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Effect of Zinc Application Methods on Root and Shoot Growth of Transplanted Summer Rice under different Irrigation Regimes in Lateritic Soil of West Bengal

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ABSTRACT: The experiment was carried out during the *boro* seasons of 2021 and 2022 at the Agricultural Farm of the Institute of Agriculture, Visva-Bharati, Sriniketan, in West Bengal, India. The experimental design was a split-plot with twenty different treatment combinations and was replicated three times. The study included four different irrigation schedules and five different zinc application methods. The main plot consists of irrigation treatments *viz*., I_1- irrigation of 5 cm when water level falls below 5 cm from soil surface in the perforated PVC water tube, I_2- irrigation of 5 cm at one day after disappearance of ponded water, I_3- irrigation of 5 cm at three days after disappearance of ponded water and I_4- irrigation of 5 cm at hair crack stage of the soil. The sub plot comprised of zinc application treatments included: Zn_0- control; Zn_1- 25 kg $ZnSO_4$, $7H_2O$ ha^{-1} as soil application; Zn_2- 0.5 % $ZnSO_4$, $7H_2O$ as foliar application at 15 and 45 DAT; Zn_3- 0.3 % $ZnSO_4$, $7H_2O$ as seed priming; and Zn_4- 0.5 % $ZnSO_4$, $7H_2O$ as nursery root dipping. The results showed that the application of irrigation of 5 cm at one day after disappearance of ponded water (I_2) and irrigation of 5 cm at three days after disappearance of ponded water (I_3) along with application of zinc through 0.3% $ZnSO_4$, $7H_2O$ as seed priming (Zn_3) registered higher root and shoot dry weight as well as root shoot ratio. Thus, these treatment combinations may be recommended for higher growth parameters of transplanted summer rice in lateritic soil of West Bengal.

Keywords: Irrigation scheduling, root shoot ratio, shoot dry weight, summer rice, zinc.

INTRODUCTION

In India, rice (*Oryza sativa* L.) is a fundamental food crop, spanning 43.82 million hectares and yielding 112.44 million tonnes. West Bengal plays a significant role, accounting for 12.38% of the area and 13.62% of the production of rice in India (Agricultural Statistics at a Glance, 2021). The production of one kilogram of rice necessitates between 3000 and 5000 liters of water, depending on the variety and cultivation methods. This is significantly more than the water requirements for crops like wheat and maize (Dey *et al.*, 2018). Both surface and underground water resources are depleting, posing a challenge to rice production. The escalating crisis of freshwater availability threatens the sustainability of irrigated rice farming in most rice-producing countries. It is projected that about 15 and 22 million hectares of rice fields in Asian countries that rely on irrigation may face physical and economic water scarcity, respectively, in the future (Tuong and Bouman 2003). To mitigate this, the International Rice Research Institute has developed a water-conserving technique called Alternate Wetting and Drying (AWD) (IRRI, 2009). This method, which can reduce water usage by up to 30%, involves cyclic periods of field flooding and drying (Tuong *et al.*, 2005; Bouman *et al.*, 2007). AWD can be implemented using a perforated water tube to monitor field water depth and maintain the alternating wet and dry periods based on the water level (IRRI, 2013). Research indicates that this approach can conserve 25-35% of water without affecting rice yield (Kulkarni, 2011; Kishor *et al.*, 2017). The drying period of the soil can range from a single day to over ten days, depending on the soil type and variety. In the Alternate Wetting and Drying (AWD) method, the field is flooded and then allowed to dry for 2 to 7 days after the water has evaporated, before it is flooded again. The field is re-flooded when plants show signs of water stress or when hairline cracks appear on the soil surface (Tuong *et al.*, 2005; Bouman *et al.*, 2007). However, the duration of the re-flooding depends on several factors, including the soil water potential, the soil type, the groundwater depth, and the number of days since the water disappeared (Hira *et al.*, 2002; Bouman *et al.*, 2007). During the drying period, the roots receive oxygen from the soil and the aerenchyma cells for respiration, and the oxygen-rich soil pores contribute to root development. This promotes root growth, enhancing the soil's capacity to retain water and nutrients (Yang *et al.*, 2009).

Zinc (Zn) is a vital nutrient for crops, influencing growth, metabolism, seed germination, and seedling development (Cakmak, 2008). However, rice grains typically have lower Zn content than other cereals, which can negatively affect seedling growth, development, and grain yield (Slaton *et al.*, 2001). Therefore, enhancing seed Zn content before sowing can significantly improve seed germination and seedling growth, particularly in Zn-deficient soils (Ajouri *et al.*, 2004). Zinc (Zn) is primarily absorbed by rice plants through their roots. To enhance this uptake, the availability of Zn in the rhizosphere, the soil region that surrounds the roots, must be increased. It has been reported that under conditions of nutrient deficiency, plants tend to modify their root size and structure to optimize nutrient acquisition (Lu *et al.*, 2008). The low Zn concentration in rice is believed to be an indirect consequence of breeding for high yield and resistance to pests and diseases. Furthermore, modern high-yielding varieties extract substantial amounts of soil Zn with each harvest, reducing the residual soil Zn concentration and contributing to a lower future grain Zn concentration. The availability of Zn for plant uptake from the soil is influenced by the concentrations of macro- and micro-nutrients, as well as the physical, chemical, and biological properties of the soil (Frageria *et al.*, 2011). Seed priming, a pre-sowing technique, can enhance seedling development by modulating pre-germination metabolic activity before radicle emergence, leading to faster and more synchronized seed germination and improved seedling establishment and plant growth (Bradford, 1986; Taylor *et al.*, 1998). Dipping seedling roots in a fertilizer solution is often more practical and feasible than applying nutrients through foliar or soil methods (Yoshida *et al.*, 1970; Katyal and Ponnamperuma 1974). Studies have shown that Gajalakshmi *et al.* (2022) they explored the impact of priming seeds with various sources and concentrations of Zinc (Zn) on plant establishment and growth and suggested that priming seeds with 0.50% $ZnSO_4$ notably enhanced the germination rate, germination speed, germination energy, and germination index. Additionally, it also improved the growth attributes of the seedlings, such as the length of the shoot and root, as well as the dry weight. Keeping all the information in preview, the present research investigation was laid out to find out the shoot and root parameters in relation to their interactions under a different irrigation scheduling and zinc application.

MATERIALS AND METHODS

A. Site and plant materials

The study was conducted during the *boro* seasons (February-May) of 2021 and 2022 at the Agricultural Farm of the Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal, India. The location of the experimental station is 23°39′N, 87°42′E, and is situated 58.9 m above sea level with a typical semi-arid tropical climate. The total rainfall during the experimental period was 142.2 mm and 174.0 mm for the respective years. The soil at the experimental site is classified as sandy loam with good internal drainage. The soil contains 0.43% organic carbon (Walkley and Black 1934), 296.2 kg ha^{-1} of nitrogen that can be oxidized by alkaline permanganate (Subbiah and Asija 1956), 27.3 kg ha^{-1} of available phosphorus (Bray and Kurtz 1954), 193.2 kg ha^{-1} of potassium that can be exchanged with 1 N ammonium acetate (Hanway and Heidel 1952), and 0.48 ppm of available zinc extracted by DTPA (Lindsay and Norvell 1978). The soil pH was 5.82, measured in a 1:2.5 soil to water ratio (Prasad *et al.*, 2006).The variety MTU 1010 was used as study material. MTU 1010 is an elite, high-yielding, short duration, widely cultivated mega variety having long slender grain.

B. Experimental treatments and design

The experiment was conducted using a split-plot design with each plot measuring 5×6 m² and the same unit of cultivation was used indiscriminately in which treatments were replicated three times, resulting in twenty different treatment combinations. The experiment included four different irrigation schedules in the main plot *viz.,* I_1: Irrigation of 5 cm, when water level falls below 5 cm from soil surface in the perforated PVC water tube, I_2: Irrigation of 5 cm at one day after disappearance of ponded water, I_3: Irrigation of 5 cm at three days after disappearance of ponded water, and I_4: Irrigation of 5 cm at hair crack stage of the soil. In addition to these, five different zinc application treatments were used in the sub plot *viz.,* Zn_0: Control, Zn_1: 25 kg $ZnSO_4.7H_2O$ ha^{-1} as soil application, Zn_2: 0.5% $ZnSO_4.7H_2O$ as foliar application, Zn_3: 0.3 % $ZnSO_4.7H_2O$ as seed priming, and Zn_4: 0.5 % $ZnSO_4.7H_2O$ as nursery root dipping. To prevent seepage loss, experimental plots and replications were separated by a bund of 0.75 m width. The main irrigation channel and the buffer channel between replications were each 1.0 m wide. Irrigation was given by flooding method; a uniform pre-sowing irrigation was applied to all the plot for preparation of good seedbed and water was given as per need to maintain wet condition of the soil. The perforated PVC pipe having height 15 cm and diameter 10 cm with a demarcation of 5 cm level from the soil surface was laid in the plot having treatment I_1 before transplanting. A demarcated peg having height of 5 cm from the soil surface was installed in each plot having the treatment I_2, I_3 and I_4. Before imposing irrigation scheduling treatments each plot was irrigated uniformly. Thereafter, alternate wetting and drying cycle was initiated. In the treatment I_1 when the water level falls 5 cm below the soil surface in the perforated PVC pipe, the field was irrigated upto the soil surface level. In the treatments I_2 and I_3, each plot was irrigated to a demarcated height of 5 cm, one day after disappearance of ponded water and three days after disappearance of ponded water, respectively. Each plot was irrigated to a demarcated height of 5 cm in the treatment I_4 with the development of hairline cracks on the soil surface. The number of irrigation events was recorded throughout the experiment.

Zinc was applied by foliar application @ 0.5% zinc sulfate ($ZnSO_4$, $7H_2O$) solution at 15 and 45 DAT. The solution was prepared by dissolving 5 g of $ZnSO_4$ powder in one litre of tap water. The prepared solution was poured into the battery-operated sprayer and was applied by evenly spraying the solution until the whole plants were wet at morning. The amount of water was

500-750 litres for 1 ha area. Seeds were primed with zinc sulphate heptahydrate @ 0.3% solution by using tap water before sowing. The ratio of seed weight to solution volume was 1:1.5 (w/v). Seeds were soaked in respective solution for 18 h at 25±2°C. Thereafter seeds were removed, given three surface washing. Afterwards, primed seeds were allowed to re-dry with forced air under shade near to original weight. For root dipping purpose, 0.5% $ZnSO_4$, $7H_2O$ suspension (7500g $ZnSO_4$, $7H_2O$ in 1500 litres water/ha) was prepared and roots of uprooted seedlings of rice were dipped for 24 hours in a plastic-coated tank in the field.

C. Crop husbandry

Transplantation of the crop occurred on February 11th, 2021, in the first year, and on February 7th, 2022, in the second year. The planting was done with a row-to-row spacing of 20 cm and a plant-to-plant spacing of 15 cm. The crop was fertilized with 120 kg of nitrogen (N), 60 kg of phosphorus (P_2O_5), and 60 kg of potassium (K_2O) per hectare. The phosphorus was applied at the basal stage, while the nitrogen was divided into three parts: 25% at the basal stage, 50% at tillering, and 25% at panicle initiation. The potassium was also divided, with three-fourth applied as a basal dose before transplanting and one-fourth applied as top dressing at the panicle initiation stage.

Determination of root and shoot dry weight

Root dry weight. Five hills were selected for root dry weight at random from the sample rows and were cut at the ground level to remove the shoot portion at 40 DAT. The hills were kept in the middle and a PVC perforated tube was inserted in the soil. The height of the insertion was 15 cm and the diameter of the perforated tube was 10 cm. The dirt and root masses were then collected in netted plastic bags and washed in irrigation channels to get most of the soil off and finally under running water to get any soil that had stuck to them. After thorough cleaning, the remaining shoot segments right above the root biomass were removed with the use of scissors. The five hills of root samples from each plot were stored in paper bags and dried in a dryer at 65°C until they reached a consistent weight. The weights were measured, recorded and converted to g hill^{-1}.

Shoot dry weight. Five hills were selected for determination of shoot dry weight. The selected hills were cut at ground level in the earmarked area in each plot kept for the purpose of destructive sampling at 40 DAT. Plants of each plot were separated into green leaves and stems and dried in a hot air oven, kept at 65°C for 72 hours till constant weights were obtained. The dry weight of leaves and stems were recorded and used for determination of shoot dry weight. The average weight was calculated and expressed as shoot dry weight g hill^{-1}.

Statistical analysis. All the data obtained from rice crop for consecutive two years were statistically analyzed using the F-test as per the procedure given by Gomez and Gomez (1984). LSD values at P=0.05 were used to determine the significance of differences between treatment means. The analysis of data on root dry weight and shoot weight was performed using SPSS software.

RESULTS AND DISCUSSION

A. Root dry weight

In a study conducted over two years (2021 and 2022), different treatments combinations were applied to rice plants to observe their effects on root dry weight at 40 DAT in Table 1. The treatment combination with irrigation of 5 cm at three days after disappearance of ponded water and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_3Zn_3) recorded the highest root dry (4.50 g hill^{-1}) and was closely followed by the treatments combinations, irrigation of 5 cm, when water level falls below 5 cm from soil surface in the perforated PVC water tube and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_1Zn_3) and irrigation of 5 cm at one day after disappearance of ponded water and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_2Zn_3) with root dry weight of 4.38 and 4.35 g hill^{-1}, respectively in the year 2021. Whilst, in the year 2022 the treatment combination with irrigation of 5 cm at one day after disappearance of ponded water and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_2Zn_3) reported the highest root dry (8.05 g hill^{-1}). This was closely followed by the treatment combination irrigation of 5 cm at three days after disappearance of ponded water and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_3Zn_3) (7.69 g hill^{-1}). From the pooled analysis of data on root dry weight of both the years, the treatment combination with irrigation of 5 cm at one day after disappearance of ponded water and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_2Zn_3) registered the highest root dry (6.20 g hill^{-1}) and was closely followed by the treatment combination irrigation of 5 cm at three days after disappearance of ponded water and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_3Zn_3) (6.09 g hill^{-1}). On the other hand, the treatment combination having application of irrigation of 5 cm at hair crack stage of the soil and control (I_4Zn_0) consistently resulted in the lowest root dry weight in both years, with 2.17 g hill^{-1} in 2021 and 2.11 g hill^{-1} in 2022, leading to the lowest average root dry weight of 2.14 g hill^{-1} in the pooled data. Pascual and Wang (2017) demonstrated that rice plants which were watered every third day developed roots that were longer (23.25 cm), had a larger volume (52.50 cm^3), and were heavier (23.3 g hill^{-1}) compared to rice plants that were watered continuously. In a study carried out by Keerthi *et al.* (2018) in aerobic rice showed the highest root volume (16.9, 27.1 cc per hill) and root dry weight (6.1, 12.9 g hill^{-1}) during the active tillering and flowering stages. This was achieved when the irrigation was applied at an IW/CPE ratio of 1.0 until the panicle initiation stage, followed by an IW/CPE ratio of 1.2 until the dough stage. Similarly, Reddy *et al.* (2023) also conferred that I_4 (maintaining at 100 % FC) treatment recorded significantly higher root dry weight (139.73 g m^{-2}) than in I_1 (scheduling of irrigation at 60-70 % field capacity (FC) throughout the season), I_2 (scheduling of irrigation at 80-90 % FC throughout the season) and I_3 (scheduling of irrigation at 60-70 % FC at vegetative stage and at 80-90 % FC at reproductive stage) under different moisture regimes.

Also, zinc priming significantly enhanced root growth, germination rate, root number, and dry weight were much higher than unprimed seed (Chanakan *et al.,* 2012). Studies also revealed that priming seed with zinc led the succinate dehydrogenase activity of hyphae of *Serendipita indica*, in symbiotic association with rice seedling roots that aids in increment in length and weight accumulation (Sadeghizadeh and Zarea 2022). Rautaray and Sucharita (2023) conferred that the technique of immersing roots in a zinc sulphate solution is particularly effective in scenarios where there is a temporary deficiency of native zinc. This deficiency can be caused by the adverse impact of high levels of phosphorous, which can be introduced through basal application and wet soil puddling. The initial requirement of zinc is fulfilled through the root dipping process; while the subsequent need for zinc is met from the soil once the available phosphorous reaches a balance with the soil particles. This process, in turn, leads to an enhancement of root parameters.

Table 1: Interaction effect between irrigation scheduling and zinc application on root dry weight of summer rice at 40 DAT.

Root dry weight (g hill^{-1})			
Irrigation scheduling × Method of zinc application	**2021**	**2022**	**Pooled**
$I_1 Zn_0$	2.64	2.72	2.68
$I_1 Zn_1$	3.76	3.69	3.73
$I_1 Zn_2$	4.07	4.02	4.05
$I_1 Zn_3$	4.38	5.13	4.75
$I_1 Zn_4$	3.31	4.16	3.73
$I_2 Zn_0$	2.52	3.79	3.16
$I_2 Zn_1$	3.23	5.52	4.38
$I_2 Zn_2$	3.91	4.19	4.05
$I_2 Zn_3$	4.35	8.05	6.20
$I_2 Zn_4$	3.81	5.24	4.53
$I_3 Zn_0$	2.55	3.84	3.19
$I_3 Zn_1$	3.12	3.50	3.31
$I_3 Zn_2$	2.85	5.26	4.06
$I_3 Zn_3$	4.50	7.69	6.09
$I_3 Zn_4$	3.40	6.36	4.88
$I_4 Zn_0$	2.17	2.11	2.14
$I_4 Zn_1$	2.52	2.36	2.44
$I_4 Zn_2$	2.15	3.34	2.75
$I_4 Zn_3$	3.26	4.90	4.08
$I_4 Zn_4$	2.59	4.47	3.53
Interaction (Irrigation scheduling × Method of zinc application)			
SEm (±)	0.20	0.34	0.20
LSD at 5%	0.59	0.98	0.56

I_1: Irrigation of 5 cm, when water level falls below 5 cm from soil surface in the perforated PVC water tube, I_2: Irrigation of 5 cm at one day after disappearance of ponded water, I_3: Irrigation of 5 cm at three days after disappearance of ponded water, I_4: Irrigation of 5 cm at hair crack stage of the soil; Zn_0: Control, Zn_1: 25 kg $ZnSO_4$, $7H_2O$ ha^{-1} as soil application, Zn_2: 0.5 % $ZnSO_4$, $7H_2O$ as foliar application at 15 and 45 DAT, Zn_3: 0.3 % $ZnSO_4$, $7H_2O$ as seed priming, Zn_4: 0.5 % $ZnSO_4$, $7H_2O$ as nursery root dipping

B. Shoot dry weight

The data pertaining to statistical analysis of study conducted over two years (2021 and 2022), showed that irrigation scheduling and zinc management had significant effect on shoot dry weight at 40 DAT in Table 2. In 2021, treatment combination having irrigation of 5 cm, when water level falls below 5 cm from soil surface in the perforated PVC water tube and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_1Zn_3) reported the highest shoot dry weight of 8.41g hill^{-1}, followed by irrigation of 5 cm at one day after disappearance of ponded water and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_2Zn_3) with shoot dry weight 7.83g hill^{-1}, irrigation of 5 cm, when water level falls below 5 cm from soil surface in the perforated PVC water tube and 0.5 % $ZnSO_4.7H_2O$ as nursery root dipping (I_1Zn_4) (7.77 g hill^{-1}) and irrigation of 5 cm at one day after disappearance of ponded water and 0.5 % $ZnSO_4.7H_2O$ as nursery root dipping (I_2Zn_4) with shoot dry weight of 7.59g hill^{-1}. The least shoot dry weight was recorded in treatment combination of irrigation of 5 cm at hair crack stage of the soil and control (I_4Zn_0) with5.20g hill^{-1}.In 2022, similar trends persisted with irrigation of 5 cm at one day after disappearance of ponded water and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_2Zn_3) recording the highest shoot dry weight of 9.38g hill^{-1} and was closely followed by treatments included irrigation of 5 cm at three days after disappearance of ponded water and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_3Zn_3) having shoot dry weight of 9.09g hill^{-1} and irrigation of 5 cm, when water level falls below 5 cm from soil surface in the perforated PVC water tube and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_1Zn_3) with shoot dry weight of 8.04g hill^{-1}.On the other hand, treatment combination having application of irrigation of 5 cm at hair crack stage of the soil and control (I_4Zn_0) recorded the lowest shoot dry weight at 4.90g hill^{-1}. When considering the pooled data from both years, the treatment combination of irrigation of 5 cm at one day after disappearance of ponded water and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_2Zn_3) consistently resulted in the highest average shoot dry weight at 8.61g $hill^{-1}$.Moreover, this was closely followed by the treatment combination irrigation of 5 cm at three days after disappearance of ponded water and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_3Zn_3),irrigation of 5 cm, when water level falls below 5 cm from soil surface in the perforated PVC water tube and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_1Zn_3) and irrigation of 5 cm at hair crack stage of the soil and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_4Zn_3) with shoot dry weight of 8.26, 8.23 and 7.42 respectively. Conversely, the treatment combination having application of irrigation of 5 cm at hair crack stage of the soil and control (I_4Zn_0) had the lowest pooled shoot dry weight at 5.05g $hill^{-1}$. Gajalakshmi *et al.* (2022) reported that applying zinc sulphate ($ZnSO_4$) via seed priming could increase the plant's zinc uptake, leading to enhanced growth and dry matter accumulation. Kumar *et al.* (2013) found that irrigation at I DADPW resulted in the highest average growth characteristics, such as dry matter accumulation (17.5 g $hill^{-1}$), which were significantly higher than those obtained with irrigation at 3 and 5 DADPW. This finding aligns with Kumar *et al.* (2014). Similarly, Mondal *et al.* (2020) found that a combined treatment of irrigation at 100% of cumulative pan evaporation (CPE) and zinc application through seed coating or seed priming resulted in a higher accumulation of dry matter in rice grown in lateritic soil.

Table 2: Interaction effect between irrigation scheduling and zinc application on shoot dry weight of summer rice at 40 DAT.

Shoot dry weight (g $hill^{-1}$)			
Irrigation scheduling × Method of zinc application	**2021**	**2022**	**Pooled**
$I_1 Zn_0$	5.41	5.57	5.49
$I_1 Zn_1$	6.71	6.34	6.53
$I_1 Zn_2$	6.83	5.82	6.33
$I_1 Zn_3$	8.41	8.04	8.23
$I_1 Zn_4$	7.77	6.53	7.15
$I_2 Zn_0$	6.27	6.42	6.35
$I_2 Zn_1$	7.09	6.83	6.96
$I_2 Zn_2$	6.95	7.62	7.29
$I_2 Zn_3$	7.83	9.38	8.61
$I_2 Zn_4$	7.59	6.70	7.15
$I_3 Zn_0$	6.15	6.21	6.18
$I_3 Zn_1$	6.90	6.68	6.79
$I_3 Zn_2$	7.10	7.18	7.14
$I_3 Zn_3$	7.43	9.09	8.26
$I_3 Zn_4$	7.34	7.38	7.36
$I_4 Zn_0$	5.20	4.90	5.05
$I_4 Zn_1$	5.90	6.77	6.33
$I_4 Zn_2$	6.88	7.21	7.04
$I_4 Zn_3$	7.21	7.63	7.42
$I_4 Zn_4$	6.85	7.27	7.06
Interaction (Irrigation scheduling × Method of zinc application)			
SEm (±)	0.20	0.23	0.15
LSD at 5%	0.58	0.66	0.43

I_1: Irrigation of 5 cm, when water level falls below 5 cm from soil surface in the perforated PVC water tube, I_2: Irrigation of 5 cm at one day after disappearance of ponded water, I_3: Irrigation of 5 cm at three days after disappearance of ponded water, I_4: Irrigation of 5 cm at hair crack stage of the soil; Zn_0: Control, Zn_1: 25 kg $ZnSO_4$, $7H_2O$ ha^{-1} as soil application, Zn_2: 0.5 % $ZnSO_4$, $7H_2O$ as foliar application at 15 and 45 DAT, Zn_3: 0.3 % $ZnSO_4$, $7H_2O$ as seed priming, Zn_4: 0.5 % $ZnSO_4$, $7H_2O$ as nursery root dipping

C. Root: shoot ratio

Table 3 represents the different treatments combinations that were applied to rice plants to observe their effects on root: shoot ratio at 40 DAT. The treatment combination with irrigation of 5 cm at three days after disappearance of ponded water and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_3Zn_3) recorded the highest root: shoot ratio of 0.61 and was closely followed by the treatments combinations, irrigation of 5 cm, when water level falls below 5 cm from soil surface in the perforated PVC water tube and 0.5 % $ZnSO_4$, $7H_2O$ as foliar application at 15 and 45 DAT(I_1Zn_2) and irrigation of 5 cm at one day after disappearance of ponded water and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_2Zn_3) with root: shoot ratio of 0.60 and 0.56, respectively in the year 2021. Meanwhile, in the year 2022 the treatment combination with irrigation of 5 cm at one day after disappearance of ponded water and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_2Zn_3) and irrigation of 5 cm at three days after disappearance of ponded water and 0.5 % $ZnSO_4.7H_2O$ as nursery root dipping (I_3Zn_4) reported the highest root: shoot ratio (0.86). This was closely followed by the treatment combination irrigation of 5 cm at three days after disappearance of ponded water and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_3Zn_3) (0.85). From the pooled analysis of data on root: shoot ratio of both the years, the treatment combination irrigation of 5 cm at three days after disappearance of ponded water and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_3Zn_3) (0.73) and was closely followed by irrigation of 5 cm at one day after disappearance of ponded water and 0.3 % $ZnSO_4.7H_2O$ as seed priming (I_2Zn_3) with root: shoot ratio of 0.71. On the other hand, the treatment combination of application of irrigation of 5 cm at hair crack stage of the soil and 25 kg $ZnSO_4$, $7H_2O$ ha^{-1} as soil application (I_4Zn_1) and irrigation of 5 cm at hair crack stage of the soil and 0.5 % $ZnSO_4$, $7H_2O$ as foliar application at 15 and 45 DAT (I_4Zn_2) resulted in the lowest root: shoot ratio of 0.39 in the pooled data. Root: shoot ratio was significantly improved due to zinc sulphate application and this can be attributed to the better growth characteristic of the crop. Better growth and spread of root are a reason for the better root: shoot ratio. Increased root dry weight was observed with the application of Zn in upland rice (Fageria, 2002; Fageria and Moreira 2015). Fageria and Moreira (2015) also reported that adequate amount of Zn might have improved the root growth which in turn improved the uptake of water and nutrients. These findings pointing the positive effect of Zn in influencing the vegetative growth of the crop.

Table 3: Interaction effect between irrigation scheduling and zinc application on root: shoot ratio of summer rice at 40 DAT.

Root: shoot ratio			
Irrigation scheduling × Method of zinc application	**2021**	**2022**	**Pooled**
$I_1 Zn_0$	0.49	0.49	0.49
$I_1 Zn_1$	0.56	0.58	0.57
$I_1 Zn_2$	0.60	0.69	0.64
$I_1 Zn_3$	0.52	0.64	0.58
$I_1 Zn_4$	0.43	0.65	0.54
$I_2 Zn_0$	0.40	0.59	0.50
$I_2 Zn_1$	0.46	0.81	0.64
$I_2 Zn_2$	0.56	0.55	0.56
$I_2 Zn_3$	0.56	0.86	0.71
$I_2 Zn_4$	0.50	0.78	0.64
$I_3 Zn_0$	0.41	0.62	0.52
$I_3 Zn_1$	0.45	0.52	0.49
$I_3 Zn_2$	0.40	0.74	0.57
$I_3 Zn_3$	0.61	0.85	0.73
$I_3 Zn_4$	0.46	0.86	0.66
$I_4 Zn_0$	0.42	0.43	0.42
$I_4 Zn_1$	0.43	0.35	0.39
$I_4 Zn_2$	0.31	0.46	0.39
$I_4 Zn_3$	0.45	0.64	0.55
$I_4 Zn_4$	0.38	0.62	0.50
Interaction (Irrigation scheduling × Method of zinc application)			
SEm (±)	0.03	0.05	0.03
LSD at 5%	0.08	0.16	0.09

I_1: Irrigation of 5 cm, when water level falls below 5 cm from soil surface in the perforated PVC water tube, I_2: Irrigation of 5 cm at one day after disappearance of ponded water, I_3: Irrigation of 5 cm at three days after disappearance of ponded water, I_4: Irrigation of 5 cm at hair crack stage of the soil; Zn_0: Control, Zn_1: 25 kg $ZnSO_4$, $7H_2O$ ha^{-1} as soil application, Zn_2: 0.5 % $ZnSO_4$, $7H_2O$ as foliar application at 15 and 45 DAT, Zn_3: 0.3 % $ZnSO_4$, $7H_2O$ as seed priming, Zn_4: 0.5 % $ZnSO_4$, $7H_2O$ as nursery root dipping

CONCLUSIONS

From the above discussions, it is clearly concluded that by applying irrigation of 5 cm at one day after disappearance of ponded water (I_2) and irrigation of 5 cm at three days after disappearance of ponded water (I_3) along with application of zinc through 0.3% $ZnSO_4$, $7H_2O$ as seed priming (Zn_3) recorded higher shoot and root dry weight along with root shoot ratio which in due to better root growth facilitation and hence improving the uptake of water and nutrients. This in turn enhances higher growth parameters which may lead to higher productivity in transplanted summer rice.

FUTURE SCOPE

The impact of elevated CO_2 levels on rice root growth under AWD conditions, involving into the role of the plant hormone abscisic acid (ABA) in rice root growth can be investigated further recommending the use of controlled-release nitrogen fertilizer (CRNF) in AWD systems. Further examination can be carried out for investigating the interaction of AWD and zinc application methods with other abiotic stresses such as drought or nutrient deficiency, and the development of drought-resistant rice varieties that are well-adapted to AWD and efficient zinc utilization. Furthermore, future research could focus on local adaptation of these techniques, taking into account local varieties of paddy, traditional farming practices, and socio-economic factors.

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Conflict of Interest. None.

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