

ZINC NUTRITION IN RICE BASED CROPPING SYSTEMS: A COMPREHENSIVE REVIEW

Abstract:

Rice based cropping systems being the most practiced cropping system in India, it suffers zinc deficiency as the majority of the Indian soils are deficient in the Zn micronutrient. Zn is considered as the fourth most important yield-limiting nutrient of Agricultural crops. Apart from the plant nutrition Zn also plays a crucial role in human nutrition. Zn plays a vital role in the physiological function of plants and is associated with the phytohormone activity, protein synthesis, and carbohydrate metabolism. To understand better about the zinc nutrition and its associated benefits from optimum nutrition and ways to manage Zn in rice based cropping systems, the present review critically examines nutrient mobilization and transformation of Zn in rice based cropping systems of India.

Keywords: Rice based cropping systems, phytohormone, protein synthesis, carbohydrate metabolism, optimum nutrition.

Introduction - Introduction:

Zinc is considered as the key element effecting the growth, development, and life of the living organisms along with playing an essential role in physiological activities (Fageria *et al.*, 2002; Stanton *et al.*, 2022; Wu *et al.*, 2022). Zn deficiency in people results in symptoms such as loss of appetite, anorexia, loss of taste and smell, and other symptoms. It can also have an impact on the immune system, leading to arteriosclerosis and anemia (Gondal *et al.*, 2021). Growth retardation, congenital fetal abnormalities, and pregnancy and birthing problems have all been linked to zinc deficiency (Black, 2001).

Micronutrient deficits, particularly those of Zn, are one of the main causes of economic loss in developing nations (Stein, 2014). According to recommendations, an average individual needs 11 mg of zinc per day for males and 8 mg of zinc per day for females (NIH, 2021).

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Zinc is a crucial element needed to improve crop growth and output; of all micronutrients, Zn is regarded as the most important nutrient (Samreen *et al.*, 2017). More than 300 enzymes, including carbonic anhydrase, alcoholic dehydrogenase, alkaline phosphate, carboxy ~~pepsidase~~ peptidase, phospholipase, superoxide dismutase (SOD), and RNA polymerase, depend on zinc for their structural and functional integrity. These enzymes regulate a variety of biochemical and physiological processes, including cell division, protein synthesis, photosynthesis, gene transcription, nucleic acid metabolism, and pollen (Hacisalihoglu, 2020).

Rice is a considerable staple food cereal on which half the ~~world~~ world's population is dependent for energy and 20% protein requirements (Rehman *et al.*, 2012). Around 50% of Asia's population, or roughly 2 billion people, are ~~at-in~~ danger of Zn insufficiency, ~~despite the fact~~ that even though Asia covers about 87% of the world's rice-growing area and consumes 90% of all rice produced (Chen *et al.*, 2017, FAO, 2018). Agronomic biofortification of Zn could be a potential option to address the problem of Zn deficiency (Zulfiqar *et al.*, 2021).

The primary cropping system used in India is the rice-based cropping system (RBCS), which rotates crops with vegetables, fodder crops, pulses, and oilseeds. The productivity of a system is significantly influenced by how nutrients are managed during different seasons. Any farming system can be made more productive by using micronutrients (Tuti *et al.*, 2018). Zn is thought to be the micronutrient that is needed the most.

Rice based cropping systems (RBCS)

Rice is the predominant crop in the world meeting 20% of the human food calories and India is considered as the largest producer occupying ~ 45 million ha under cultivation (Tuti *et al.*, 2018). Due to varying climatic situations during the crop year, the annual crops are grown in progression. The crops may either be grown along with rice as ~~a~~ an inter-crop inter-crop or in

sequence according to the climatic conditions and feasibility ~~in order to~~ maximize ~~the~~ resource utilization (Sarwar *et al.*, 2022).

Rice based cropping system can be described as, in a farming practice considering rice as the major crop is succeeded by other adaptable crops. In India major cropping system ~~followed~~ is the ~~Rice based~~Rice-based cropping system where, the major crop of rice is followed by ~~either~~ pulses, cereals, oilseeds, etc. (Tuti *et al.*, 2018).

The central principle in considering a crop in a cropping system lies with a. the biological traits of the crop and how they interact with and are influenced by its physical, chemical, and ecological environment, b. the crop to be grown in sequence after the major crop, c. the management practices to be followed for the cropping system (Jensen *et al.*, 2010). The major crop in cropping systems was rice, which was chosen based on the agro-climatic and socio-economic circumstances of the area. In India, ~~rice-rice~~ rice, ~~rice-wheat~~ rice-wheat rice wheat, rice-pulse, and rice-potato are the most common rice-based cropping systems (Sravan and Murthy, 2018).

Table 1: Rice cropping systems occurring in Indian states (Tuti *et al.*, 2018)

Agro-climatic region	Cropping system followed
Western himalayan	Rice-wheat, rice-potato-potato
Eastern himalayan	Rice fallow, rice-rice, rice-pulses/oilseeds
Lower gangetic plain	Rice-rice, rice-wheat, rice-potato-jute/vegetables
Middle gangetic plain	Rice-wheat, rice-maize, rice-potato-sunflower
Upper gangetic plain	Rice-wheat, sugarcane-ratoon-wheat
Trans gangetic plain	Rice-wheat
Eastern plateau and hills	Rice-blackgram, rice-niger/linseed, rice-vegetables
East coast plain and hills	Rice-groundnut-greengram, Rice-greengram/blackgram, rice-rice
West coast plains and hills	Rice-rice
Andaman and Nicobar	Rice- fallow

Nutrient mobilization of zinc in RBCS

~~Movement~~ ~~The movement~~ of the nutrient Zn in ~~the~~ crop sequence of the cropping system can be understood as ~~the~~ nutrient mobilization. Cropping systems following the integrated mode of nutrient management ~~was-were~~ found to have ~~a~~ significant effect on soil fertility. Including pulse crops like green gram and vegetable crops in the ~~rice-based~~ ~~rice-based~~ cropping system along with supplementing nutrients through different sources of biofertilizers and organic manures significantly improves crop nutrient absorption by increasing the availability of soil nutrients, the total zinc nutrient uptake by the rice and wheat (Verma *et al.*, 2020).

The organic sources of nutrients and biofertilizers ~~supplies-supply~~ considerable amounts of the major and micronutrients continuously throughout the crop growth period unlike, ~~in~~ the inorganic sources the nutrients are available to the plants in the earlier and the later stages of ~~the~~ growth, organic sources provide long-term availability of nutrients (Singh *et al.* (2010); Garai *et al.* (2013) and Verma *et al.* (2017)).

Change from the current, conventional cropping system to an enhanced cropping system including potato and cucumber between two seasons of rice has resulted ~~in~~ 49% higher rice equivalent yield due to the ~~more-greater~~ profits gained under higher yield of cucumber and potato (Alam *et al.*, 2021). Rice-non rice ~~crop-based~~ ~~based~~ ~~crop-based~~ cropping systems were more profitable compared to ~~rice-rice~~ ~~rice-rice~~ cropping ~~system-systems~~ (Nagoliet *et al.*, 2017).

In a rice-based cropping system, crop intensification results in a rice equivalent yield that is two to four times greater (Samant, *et al.*, 2015, Jat *et al.*, 2012). The rate of increase of REY depends on ~~the~~ type of crop, ~~the~~ number of crops involved, and the ecosystem in which the crop is grown (Alam *et al.*, 2021). ~~In an~~ ~~An~~ improved cropping system consisting of transplanted Aman rice followed by potato, cucumber and transplanted Aus rice has received 49% higher rice

equivalent yield compared to the existing cropping system consisting of transplanted Aman rice followed by potato and transplanted Boro rice (Alam *et al.*, 2021).

The Nutrient Index (N.I) gauges how well a soil can supply nutrients to plants (Singh *et al.*, 2016). Cropping systems with pulse as a component will have a higher nutrient index than the vegetables as a component (Singh *et al.*, 2020). Supply of the recommended dose of fertilizers along with the inclusion of pulse crops as a component/sequence in a cropping system will result in the improved nutrient response of the crop to Zn (Shankar *et al.*, 2021). In order to gain higher productivity and profitability from a cropping system need-based application of Zn is essential along with the application of inorganic sources of fertilizers as the nutrients will be present in the available forms plants get the maximum benefited benefit (Xu *et al.*, 2014).

Thus, the application of both organic and inorganic sources of nutrients will make the nutrients more available as is the case with DTPA-extractable Zn content in post-harvest soil of both rice and wheat, Customized fertilizer application had shown increased Zn content by 95% and 158% over 100% RDF in soils of wheat and rice, respectively (Kumar *et al.*, 2021).

Status of Zn in Indian soils

Fertility of Indian soils is generally poor with progressively emerging micronutrient deficiencies due to their catalyzed removal under agricultural intensification. According to latest estimates, out of about 188.4 thousand tonnes (Tt) of micronutrients removed by 263 Mt of food grains produced, nutrient removal by Zn is 23.9 Tt and in Indian soils, total Zn content ranges from 7-2960 mg/kg and available Zn content ranges from 0.01-52.9 mg/kg. Currently, 36.5% of soil samples nationwide have deficiencies in available Zn, with acute, latent, and total deficiencies occurring in 8, 29, and 15% of the country, respectively (Shukla *et al.*, 2019). Zn is currently regarded as the fourth-most significant nutrient for agricultural crops in India that

limits productivity. By 2025, zinc deficiency in Indian soils is predicted to rise from 42 to 63%(Sharma *et al.*, 2021).According to a study of Indian soils, out of 2.52 lakh soil samples examined, 49% were found to be low in the available Zn spread throughout 20 states. There is widespread zinc deficiency throughout all agro-ecological zones (AEZ). Maximum Zn deficit extended, up to 60%, in AEZ 6 and 10 soils. Agro-ecological zones 3, 4, 7, 8, 13, and 14 had soils that were 50–60% zinc deficient. In states like Punjab, Haryana, Uttar Pradesh, Andhra Pradesh, Bihar, and Madhya Pradesh, the severity of Zn deficiency is decreasing.

The extent of zinc deficiency was found to be 55, 47, and 36% in Trans-northern, Central, and Eastern sections of IGP alluvial plains, according to analysis of 90419 surface soil samples from AEZ 4, 9, 13, and 16 of the Indo-Gangatic alluvial plains(IISS, 2021).

Map 1 :Map showing area having Zinc deficient soils

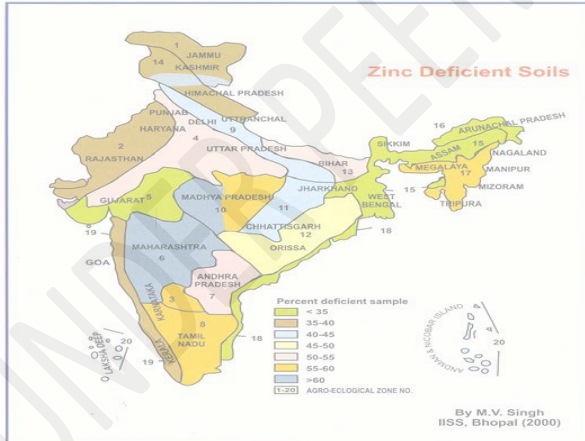


Table 2: Critical limits of available Zn for agricultural soils of India.

	AvailableZn(mgkg ⁻¹)
Acutedeficient	≤ 0.30
Deficient	$> 0.30 - \leq 0.60$

Latent deficient	$>0.60-\leq 0.90$
Marginal sufficient	$>0.90-\leq 1.20$
Adequate	$>1.20-\leq 1.80$
High	>1.80

UNDER PEER REVIEW

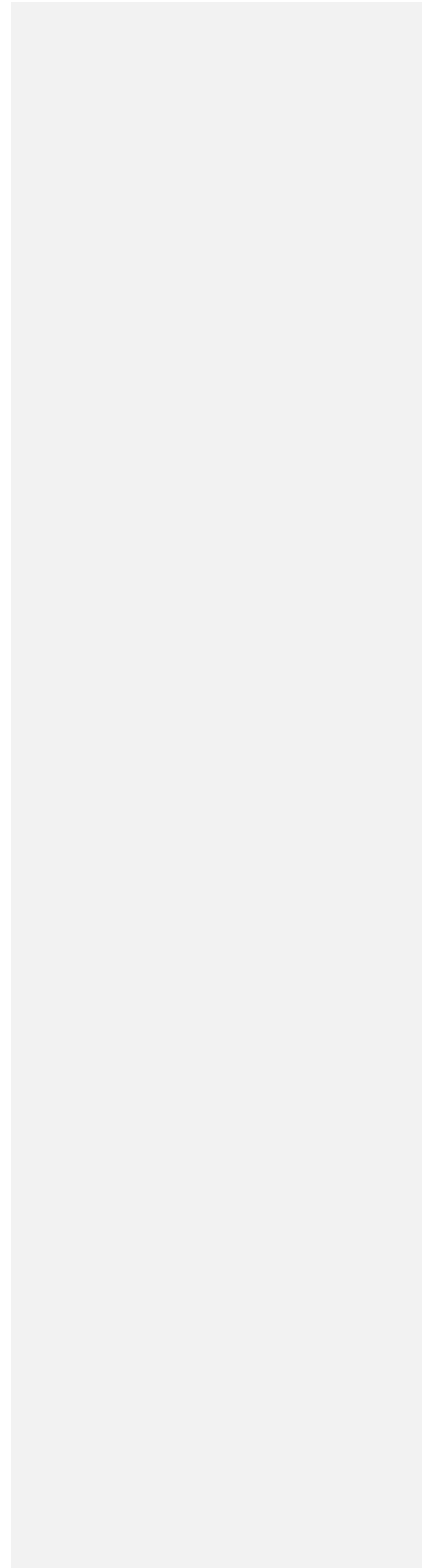
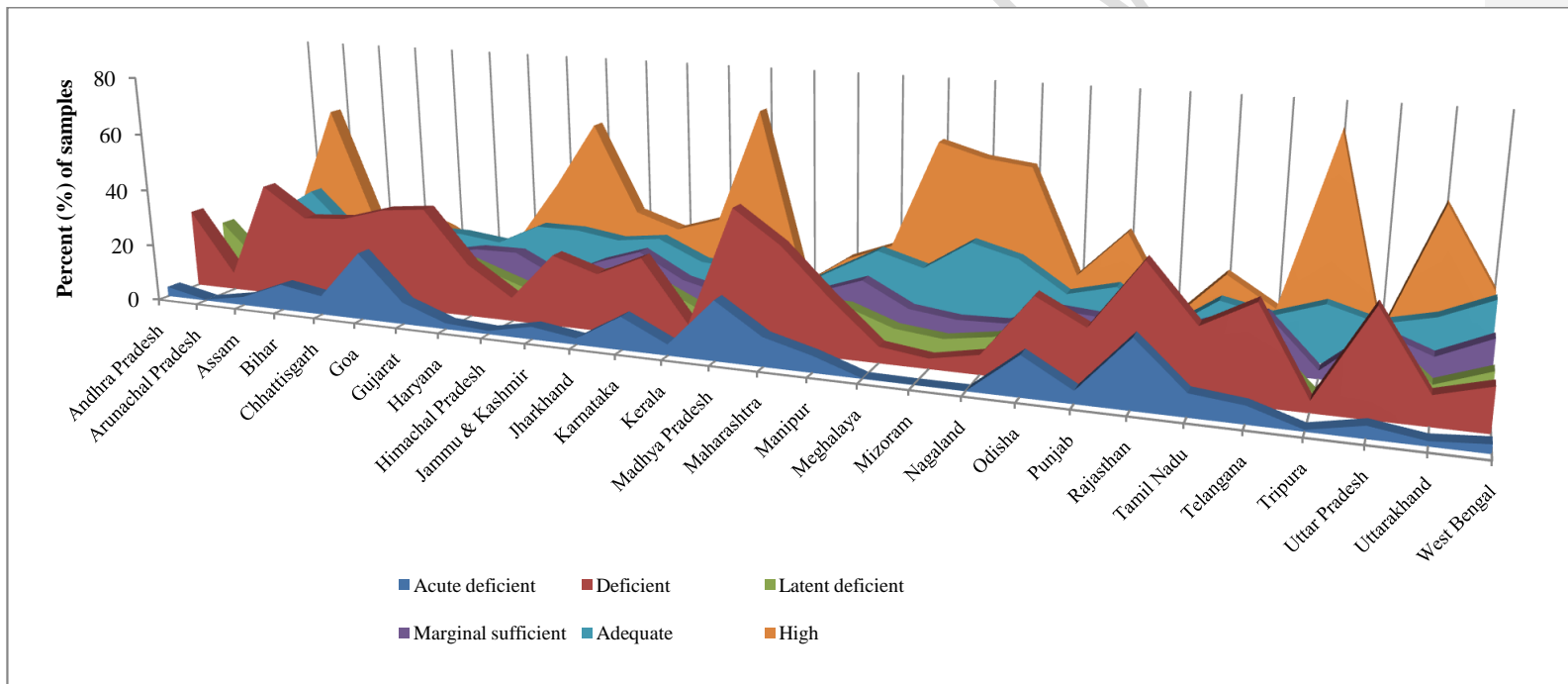


Fig 1: Deficit by state (% of soil samples) available Zn. (Shukla *et al.*, 2021)



Physiological functions of Zn in plants

Zinc is the vital nutrient having its role in normal growth and productivity of the plants (Suganya A. *et al.*, 2020). The nutrient was also found to have its role in structurally and functionally maintaining the cell membranes (Hafeez, B., *et al.* 2012). Optimum Zn nutrition helps in the improvement of the photosynthetic activity by 50%-70% and thus increases the chlorophyll content, net photosynthetic rate, transpirational rate, and stomatal conductance (Liu *et al.*, 2016, Rudani *et al.*, 2018). Zn application improves the plant activity under drought conditions by enhancing the photosynthetic process (Hassan, M.U., *et al.* 2020). Deficiency-A deficiency of zinc in plants results in ~~the~~ decreased content of ~~the~~ chlorophyll content and also affects the ratio of chl a: chl b. Reduced photosynthetic activity leads to reduced growth, leaf area (up to 72%) and reduced number of leaves (Hajiboland R. *et al.*, 2010). Zinc plays a role in phytohormone activity, enzyme activation, protein synthesis, carbohydrate metabolism and has a noticeable role in defending against phytopathogens (Grungreiff *et al.*, 2020, Suganya A. *et al.*, 2020). Zinc is identified as the primary requisite of enzyme classes such as transferases, ligases, oxidoreductases, isomerases, lyases, hydrolases and is also a constituent of ribulose 1,5-biphosphate carboxylase (RuBpc) involved in photosynthesis. As the element is involved in different categories of enzymes the functions indirectly involved in the metabolism of carbohydrates, proteins, auxins will get affected, meanwhile the productivity of the plants gets hindered under the deficient conditions (Romheld and Marschner 1991, Singh *et al.*, 2005). The enzyme carbonic anhydrase which governs the fixation of carbohydrates by conversion of carbon dioxide to bicarbonates is managed by zinc (Kandil *et al.*, 2022). The most rudimentary effect of zinc in protein metabolism is its activity in maintaining the stability and functioning of genetic material (Rudani *et al.*, 2018). Living membranes are maintained by zinc, cell membrane integrity is often regulated by the availability of zinc which drives the detoxification of membrane

damaging ROS and thus involved in the plant water relations (Ghazi *et al.*, 2022). So, in the absence of the Zn sulphhydryl groups and lipids in the membrane undergoes injury and organic compounds leaks through the cells, especially root cells exposed to certain situations leads to root diseases in Zn deficient plants (Mousavi, S. R. *et al.*, 2013, Sadeghzadeh, B. 2013). The ~~defence~~ defense mechanism of plants against the ~~diseases~~ diseases is often correlated to the Zn nutrition through which the plants ~~attains~~ attain resistance by modifying the physiology and morphology of the plants (Kandil *et al.*, 2022).

Factors affecting the availability of zinc:

Parent material from which the soils are derived has a significant effect on the availability of Zn. The soils ~~those~~ originating from gneisses, granite, sandstone, and ~~lime stone~~ limestone are found to be lower in the available Zn contents (Barak and Helmke 1993). The major concern in the availability of Zn lies in its fixed/ insoluble/ unexchangeable forms (Suganya *et al.*, 2020).

Availability of Zn is highly reliant on pH, with an increase in pH above 6, Zn availability decreases with an increase in pH. Precipitation of Zn into insoluble forms of soil Zn, $ZnSiO_4$ or $ZnFe_2O_4$ will ~~takes~~ take place leading to reduced solution Zn / available Zn.

Zn deficiency is more likely to be noticed in ~~the~~ alkaline soils than in acid soils. Soils-In soils with high hydroxyl (OH⁻) ions, the response of the plants to external application of the Zn is ~~negligeable~~ negligible. Under alkaline situations, Zn is precipitated as ~~Zn~~ Zn (OH)₂ or ZnCO₃ (Barak and Helmke 1993, Suganya and ~~saravanan~~ Saravanan 2015). Soils with higher carbonate contents will relatively exhibit unavailability of the Zn due to absorption of Zn ~~on~~ onto soil particles and turned to unexchangeable forms (Alloway 2004).

Zn deficiency is more prevalent in the soils with low organic matter. In high organic matter containing soils available Zn is accordingly high (Hafeez *et al.*, 2013).

Humic acid and fulvic acids are the identified stable organic compounds with comparably ~~contains~~ contain more functional group ions like (OH, COOH, and SH) which ~~shows showan~~ affinity to Zn^{2+} (Suganya *et al.*, 2020). Fulvic acids generally ~~forms-form~~ chelates with Zn increasing the mobility and solubility of Zn. In case of the high organic soils like peat and muck binding of zinc to humic substances takes place and ~~make-makes~~ Zn unavailable (Katyal and Randhawa 1983).

Soil texture also ~~has-effect-on~~ affects the effect on the Zn availability, sandy soils with lighter texture ~~exhibits-exhibit~~ more deficiency in available Zn compared to the heavier textured clay soils. Clay soils with high CEC values certainly have more affinity to retain Zn (Hafeez *et al.*, 2013, Suganya *et al.*, 2020).

Soil moisture significantly affects the availability of nutrients to the plants as the diffusion of nutrients to roots is affected by soil moisture. Zn nutrition is considered to be at stake in arid and ~~semi-arid~~ semi-arid regions due to the coincidence of prolonged water deficit periods during the growing season. Whereas, in ~~water-logged~~ water-logged situations Zn co-precipitates with iron and ~~aluminium-aluminum~~ makes-making Zn unavailable to the plants (Hafeez *et al.*, 2013, Suganya *et al.*, 2020). Compared to dry soils, flooded soils are more prone to Zn deficiency because in the prior case, Zn reacts with free sulphide sulfide. In the case of rice delayed application of the Zn until after flooding rice decreases the fixing of zinc with sesquioxides (Suganya and Saravanan 2014, 2015)

Fluctuations in temperature towards the colder side below $16^{\circ}C$ during growing period will hinder the zinc availability to the plants due to change in the rate of Zn mineralization. Besides plants suffer Zn deficiency as a result of unfavourable climatic situations (Alloway, 2008).

Available sources of Zn

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The following order describes the reduction in solubility of several zinc minerals: Zn (OH)₂ (amorphous) > Zn(OH)₂ > ZnCO₃ (smithsonite) > ZnO (zincite) > Zn (PO₄)₂·4H₂O (willemite) > soil Zn > Zn Fe₂O₄ (franklinite). Zinc forms soluble complexes with chloride, phosphate, nitrate, and sulphate ions however, the neutral sulphate (ZnSO₄) and phosphate (ZnHPO₄) species are the most significant and contribute to the overall concentration of zinc in solution. When acidifying fertilizers like ammonium sulphate [(NH₄)₂(SO₄)₂] are employed, the ZnSO₄ complex accounts for the enhanced availability of zinc and may increase the solubility of Zn²⁺ in soils (Arunachalam *et al.*, 2013). Most commonly available forms of zinc are ZnSO₄·H₂O (33%) Zn - Zinc sulphate monohydrate, (ZnSO₄·7H₂O)-21% Zn - Zinc sulphate heptahydrate and chelated form as (Zn EDTA)-9% Zn (Gite *et al.*, 2021).

Nano Zn- ZnO-Zinc oxide nanoparticles in a colloidal solution are utilized as fertilizer. A plant nutrient known as nano fertilizer is more than just a fertilizer because it not only gives plants the nutrients they need, but also restores the soil to its organic state without the negative effects of chemical fertilizers. Nano fertilizers have the benefit of being able to be applied in extremely small quantities (Sabir *et al.*, 2014). ZnO as a fertilizer source will aid in improved growth and yield resulting in an enhanced qualitative and quantitative value of the crop (Azam *et al.* 2022).

Zinc deficiency symptoms in plants:

In general, the deficiency symptoms of Zn include: shortening of internodes leading to stunted growth, and malformation of leaves which will be visible as little leaf and rosette leaf formation. Usually, the deficient symptoms tend to be visible in younger leaves because under deficient conditions Zn gets immobile in plants. Necrosis

symptom is often seen in the ~~middle-aged~~ middle-aged leaves, interveinal chlorosis is another predominant symptom visible under ~~Zn deficient~~ Zn-deficient situations.

In rice:

Chlorosis of the basal leaves, loss of turgidity in leaves leading to wilting, bronzing of the leaves, and death of the young seedlings is seen. In younger seedlings of age 2-4 weeks after transplanting or sowing, chlorosis of the youngest leaves in the midrib at the base is seen. ~~Appearance~~ The appearance of brown spots on the older leaves, which eventually enlarge and coalesce to form ~~brown-colored~~ brown-colored leaves (Hafeez *et al.*, 2013). Other predominant symptoms ~~includes-include~~ reduced tillering, stunted growth, loss of turgidity and plants ~~fall~~ falling down on the surface of the water and ~~float~~ floating.

In many cases, the zn deficiency can be mistaken for the deficiency of N, Mg, Mn, or Fe. So, plant analysis is often recommended before ~~drawing conclusions~~ concluding.

Effective Zinc ~~management methods~~ Management Methods in Rice Based Cropping Systems

Soil conditions and rice production systems play a crucial role in deciding the method of application of zinc to the plants ~~in order to~~ to maximize benefits. ~~Most~~ The most promising methods followed in ~~rice-based~~ rice-based cropping systems are soil application, seed priming, zinc encapsulated fertilizers, foliar application, seed coating, seedling root dip method, ~~bio-fertilizer-based~~ bio-fertilizer-based application.

Soil application of Zn fertilizers ~~are-is~~ is found to be effective in promoting the growth, yield, and biofortification of the grains. Basal application of zinc has improved the yield by 18% compared to control (Zulfiqar *et al.*, 2020). Plants are capable of absorbing soluble compounds and gases through leaves. ~~Application~~ The application of foliar sprays ~~make-makes~~ make the leaves absorb them and export them to the growing tissues. Jose (2019) reported that higher grain and

straw ~~yield-yields~~ of rice were recorded with foliar spray of ZnSO₄ at 0.1% at different growth stages. Combined soil + foliar applied Zn resulted in maximum kernel yield and kernel Zn concentration in fine rice (Ali *et al.*, 2021). Improved yield components and nutrient recovery through Zn foliar nutrition ~~is-are~~ observed by (El-Sobky *et al.*, 2022).

Seed coating with nutrients like zinc using ~~plant-based~~ ~~plant-based~~ substances as adhesives is also a possible method to maximize the benefits, a 13 % increase in yield was noticed with this practice in rice ~~by~~ (Zulfiqar *et al.*, 2020).

By partially hydrating seeds, a practice known as "seed priming," germination-related metabolic processes can start to take place but radicle emergence is prevented. This is a feasible method to raise the Zn content in seeds to improve yield-attributing characteristics and yields because of the tiny amounts of Zn required for seed priming and the simplicity of the procedure. (Sharma *et al.*, 2021). Seed priming has a significant effect on yield and grain Zn contents in ~~the~~ rice under different production systems and zinc application methods (Ali *et al.*, 2021).

The growth, Zn nutrient content, and Zn nutrient uptake of rice were all found to be improved by inoculating it with arbuscular mycorrhizal fungus (Purakayastha and Chhonkar, 2001). Replacing 25% of inorganic nutrients with bio-fertilizers has shown promising nutrient uptake and performance of zinc in rice (El-Sobky *et al.*, 2022).

CONCLUSION

Through the review, it is understood that India is highly ~~under-at~~ risk of zinc malnutrition as the soils are deficient in ~~the nutrient-nutrients at in the~~ first place and ~~the~~ zinc nutrition is often neglected in agriculture. Correcting the zinc deficiency in rice-based cropping systems will be a significant endeavor to achieve the benefits of biofortification through fertilization because rice-based cropping systems are widely used in India and rice is the main diet for the majority of Indians. As availability of ~~the-Zn~~ to plants is dependable on various factors related to the soil

like pH, organic matter, moisture availability etc. considering the factors responsible for unavailability, with available sources of Zn, effective zinc management methods like seed priming, foliar application etc. has to be adopted to deal with zinc deficiency.

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