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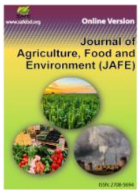

Original Article

Effects of zinc on growth and yield of rice cv. BRRI dhan29 under alternate wetting and drying water management practice

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A B S T R A C T

Insufficient zinc (Zn) and water are key concerns in agricultural production, resulting in lower yields and nutritional qualities. The goal of the study was to figure out how water management and Zn application rates affect the growth and yield of rice. The experiment was carried out in a split-plot design with three replications. The treatments consisted of two factors, a) water management, like 1) Continuous flooding (CF) and 2) Alternate wetting and drying (AWD) system and b) Zn application like 1) Control (0% Zn), 2) 75% Zn, 3) 100% Zn, 4) 125% Zn, and 5) 150% Zn of the recommended dose. All the plots received an equal amount of NPKS fertilizers. The application of Zn in both AWD and CF systems had a significant effect on a number of grains panicle^{-1}, 1000 grain weight and grain yield. The highest value for both yield contributing traits and yield was obtained by the application of 150% Zn in the AWD system. However, the lowest value was found in the control treatment of the CF system for both the yield components and yield. It is also evident that the growth rate of yield components and yield was increased with increased doses of Zn in both AWD and CF systems. In Bangladesh, farmers involved in rice cultivation may be benefited following the treatment of 150% Zn and AWD irrigation systems.

Introduction

Zinc (Zn) is an essential trace element whose deficiency is common in both plants and humans. Zinc deficiency can inhibit plant growth and result in significant yield losses (Tripathi *et al.*, 2015) as it plays critical roles and performs metabolic functions in plants. Deficiency of Zn is still a major factor influencing rice production in many parts of the country. Rice has a higher rate of Zn deficiency than other crops, and making it susceptible to a number of nutritional problems. (Dobermann and Fairhurst, 2000; Fageria *et al.*, 2002). It is assumed that one third of the world's population suffers from Zn deficiency, which is caused by inadequate dietary intake (Panomwan *et al.*, 2013). Zinc deficiency has been linked to serious health problems in humans, particularly in children, including delays in physical growth, immune system function, and learning ability, as well as DNA damage and cancer formation (Keen and Gershwin, 1990; Ho *et al.*, 2003; Black *et al.*, 2008). Adults and pregnant/lactating women need 8 to 11 mg and 11 to 13 mg of Zn per day to maintain good health (Bhowmik *et al.*, 2010). Consequently, staple food crops with higher Zn content are a significant ethical concern.

Rice production is frequently hampered by Zn deficiency. Water scarcity is causing a shift from flooded to dry land rice cultivation, which may have an influence on Zn deficiency in rice and ultimately reduce productivity (Gao *et al.*, 2012). To prevent Zn deficiency and boost grain yield, Zn is often applied to rice in wetland conditions prior to flooding or after transplanting (Dobermann and Fairhurst, 2000; Naik and Das, 2007). The precipitation or adsorption of Zn with various soil components, depending on the pH and redox potential, is the principal source of plant accessible Zn deficiency in soil (Impa and Johnson-Beebout, 2012). The concentration, mobility, and solubility of ions in soil solution, as well as their uptake by plants, are all influenced by soil pH (Nadeem and Farooq, 2019). At high soil pH, Zn concentration decreases. When the pH of the soil rises by one unit, the amount of Zn in the soil falls by 100 times (Nadeem *et al.*, 2013). The availability of Zn in calcareous soils decreased due to adsorption with clay and $CaCO_3$ under high pH conditions (Broadley *et al.*, 2007). Cereals grown on alkaline calcareous soils might well be lacking in Zn (Rehman *et al.*, 2018).

Water-food security for the growing population necessitates more rice with less water (Nisha and Samir, 2021). Rice is the world's largest user of freshwater resources, accounting for 24-30% of overall water usage and 34-43% of total irrigation water intake (Dixit *et al.*, 2016). Recently, rice farmers are being forced to move from traditional rice transplanting in flooded soils to water-saving farming as a result of changing weather patterns. Changes in soil parameters, as a result of altered soil and water management, are able to affect Zn absorption and plant uptake. Water management, in general, alters the physical conditions of the soil (e.g., soil O_2 condition and soil moisture) (Fang *et al.*, 2018), affecting rice development and soil microbial processes (e.g., mineralization, nitrification, and denitrification).

Alternate wetting and drying irrigation (AWD) is a revolutionary water-saving technique that was recently reported (Carrijo *et al.*, 2017). This technique has the potential to improve soil aeration (Fang *et al.*, 2018), minimize toxic substance over supply (Cucu *et al.*, 2014), and facilitate root functions and N uptake by rice (Zhang *et al.*, 2009; Chu *et al.*, 2015), even as reducing greenhouse gas emissions (Li *et al.*, 2018) and nitrogen depletion from runoff and leaching (Liang *et al.*, 2013; Zheng *et al.*, 2019). The AWD approach is essential for modern rice farming because it is more cost effective than the continuous flooding irrigation system, which saves water, reduces irrigation costs, and prevent environment from pollution (Subedi and Poudel, 2021). Recently, water scarcity has prompted a shift toward water-saving agriculture, from flooded to alternate wetting and drying to aerobic rice fields (Farooq *et al*. 2009a, 2011b). Advances in agricultural production technology frequently give chance to improve fertilization systems that might lower production costs as well enhancing nutrient delivery to plants. The purpose of this study was to determine the effect of alternative irrigation methods and different doses of Zn fertilizer on the productivity and yield components of BRRI dhan29.

Materials and Methods

The present study was carried out at Soil Science Field Laboratory, Bangladesh Agricultural University (BAU), Mymensingh (18 meter elevation, 24.75^0N latitude and 90.50^0E longitude) during 2018-2019 to study the effect of Zn on yield attributes and yield of BRRI dhan29.

Climate and soil

The climate in the experimental location is subtropical. The experiment site experienced moderately low temperatures and low rainfall over the Rabi season (October to March) (Figure 1). The experimental area comprises the Old Brahmaputra Flood Plain (AEZ-9). Soil of the experimental site is Sonatola silt loam and non-calcareous in nature. The physico-chemical properties of experimental soil are presented in Table 1.

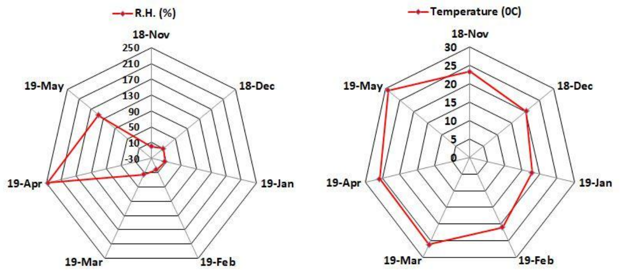

Figure 1. Monthly average temperature (^{0}C) and relative humidity (%) of BAU farm during research period (2018-2019).

Table 1. Physico-chemical properties of experimental soil.

Soil properties	Value
pH (1:2.5)	6.9
Organic matter (%)	1.92
Total nitrogen (%)	0.09
Available sulphur (mg kg^{-1})	10.0
Available zinc (mg kg^{-1})	0.70
Sand (%)	20.4
Silt (%)	68.0
Clay (%)	11.6
Textural class	Silt loam

Experimental design and treatments

The experiment was laid out in spilt-plot design with three replications, where irrigation systems (AWD and continuous flooding) were in the main plot and the different Zn doses (0% Zn, 75% Zn, 100% Zn, 125% Zn and 150% Zn of the recommended dose) were in the sub-plot (Table 2). The size of a unit plot was 5 m × 3 m. The distance between replications and between plots was 40 cm and 30 cm respectively. The variety BRRI dhan29 was used as planting material. 20 cm × 20 cm planting spacing, and 2-3 seedlings/hill were considered in this experiment. During final land preparation, all fertilizers were applied, however urea was applied as a top dress in three equal splits at 15, 30, and 45 DAT (day after transplanting).

Table 2. Treatments, methods, rate and percent (%) of Zn and N, P, K & S application.

Treatments		N-P-K-S (kg ha^{-1})
Main plot	Sub plot	
I_1: Alternate wetting and drying (AWD) and I_2: Continuous flooding (CF)	T_1: control	144-21-60-8
	T_2: 75% Zn	144-21-60-8
	T_3: 100% Zn	144-21-60-8
	T_4: 125% Zn	144-21-60-8
	T_5: 150% Zn	144-21-60-8

Here, I_1: Irrigation system 1, I_2: Irrigation system 2

Intercultural operations and harvesting

All weeding and plant safety procedures were carried out in accordance with the IRRI standard protocol (IRRI, 2002). The water levels in the experimental plot were regularly checked. AWD irrigation was practiced with 15 days interval. At maturity, the middle portion of each plot (5 m^2) was selected for harvest and the grain yield was estimated after drying (at 14 percent moisture).

Data collection

Data were recorded on plant height (cm), number of effective tillers $hill^{-1}$, panicle length (cm), number of grains $panicle^{-1}$, 1000 grain weight (g), grain yield (t ha^{-1}), straw yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index (HI%).

Statistical analysis

MSTAT-C software was used to perform data analysis. The least significant differences (LSD) test was used to analyze the statistical differences between mean values at significance levels of $P<0.05$ and $P<0.01$.

Results and discussion

Plant height

In present study, plant height was insignificantly influenced with the application of Zn and irrigation system with recommended dose of NPKS (Table 3). The tallest plants were measured with the application of 150% Zn in AWD irrigation system. The control treatment with continuous flooding produced the shortest plant. Previous study (Maqsood *et al.,* 1999; Khan *et al.*, 2007) shown that all Zn fertilizer doses (5, 10, 15 kg ha^{-1}) significantly increased the plant height compared to control. A sufficient amount of Zn aids in the acceleration of plant enzymatic activity and auxin metabolism. In another study (Khairi *et al.,* 2016), it was evident that continuous flooding (CF) water significantly increased plant height compared to AWD.

Effective tillers $hill^{-1}$

Tillering capacity is an important component of grain yield in cereals. Increased tillers per plant can result in higher yield potential (Rana and Kashif, 2014). In present investigation, there was no significant difference in number of effective tillers $hill^{-1}$ between the plants grown under AWD and CF with different doses of Zn treatment. The highest number (15.66) of effective tillers were found for 150% Zn dose in AWD condition and the lowest number for control in both AWD and CF (Table 3). This result is consistent with the scientific report of Singh *et al.,* 2020. Literature has shown (Tuyogon *et al.,* 2016) that the rapid immobilization of Zn in anaerobic soils with low redox potential makes Zn application under flooded situations ineffective. However, the AWD method increases the effectiveness of Zn application to soil. According to Norton *et al.,* (2017), AWD stimulates rice plants to establish stronger roots and more effective tillers, both of which result in greater rice yield.

Table 3. Effects of Zn on plant height, effective tillers $hill^{-1}$ and panicle length at maturity stage of BRRI dhan29 under AWD.

Treatments	Plant height (cm)		Effective tillers $hill^{-1}$ (no.)		Panicle length (cm)	
	AWD	CF	AWD	CF	AWD	CF
Zn (0%)	78.24	77.93	13.33	13.33	20.57	20.16
Zn (75%)	79.44	78.8	15.33	15.00	22.16	20.78
Zn (100%)	79.53	78.96	14.66	14.66	22.23	21.63
Zn (125%)	79.41	79.20	15.66	15.33	22.23	21.75
Zn (150%)	79.81	79.46	16.66	15.33	22.40	22.00
Mean	79.29	78.87	15.13	14.73	21.92	21.26
CV (%)	7.76	7.74	8.18	5.64	3.46	3.62
Lsd (0.05)	1.57	1.53	3.33	2.00	1.80	1.84
Level of significant	NS	NS	NS	NS	NS	NS

AWD: Alternate wetting and drying, CF: Continuous flooding, **: Significant at 1% level, *: Significant at 5% level and NS: Not significant

Panicle length

The interaction effect of Zn and irrigation systems was not significant on panicle length (Table 3). The highest panicle length (22.40 cm) obtained from interaction between 150% Zn and AWD irrigation system. The lowest panicle length (20.16 cm) was obtained from control with CF irrigation system. Due to improved nutrient uptake by plants as well as agro-climatic conditions, panicle length increased slightly as Zn rates increased (Rahman *et al.,* 2011; Anzer-Alam *et al.,* 2015). Rice cultivated in flooded environments requires higher Zn because the availability of other nutrient elements rises in flooded environments and lowers Zn availability to crop. However, in AWD irrigation system, Zn and other nutrient elements are readily available to plants, which expedite crop growth (Qaisrani *et al.,* 2011).

Number of grains $panicle^{-1}$

From the Table 4, it was revealed that Zn application gradually influenced on production of the number of grains $panicle^{-1}$ in both AWD and CF condition. The highest number of grains $panicle^{-1}$ (138) was obtained from 150% Zn with AWD condition treatment while the lowest number was obtained from control with AWD. All the treatments were statistically significant over control treatment. Wang *et al.,* (2014) reported that increased rate of Zn and water management systems (AWD and CF) significantly increased the number of grains $panicle^{-1}$ of rice which was similar with the present study. Previous studies (Bodruzzaman *et al.,* 2002; Khan *et al.,* 2007) confirmed that Zn fertilizer significantly enhanced the number of grains $panicle^{-1}$ through improving physiological processes of the crop such as photosynthesis and nutrient translocation.

1000-grain weight

It is evident from the Table 4 that the effect of Zn and water management system on 1000-grain weight was significant. All the doses of Zn fertilizer in AWD significantly increased 1000-grain weight compared to CF. The highest 1000-grain weight (28.43 g) was found for 150% Zn dose in AWD condition and the lowest number for control in CF condition. Proper Zn application rates and irrigation management system may increase grain weight by allowing Zn to participate more efficiently in the various metabolic processes engaged in good seed production (Ghani *et al.,* 1990; Maqsood *et al.,* 1999).

Table 4. Effects of Zn on grains $panicle^{-1}$ and 1000-grain weight of BRRI dhan29 under AWD.

Treatments	Grains $panicle^{-1}$ (no.)		1000-grain weight (g)	
	AWD	CF	AWD	CF
Zn (0%)	117.67 b	119.00 b	27.10 ab	25.53 b
Zn (75%)	131.67 a	131.67 a	28.06 a	26.60 ab
Zn (100%)	136.00 a	133.00 a	28.10 a	27.76 a
Zn (125%)	136.00 a	135.67 a	28.30 a	27.79 a
Zn (150%)	138.00 a	137.33 a	28.43 a	27.83 a
Mean	131.87	131.33	27.99	27.10
CV (%)	6.27	5.51	1.87	3.76
Lsd (0.05)	20.33	18.33	1.33	2.23
Level of significant	**	**	**	**

AWD: Alternate wetting and drying, CF: Continuous flooding, ** : Significant at 1% level, * : Significant at 5% level and NS: Not significant

Grain yield

Yield is the result of several independent variables such as number of effective tillers, panicle length, number of grains panicle^{-1} and 1000-grain weight. The results showed that Zn application in both AWD and CF irrigation systems significantly increased the grain yield of rice. The highest grain yield (5.98 t ha^{-1}) was recorded from 150% Zn application in AWD irrigation condition and the lowest (5.36 t ha^{-1}) recorded in control of CF irrigation condition (Table 5). According to Fageria *et al.* (2011), Zn fertilization increased rice yield by 97%. The increased yield due to Zn fertilization is related to its participation in various metallic enzyme reactions, regulatory functions, and auxin production (Sachdev *et al.,* 1988), as well as improved carbohydrate synthesis and transportation to the grain-growing area (Babu *et al.*, 2013).

Table 5. Effects of Zn on grain yield and straw yield of BRRI dhan29 under AWD.

Treatments	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})	
	AWD	CF	AWD	CF
Zn (0%)	5.39 b	5.36 b	5.80	5.73
Zn (75%)	5.45 ab	5.64 ab	6.19	6.07
Zn (100%)	5.80 ab	5.70 ab	6.22	6.09
Zn (125%)	5.91 ab	5.68 ab	6.41	6.22
Zn (150%)	5.98 a	5.84 ab	6.47	6.28
Mean	5.71	5.64	6.22	6.08
CV (%)	4.72	3.12	4.22	3.51
Lsd (0.05)	0.59	0.48	0.67	0.55
Level of significant	*	*	NS	NS

AWD: Alternate wetting and drying, CF: Continuous flooding, **: Significant at 1% level, *: Significant at 5% level and NS: Not significant

Straw yield

The data on the straw yield of rice was not significantly influenced by the application of various doses of Zn fertilizer to soil in both AWD and CF irrigation condition (Table 5). The maximum straw yield (6.47 t ha^{-1}) observed in the treatment of 150% Zn dose in AWD condition and minimum (5.73 t ha^{-1}) was found in control of CF condition. These results have conformity with the evidence of Vivek *et al.*, (2019). Alwahibi *et al.*, (2020) reported that higher Zn levels (10 and 15 kg Zn ha^{-1}) increased yield and Zn content in both rice grains and straw, supporting the findings of the current study.

Harvest index (HI)

Figure 2 shows the effect of Zn doses on harvest index exerted significant variation in both AWD and CF irrigation systems. Harvest index was the highest (48.35%) in I_2 × Zn (100%) and the lowest (46.82%) was observed in I_1 × Zn (75%). Other studies (Hazra *et al.,* 2015; Amanullah 2016) also confirmed that higher Zn rates (10 and 15 kg/ha) have an impact on yield components and grain yield, as well as dry matter accumulation, which leads to higher rice HI and vice versa.

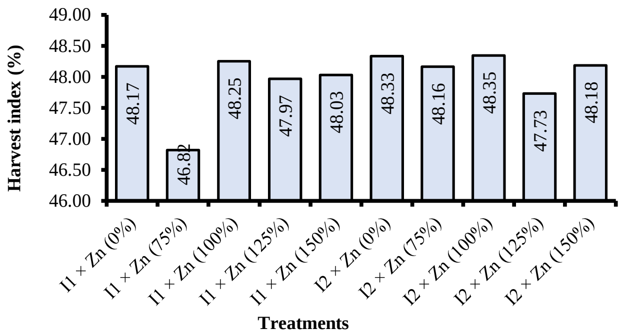

Figure 2. Effects of Zn on harvest index (%) under AWD.

Conclusions

Overall, the current study found that the rate of Zn application had a significant impact on the number of grains panicle^{-1}, 1000-grain weight and grain yield in both AWD and CF conditions. Considering all treatment combinations in relation to growth and yield of BRRI dhan29, the use of 150% Zn in AWD irrigation system gave the best results in terms of both yield components and yield. So, the application of this technology is most pressing issues to achieve long-term agricultural sustainability.

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References

Abbas M, Zahida TM, Uddin R, Sajjid I, Akhlaq A, Moheyuddin K, Salahuddin J, Mari AH, Panhwar RN (2013). Effect of zinc and boron fertilizers application on some physicochemical attributes of five rice varieties grown in agro-ecosystem of Sindh, Pakistan. American-Eurasian J Agric Environ Sci 13(4):433-9.

Al Viandari N, Adriany TA, Pramono A (2020). Alternate wetting and drying system (AWD) combined with farmyard manure to increase rice yield and reduce methane emission and water use. In IOP Conference Series: Materials Science and Engineering 980(1):012066).

Alwahibi MS, Elshikh MS, Alkahtani J, Muhw2ammad A, Khalid S, Ahmad M, Khan N, Ullah S, Ali I (2020). Phosphorus and Zinc Fertilization Improve Zinc Bio fortification in Grains and Straw of Coarse vs. Fine Rice Genotypes. Agronomy 10(8):1155.

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

Anzer-Alam MD, Kumar M (2015). Effect of zinc on growth and yield of rice var. Pusa Basmati-1 in Saran district of Bihar. Asian J Plant Sci Res 5(2):82-5.

Babu VR, Shreya K, Dangi KS, Usharani G, Nagesh P (2013). Evaluation of Popular Rice (*Oryza sativa* L.) Hybrids for quantitative, qualitative, and nutritional aspects. Int J Sci Res Publicat 3:1–8.

Bhowmik D, Chiranjib K, Kumar S (2010). A potential medicinal importance of zinc in human health and chronic. Int J Pharm 1(1):05-11.

Black RE, Allen LH, Bhutta ZA, Caulfield LE, De Onis M, Ezzati M, Mathers C, Rivera J (2008). Maternal and Child Undernutrition Study Group. Maternal and child undernutrition: global and regional exposures and health consequences. Lancet 371(9608):243-60.

Bodruzzaman M, Sadat MA, Meisner CA, Hossain AB, Khan HH (2002). Direct and residual effects of applied organic manures on yield in a wheat–rice cropping pattern. In Proceedings of the 17th World Congress of Soil Science, Bangkok, Thailand, 14-21.

Broadley MR, White PJ, Hammond JP, Zelko I, Lux A (2017). Zinc in plants. New phytologist. 173(4):677-702.

Carrijo DR, Lundy ME, Linquist BA (2017). Rice yields and water use under alternate wetting and drying irrigation: A meta-analysis. Field Crops Res 203:173-80.

Chu G, Wang Z, Zhang H, Liu L, Yang J, Zhang J (2015). Alternate wetting and moderate drying increases rice yield and reduces methane emission in paddy field with wheat straw residue incorporation. Food Energy Secur 4(3):238-54.

Cucu MA, Said-Pullicino D, Maurino V, Bonifacio E, Romani M, Celi L (2014). Influence of redox conditions and rice straw incorporation on nitrogen availability in fertilized paddy soils. Biol fertile soils 50(5):755-64.

Dixit S, Kumar A, Woldring H (2016). Water scarcity in rice cultivation: current scenario, possible solutions, and likely impact.

Dobermann A, Fairhurst TH (2000). Nutrient disorders and nutrient management. Potash and Phosphate Institute, PPI of Canada and International Rice Research Institute, Singapore, 192.

Fageria NK, Baligar VC, Clark RB (2002). Micronutrients in crop production. Adv Agron 77:185–268

Fageria NK, Dos Santos AB, Cobucci T (2011). Zinc nutrition of lowland rice. Commun in Soil Sci Plant Anal 42(14):1719-27.

Fang H, Zhou H, Norton GJ, Price AH, Raffan AC, Mooney SJ, Peng X, Hallett PD (2018). Interaction between contrasting rice genotypes and soil physical conditions induced by hydraulic stresses typical of alternate wetting and drying irrigation of soil. Plant and soil 430(1):233-43.

Farooq M, Kobayashi NK, Wahid A, Ito O, Basra SMA (2009a) Strategies for producing more rice with less water. Adv Agron 101:351–388

Farooq M, Rehman A, Aziz T, Habib M (2011b). Boron nutripriming improves the germination and early seedling growth of rice (*Oryza sativa L*.). J Plant Nutr 34:1507–1515

Gao X, Hoffland E, Stomph T, Grant CA, Zou C, Zhang F (2012). Improving zinc bioavailability in transition from flooded to aerobic rice. A review. Agron Sustain Dev 32**:** 465-478. https://doi.org/10.1007/s13593-011-0053-x.

Ghani A, Shah M, Khan DR (1990). Response of rice to elevated rates of zinc in mountainous areas of Swat. Sarhad J Agric. 6(4):411-5.

Hazra GC, Saha B, Saha S, Dasgupta S, Adhikari B & Mandal B (2015). Screening of rice cultivars for their zinc biofortification potential in Inceptisols. J Indian Soc Soil Sci 63(3):347-57. DOI.10.5958/0974-0228.2015.00045.6.

Ho E, Courtemanche C, Ames BN (2003). Zinc deficiency induces oxidative DNA damage and increases p53 expression in human lung fibroblasts. J Nutr 133:2543–2548.

Impa SM, Johnson-Beebout SE (2012). Mitigating zinc deficiency and achieving high grain Zn in rice through integration of soil chemistry and plant physiology research. Plant Soil 361(1):3-41.

IRRI, I., 2002. Standard evaluation system for rice. Int Rice Res Inst. *PO Box*, *933*:1099.

Jena PK, Rao CP, Subbaiah G (2006). Effect of zinc management practices on growth yield and economics in transplanted rice (*Oryza sativa L*).

Keen CL, Gershwin ME (1990). Zinc deficiency and immune function. Ann Rev Nutr 10:415–431.

Khairi M, Nozulaidi M, Jahan MS (2016). Effects of Flooding and Alternate Wetting and Drying on the Yield Performance of Upland Rice. Pertanika J Trop Agric Sci 1;39(3).

Khan MU, Qasim M (2007). Effect of Zn fertilizer on rice grown in different soils of Dera Ismail Khan. Sarhad J Agric 23(4):1033.

Lan PD, Hang NN, Thanh HN (2020). Impact of irrigation techniques on rice yield and dynamics of zinc in plants and soil. Plant Soil Environ 66(3):135-42.

Li J, Wan Y, Wang B, Waqas MA, Cai W, Guo C, Zhou S, Su R, Qin X, Gao Q, Wilkes A (2018). Combination of modified nitrogen fertilizers and water saving irrigation can reduce greenhouse gas emissions and increase rice yield. Geoderma 315:1-0.

Liang XQ, Chen YX, Nie ZY, Ye YS, Liu J, Tian GM, Wang GH, Tuong TP (2013). Mitigation of nutrient losses via surface runoff from rice cropping systems with alternate wetting and drying irrigation and site-specific nutrient management practices. Environ Sci Pollut Res 20(10):6980-91.

Maqsood M, Irshad M, Wajid SA, Hussain A (1999). Growth and yield response of Basmati-385 (*Oryza sativa L.)* to ZnSO4 application. Pak J Biol Sci

Nadeem F and Farooq M (2019). Application of micronutrients in rice-wheat cropping system of south Asia. Rice Sci 26:356–371. doi: 10.1016/j.rsci.2019.02.002

Nadeem F, Ahmad R, Rehmani MI, Ali A, Ahmad M, Iqbal J (2013). Qualitative and chemical analysis of rice kernel to time of application of phosphorus in combination with zinc under anaerobic conditions. Asian J Agric Biol 1(2):67-75.

Naik SK and Das DK (2007). Effect of split application of zinc on yield of rice (*Oryza sativa L*.) in an Inceptisol. Arch Agron Soil Sci 53(3):305-313.

Nisha S and Samir P (2021). Alternate wetting and drying technique and its impacts on rice production. Tropical Agrobiodiversity 2(1):01-06.

Norton GJ, Shafaei M, Travis AJ, Deacon CM, Danku J, Pond D, Cochrane N, Lockhart K, Salt D, Zhang H, Dodd IC (2017). Impact of alternate wetting and drying on rice physiology, grain production, and grain quality. Field Crops Res 205:1-3.

Panomwan B, Ismail C, Benjavan R, Chanakan PT (2013). Effect of different foliar zinc application at different growth stages on seed zinc concentration and its impact on seedling vigor in rice. Soil Sci Plant Nutr 59(2):180-188.

Qaisrani, Saeed. (2011). Effect of Zinc Application on Growth and Yield of Rice (*Oryza sativa L*.). Int J Agro Vet Med Sci 5. 530-535.

Rahman KM, Chowdhury MA, Sharmeen F, Sarkar A, Hye MA, Biswas GC (2011). Effect of zinc and phosphorus on yield of *Oryza sativa* (cv. br-11). Bangladesh Res Pub J 5(4):315-58.

Rana WK, Kashif S (2014). Effect of different Zinc sources and methods of application on rice yield and nutrients concentration in rice grain and straw. J Environ Agric Sci 1:9.

Rehman A, Farooq M, Ozturk L, Asif M, Siddique KHM (2018). Zinc nutrition in wheat-based cropping systems. Plant Soil 422, 283–315. doi: 10.1007/s11104-017-3507-3

Sachdev P, Dep DL, Rastogi DK (1988). Effect of varying levels of zinc and manganese on dry matter yield and mineral composition of wheat plant at maturity. J Nuclear Agric Biol 17:137- 143.

Singh V, Singh V, Singh S (2020). Effect of Zinc and Silicon on Growth and Yield of Aromatic Rice (*Oryza Sativa*) in North-Western Plains of India. J Rice Res Dev 3(1):82-86.

Subedi N, Poudel S (2021). Alternate Wetting and Drying Technique and Its Impacts on Rice Production. TRAB, 2(1): 01-06. https://doi.org/10.26480/trab.01.2021.01.06.

Sudha S and Stalin P (2015). Effect of zinc on yield, quality and grain zinc content of rice genotypes. Int J of farm Sci 5(3):17-27.

Tripathi DK, Singh S, Singh S, Mishra S, Chauhan DK, Dubey NK (2015). Micronutrients and their diverse role in agricultural crops: advances and future prospective. Acta Physiol Plant 37:139. doi: 10.1007/s11738-015-1870-3

Tuyogon DSJ, Impa SM, Castillo OB, Larazo W, Johnson-Beebout SE (2016). Enriching rice grain zinc through zinc fertili-zation and water management. Soil Sci Soc Am J 80:121–134.

Vivek N, Zinzala, Ajay V, Narwade (2019). Effect of Zinc applications on Grain Yield, Straw Yield and Harvest Index in kharif Rice (*Oryza sativa L*.) Genotypes. Int J Curr Microbiol App Sci 8(11):27-35

Wang YY, Wei YY, Dong LX, Lu LL, Feng Y, Zhang J, Pan FS, Yang XE (2014). Improved yield and Zn accumulation for rice grain by Zn fertilization and optimized water management. J Zhejiang Univ Sci 15(4):365–374. https://doi.org/10.1631/jzus.B1300263

Zhang H, Xue Y, Wang Z, Yang J, Zhang J (2009). An Alternate Wetting and Moderate Soil Drying Regime Improves Root and Shoot Growth in Rice. J Crop Sci 49:2246–2260.

Zheng C, Zhang Z, Wu Y, Mwiya R (2019). Response of Vertical Migration and Leaching of Nitrogen in Percolation Water of Paddy Fields under Water-Saving Irrigation and Straw Return Conditions. Water 11:868.