

Effect of different methods of Zn application on rice growth, yield and nutrients dynamics in plant and soil

Authors' contributions

This study research was carried out in collaboration between the authors. Author AMG designed the study and carried out field experiments. Author AIE contributed in commenting and facilitating necessary materials for the research work and manuscript preparation. All authors read and approved the final manuscript.

ABSTRACT

Zinc (Zn) deficiency is widely spread in Egyptian paddy soils and has negative impact on national rice (**Oryza sativa L.**) production. Field experiments were conducted at the research farm of the Rice Research and Training Center, Sakha, Egypt, to evaluate the effects of different methods of Zn application on rice growth, yield of Sakha 104 and nutrients dynamics in soil and plant. The experiment included four treatments: no Zn, root soaking, foliar and soil application. The results indicated that Zn application by different methods, significantly increased number of tillers, panicles, plant height, 1000-grain weight, filled grains% and grains yield of Sakha 104. Among the different **methods** of Zn application, soil application of 15 kg ha⁻¹ ZnSO₄.H₂O caused **highest increase in** total N percentage, total K percentage and available Zn content in both grains and straw, however, **the percentage of total P** decreased significantly. Zinc content in

soil after harvesting was significantly affected by Zn application. ~~Application of~~ Different methods of Zn application tends to increase the total N and total K contents of soil but decreased P concentration significantly.

Key words: ~~Methods of Zn application, soils properties, Rice yield, Rice~~ nutrient uptake.

1. INTRODUCTION

Zinc deficiency in rice has been widely reported in many rice-growing regions of the world [1, 2, 3]. Zinc deficiency in crop plants results in not only yield reduction but also Zn malnutrition in humans, where a high proportion of rice is consumed as a staple food [4, 5]. Low bioavailability of Zn in soil generally results in Zn deficiency in rice plants, and thus becomes one of the common constraints for Zn bio-fortification in rice grain. Zn deficiency in rice can be alleviated through Zn fertilization, which is considered to be a cost-effective method to alleviate Zn malnutrition [6].

Recently, water crisis in Egypt, has resulted in a move towards water-saving cultivation, from flooded to alternate wetting and drying to aerobic rice systems [7, 8]. Importantly, adoption of these water saving systems may decrease Zn availability [9]. High-yielding varieties and greater fertilizer inputs in Egypt were the strategies to raise the crop yield potential and feed increasing population. The increased application of fertilizers was not sufficient to compensate for over-use of cultivated land. Zinc deficiency is considered as a major threat to the global and regional food security [10]. Amongst several factors of low plant Zn availability in paddy fields are high soil pH, ~~and~~ high CaCO_3 content and low redox potential [11]. Widespread occurrence of Zn deficiency in traditional lowland [12] and newly developed alternate wetting and drying or aerobic rice systems [13] necessitates harnessing of breeding efforts to increase Zn uptake [14, 15].

Widespread Zn deficiency has been found responsible for yield reduction in rice [16]. Globally, more than 30 % of soils are low in plant-available Zn [17].

Nonetheless, frequency of Zn deficiency is greater in rice than other crops, with more than 50 % of the crop worldwide prone to this nutritional disorder [18]. Zinc application methods and sources are aimed at improving Zn availability for plant uptake. Zn can be applied to soil, seed and leaves [18] and by dipping seedlings into a fertilizer solution. Zn-use efficiency is often determined based on the ratio of shoot dry matter or grain yield produced under Zn deficiency to that produced with Zn fertilization.^[n1] Zinc fertilization to cereal crops improves productivity and grain Zn concentration [19, 20] and thus ~~contributes to~~improves grain nutritional value for human beings. However, the vast majority of Zn fertilizer trials and resulting fertilizer recommendations in rice have been in the context of managing the Zn deficiency, with very few studies related to Zn bio-fortification [21]. Selection of appropriate Zn sources for soil application is considered to be an alternative strategy to improve plant availability of Zn under lowland conditions. Generally, ZnSO₄ is the most widely applied Zn source for its high solubility and low cost. In addition, Zn-EDTA (Ethylene Diamine Tetra acetic Acid) is also being recommended due to its efficiency of Zn availability for the plants [22].

Alternate wetting and drying (AWD) management is one of the most important water-saving strategies commonly practiced, which is being widely adopted in Egypt. It has been reported that AWD potentially results in decreased water inputs by 5%-35% when compared with contentious flooding, with the yield of rice grain either being maintained [23, 24, 25] or even increasing [26]. This study was aimed to investigate the effects of different methods of Zn applied through soil, root soaking and foliar on rice growth, yield and nutrients dynamics status in grains and straw of rice variety Sakha 104~~rice variety~~. The obtained results of this study will help to mitigate Zn deficiency in rice and improve zinc use efficiency.^[n2]

2. Materials and Methods

2.1 Area description and soil sampling

Field experiment was carried out at the research area of Rice Research and Training Center, Sakha, Kafr El-Sheikh, Egypt (31°6'42" N, 30°56'45" E). Represented soil samples were taken in bulk from 0-25 cm depth before the growing season. The samples were air-dried, ground and passed through 2-mm sieve. Composite samples were taken and analyzed for physical and chemical characteristics namely, EC, pH, texture, cations and anions following standard methods [27]. The characterization of the soil used is presented in Table 1.

Table 1. Selected soil characteristics of the experimental site

pH	EC (dS m ⁻¹)	Cations (meq L ⁻¹)				Anions (meq L ⁻¹)				Particles size %			Zn (mg kg ⁻¹)*
		Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	CO ₃ ²⁻	SO ₄ ²⁻	Sand	Silt	Clay	
7.89	1.60	2.70	1.65	3.75	2.69	3.80	2.25	3.69	2.67	12.0	28.9	59.1	0.29

* Extracted by using Diethylene Triamine Pentaacetic Acid (DTPA).

2.2 Field experiment

Field experiment was laid out in RCBD with four treatments with plot size of 2x5m. The experiment included four treatments as given in Table 2.

Table 2. Treatments

Symbolic names	Recommended ~~13~~ NPK (kg ha ⁻¹)	Method of Zn application	Zn application rate (kg ha ⁻¹)	Zn sources
T1 (no Zn applied)	Only 150-81-72	-	-	-
T2 (Root	150-81-72	Root soaking in	7.50	ZnSO ₄ .H ₂

soaking)		1.50% solution		☉
T3 (Foliar spray)	~~150-81-72~~	Spray at 20 DAT	2.50	~~ZnSO₄.H₂O~~ ☉
T4 (Soil application)	~~150-81-72~~	Soil application just after transplanting	15.0	~~ZnSO₄.H₂O~~ ☉

DAT, Days after transplanting

All plots except T1 received 150 kg ha⁻¹ N as urea, 81 kg ha⁻¹ of P as P and 72 kg ha⁻¹ K as K. Full dose of P and K was applied just before transplanting. Nitrogen fertilizers **were** applied in two split application: the first split was applied at the time of final land preparation and second split was added at panicle initiation stage. Zinc was applied as ZnSO₄.H₂O. All other cultural practices were kept same and uniform for all treatments. ~~The following observations—Plant height and number of tillers~~ were recorded during growing ~~season~~^[n4]: ~~plant height and number of tillers~~. At crop maturity, harvesting stage, rice plants were manually harvested from 1m² area in the center of each plot, ~~and~~ ~~these~~ plants were used to determine grain yield and its components [28] after separating into straw and grains. Dry weight of straw was determined after oven-drying at 70°C to constant weight. Yield components included panicle number, spikelets per panicle, percentage of filled grains and 1000-grain weight.

2.3 Plant analysis

Samples (0.10 g) **from** each treatment were digested with 5.0 ml HNO₃-H₂O₂ (4:1, v/v) using a hot block heater. After cooling, the digest was transferred to a 20-ml volumetric flask composed of distilled water^[n5] and then filtered. Zn concentrations of these samples were determined using inductively coupled plasma mass spectrometry (ICP-MS; Agilent Modell 7500a, Agilent Technologies, USA).

~~All plants were harvested at maturity, and separated into straw and grains. The dry weight of the straw was determined after oven-drying at 70°C to constant weight. Yield~~

component included panicle number, percentage of filled grains, 1000-grain weight, and grain yield of each treatment were recorded.

2.4 Soil samples

Samples of rhizosphere soil were collected by gently shaking off from the root system, and were extracted available Zn extracted by DTPA according to the method of Lindsay and Norvell [29] and determined using ICP-MS (Agilent 7500a, USA).

2.5 Statistical analysis

All the data including soil and plant samples were analyzed for critical differences using the ANOVA statistical package [30].

3. Results and Discussion

3.1 Growth characters

The height of Sakha 104 rice^[n6] plant as affected by different methods of Zn application are shown in Figure 1. It is observed from the figure that methods of Zn application significantly affected the plant height. Maximum plant height of 100 cm was recorded~~obtained from~~ with the treatment T4 which received 15 kg Zn ha⁻¹ as soil application which differs significantly from the other treatments. Minimum plant height was recorded with T1 in (control). The tillers (numbers/m²) of Sakha 104 rice plant as affected by different methods of Zn application are shown in (Figure 2). The data indicated that application of different methods of Zn application, significantly affected the tillers number.^[n7]

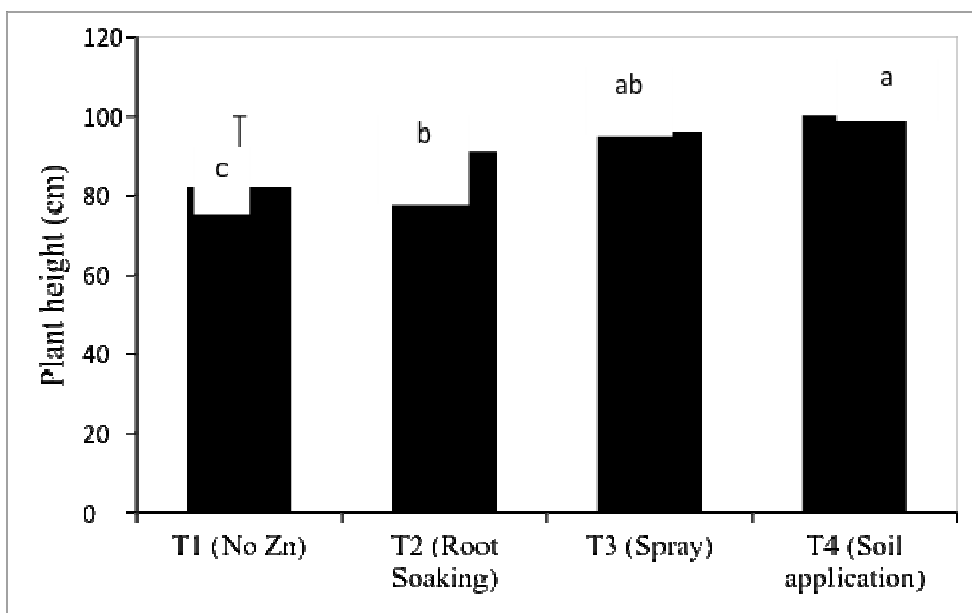


Fig. 1. Plant height of Sakha 104 as affected by different methods of Zn application. Means followed by the same letters are not significantly different at 5% level of probability. Vertical bars represent $\pm$ standard error (SE, n=4)

rice plant compared with control. It is known that, tillering capacity **is** one of the most important rice components which **are** responsible for yield production. Maximum tillers numbers/m² of 430 were recorded **for** by T4 (**soil application**) followed by T3 (**Zn was applied as foliar**); while the minimum tillers **numbers were** recorded in T1 (**control**). The increase of tillers numbers by soil application of Zn may be attributed due to increased **s of** nutrients availability in soil compared with other treatments. Similar results were reported **by** [n8] [31, 32].

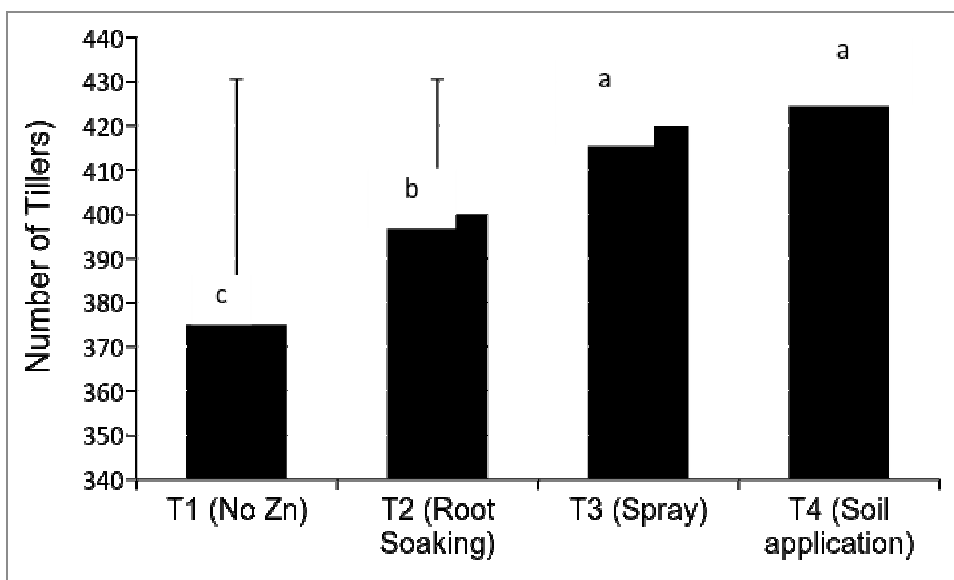


Fig. 2. Number of tillers of Sakha 104 as affected by different methods of Zn application. Means followed by the same letters are not significantly different at 5% level of probability. Vertical bars represent $\pm$ standard error (SE, n=4)

3.2 Yield components

Table 3 shows the number of panicles/m², number of spikelet/panicle, filled grains percentage and 1000-grain weight as affected by different methods of Zn application.

The results indicated that number of panicles/m² is significantly affected by methods of Zn application. All the different methods Zn application (T2, T3 and T4) significantly increased the number of panicles/m² compared with T1 (control). The maximum number of panicles/m² was recorded in T4 (soil application) followed by T2 (root soaking) and T3 in which Zn applied as foliar, while the minimum number of panicles/m² of Sakha 104 rice plant was recorded in T1 (control). The results of number of spikelet/panicle as affected by different Zn application (Table 3) indicated that the number of spikelets/panicle, percentage of filled grains and 1000-grain weight followed the same trend of response i.e. increased with different methods of Zn application increased the number of spikelet/panicle compared to control, however but no significant differences were found amongst the various methods of Zn application on number of

spikelet/panicle. Both filled grains percentage and 1000-grain weight of Sakha 104 as affected by different methods of Zn application follows the same trend in which the different of Zn application increased the filled grains percentage and 1000-grain weight compared with T1 (control), however, there was no significant difference was observed among the methods Zn application on filled grains percentage and 1000-grain weight. Similar results were reported [33, 34, 35].

Table 3. Number of panicles/m², Number of spikelet/panicle, filled grains% and 1000-grain weight-Yield attributes of rice as affected by different methods of Zn application

Treatments	Number of panicles/m ²	Number of spikelet/panicle	Filled grains%	1000-grain weight (g)
T1 (No Zn)	325 d	110 b	80 b	20.1 b
T2 (Root soaking)	348 a	130 a	83 a	25.9 a
T3 (Foliar spray)	339 c	128 a	81 b	26.5 a
T4 (Soil application)	350 a	129 a	82 a	27.1 a

Means values on each column followed by the same letters are not significantly different at 5% level of probability.

3.3 Grain and straw yield of Sakha 104

The impact of different methods of Zn application on grains and straw yield of Sakha 104 are shown in (Figure 3). The results indicated that the different methods of Zn application significantly increased the grain yield of Sakha 104 compared to no Zn application (T1). Maximum grain yield of 9.60 tones ha⁻¹ was recorded by applied 15 kg Zn ha⁻¹ as soil application of Zn. No significant differences were observed in grain yield with between plots receiving Zn either root soaking (T2) or foliar (T3). The increases in Sakha 104 yield by Zn applied with Zn as soil application may be attributed due to its

effectiveness^[n9] and has more residual effect compared with root soaking or foliar. The results indicated that straw yield of rice significantly increased with the different methods of Zn application (T2, T3 and T4) compared with T1 but no significant differences were observed between~~significantly increased the straw yield compared with T1~~ however, there was no significant differences were observed among the Zn application methods. Similar findings were reported [36, 37, 38].

3.4 Effect of different methods of Zn application on **nutrients** content

Zinc content in grains and straw of ~~Sakha 104~~ rice ~~variety~~ as affected by different methods of Zn application are presented in Table 4. ~~The results indicated that, the highest Zn content of 31.1 mg kg⁻¹ was recorded in T3 followed by T4 and T2. The variation of Zn content was significant difference at 5% level among the treatments.~~ The lowest Zn content in grain and straw was recorded in T1 ~~(no Zn applied)~~. The treatment differences were significant at 5% level. Although foliar application is effective in increasing grains Zn content [39, 40,

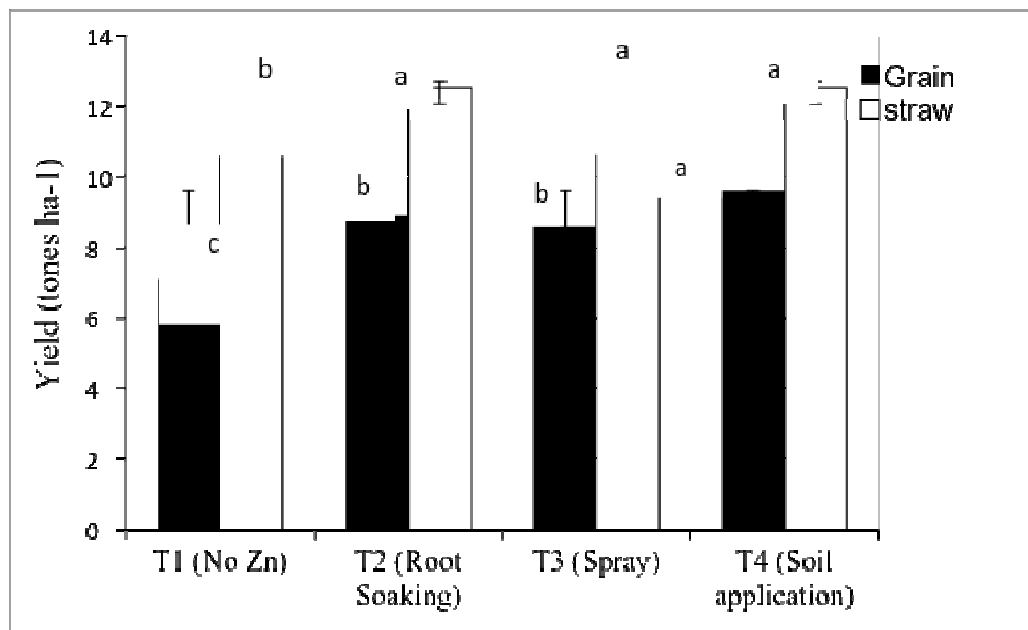


Fig. 3. Grain and straw yield of Sakha 104 as affected by different methods of Zn application. Means followed by the same letters are not significantly different at 5% level of probability. Vertical bars represent $\pm$ standard error (SE, n=4)

41], time of foliar Zn application is an important factor in this regard [42]. The increases in Zn content by grains occur when it is applied as foliar at later stages of plant growth. [43] [n10]evaluated[n11] Zn translocation towards rice grains in a nutrient solution using aerobic rice genotypes. They reported that, when Zn was applied to roots or as foliar spray; under sufficient Zn supply, Zn partitioning ~~from to the~~ grains was greater from root-supplied than ~~Zn applied as foliar application form~~. Foliar application can avoid the problems of Zn binding in soil, but the time of Zn application should be around flowering for increasing grain-Zn concentration. The increase in grain-Zn concentration was attributed may be due to improved leaf remobilization of Zn during grain filling.

Table 4 showed that, total N percentage in rice grains and straw of Sakha 104 affected significantly by different methods of Zn application compared with no Zn (T1). The highest total N percentage in grains (0.97%) was recorded in T2, followed by T4 and T3, respectively. The increases in total N percentage in grains by applying different methods of Zn application may be attributed due to the enhancing the micrograms [n12]in N recycling and organic N mineralization. The results are in agreement with findings of [44].

Phosphorus (P) content of plant as affected by different methods of Zn application is shown in Table 4. The results indicated that, application of different methods of Zn significantly decreased the total P percentage in grains and straw of Sakha 104 compared with T1 (no Zn applied). The highest total P percentage 0.26% and 0.041% were observed in T1, however, there was no significant difference was observed between different methods of Zn application.

Table 4. Effect of different methods of Zn application on total N, P, K, and Zn content of rice plant

Treatments	Zn (mg kg ⁻¹)		N		P		K	
			%					
	Grains	Stra	Grain	Stra	Grain	Straw	Grains	Stra
		w	s	w	s			w
T1 (No Zn)	22.1 c	23.2 b	0.73 b	0.33 b	0.26 a	0.041a	0.160 c	1.40 d
T2 (Root soaking)	29.1 b	27.3 a	0.97 a	0.50 a	0.23 b	0.036 b	0.210 a	0.17 c
T3 (Foliar spray)	32.1 a	28.3 a	0.94 c	0.48 a	0.24 b	0.031 b	0.207 a	0.18 [13]b
T4 (Soil application)	30.1 ab	29.1 a	0.96 a	0.47 a	0.24 b	0.026 c	0.180 b	1.80 a

Means values on each column followed by the same letters are not significantly different at 5% level of probability.

All the Zn applied by different methods decreased the total P percentage. This may be attributed due to the antagonistic effect of Zn on P uptake. [45] reported that application of P, not only decreased water-soluble and exchangeable-Zn, but also increased bound forms of adsorption of Zn with soil particles. These effects were more pronounced under flooded than non-flooded water regime.

The data of total K percentage in grains and straw of Sakha-104 are presented in Table 4. The results showed that with application of different methods of Zn sources, total K percentage increased significantly compared with T1 (control). These results are in agreement with the confirmation findings of [14] [46], they that reported increase in that K concentration of both rice grains and straw showed increasing trend with Zn fertilizer application.

3.5 Nutrients dynamics in soil

Zinc content of soil after harvesting as influenced by different methods of Zn application is presented in Table 5. The results indicated that the application of different methods of Zn application significantly increased Zn of soil compared with control (T1). Maximum Zn content were recorded in the order T4>T3>T2. However, the Zn content of soil after harvesting time was increased compared with the initial Zn content of soil as presented in Table 1.

Table 5. Effect of different of methods of Zn application on available Zn, total N, P and K concentrations of soil after harvesting time

Treatments	Zn content (mg kg ⁻¹)	N	P	K
		%		
T1 (No Zn)	0.35 c	0.73 d	0.26 a	0.15 b
T2 (Root soaking)	0.69 b	0.96 b	0.21 b	0.16 b
T3 (Foliar spray)	0.75 ab	0.91 c	0.22 b	0.18 a
T4 (Soil application)	0.81 a	0.99 a	0.23 b	0.19 a

Means values by each column followed by the same letters are not significantly different at 5% level of probability.

Zinc content in soil is present in a number of chemical forms with varying solubility. These forms include soluble Zn present in soil solution (water soluble), adsorbed on exchange sites (exchangeable), associated with OM, co-precipitated as secondary minerals or associated with sesquioxides [47]. These different forms mainly control solubility and availability of Zn to plants [48]. In addition, Soil chemical properties such as pH, Rh, soil organic matter (OM), have strong influence on Zn adsorption-desorption reactions and play a critical role in regulating Zn solubility and its fractionation in soils

[49]. Varied responses of rice to the Zn fertilizers have been reported, depending on the source, application time, methods of application and soil chemical properties [49].

Nitrogen (N) content of soil at harvesting time as affected by applying different methods of Zn are presented in Table 5. The data showed that, there is significant different in total N percentage among the methods of Zn application. The maximum total N percentage of 0.99 was recorded by T4, followed by T2 and T3, while the T1 has the lowest total N percentage value. Maximum total N percentage of soil content was observed with combined application of N and Zn. Among Zn application methods, soil application was considered superior treatment [50].

Phosphorus (P) content of soil after harvesting as affected by applying different methods of Zn are presented in Table 5. The application of different methods Zn application, content in soil decreased P significantly compared with no Zn (control). The highest P% content observed in T1, however no significant differences were recorded among the methods of Zn application. Phosphorus interacts with Zn in soil which reduces Zn translocation from roots to the shoots [51] and also imbalanced P: Zn ratio in plant (dilution effect) has a negative effect on rice yield. Other studies also indicated that P application influenced Zn uptake by rice and translocation into shoots [52].

The content of total K percentage of soil at harvesting time as affected by different of methods Zn application are presented in Table 5. The results indicated that the application of different of methods Zn application has a little effect of increase the total N percentage compared with no Zn added (control). The maximum total N percentage of 0.19% was recorded with T4, followed by T3 and T2. Similar results are reported [53].

4. CONCLUSION[15]

The effect of various methods of Zn application (root soaking, foliar and soil application) on Sakha 104 rice growth, yield and nutrient concentration in plant and soil was studied. Zinc application by any of the methods increased significantly the number of tillers, panicles, plant height, 1000-paddy weight, straw and grain yield over control. No

significant difference was observed among the methods of Zn application in most of the cases. Maximum soil Zn concentration was found in plots with soil Zn application as compared to foliar or root soaking application. Zinc content in soil after harvest was also significantly affected by methods of Zn application. Application of Zn tended to decrease P concentration but increases the total-N, total-K and Zn concentrations of the straw. Maximum soil Zn concentration was found in soil Zn application treatment as compared with foliar and root soaking. The study suggested that, soil application of Zn resulted in better results and easier as compared to foliar and root soaking treatment.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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