Chandra Shaker K. 2022. Growth and yield attributes of rice as influenced by systems of cultivation in different varieties. *Biological Forum-AN International Journal* 14(2): 1541-1545

Midya A, Saren BK, Dey JK, Maitra S, Praharaj S, Gaikwad DJ, Gaber A, Alsanie WF and Hossain A. 2021. Crop establishment methods and integrated nutrient management

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improve: par I crop performance, water productivity and profitability of rice (*Oryza sativa* L.) in the lower Indo-Gangetic Plain, India. *Agronomy* 11(9): 1860

Patel DP, Das A, Munda GC, Ghosh PK, Bordoloi JS and Kumar M. 2010. Evaluation of yield and physiological attributes of high-yielding rice varieties under aerobic and flood-irrigated management practices in mud-hills ecosystem. *Agricultural Water Management* 97(9): 1268-1276

R Core Team. 2023. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria

Rao AN, Johnson DE, Sivaprasad B, Ladha JK and Mortimer AM. 2007. Weed management in direct-seeded rice. *Advances in agronomy* 93: 153-255

Saikh R, Murmu K, Sarkar A, Mondal R and Jana K. 2022. Effect of foliar zinc application on growth and yield of rice (*Oryza sativa*) in the Indo-Gangetic Plains of India. *Nusantara Bioscience* 14(2): 182-187

Singh AK, Bhushan M, Meena MK and Upadhyaya A. 2012. Effect of sulphur and zinc on rice performance and nutrient dynamics in plants and soil of Indo Gangetic Plains. *Journal of Agricultural Science* 4(11): 162-170

Singh AK, Meena MK and Bharati RC. 2011. Sulphur and zinc nutrient management in rice-lentil cropping system. In: International Conference on "Life Science Research for Rural and Agricultural Development" (pp 66-67). 27-29 December, 2011, CPRS Patna (Bihar)

Solanki M. 2021. The Zn as a vital micronutrient in plants. *Journal of microbiology, biotechnology and food sciences* 11(3): e4026-e4026.

Wissuwa M, Ismail AM and Yanagihara S. 2006. Effects of zinc deficiency on rice growth and genetic factors contributing to tolerance. *Plant Physiology* 142(2): 731-741

Zayed BA, Ghazy HA, Negm ME, Bassiouni SM, Hadifa AA, El-Sharnobi DE, Abdelhamed MM, Abo-Marzoka EA, Okasha AM, Elsayed S and Farooque AA. 2023. Response of varied rice genotypes on cell membrane stability, defense system, physio-morphological traits and yield under transplanting and aerobic cultivation. *Scientific Reports* 13: 5765

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