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Lime and Zn interactions effects on yield, yield component, and quality of rice in Zn deficit tropical paddy soil

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ABSTRACT

A glasshouse experiment was conducted to investigate the lime and Zn application and interactions on rice, yield and yield components, and rice quality in various Zn deficit tropical paddy soil types. The tiller number, plant height and straw dry matter at maximum tillering and flowering stages significantly increased by the application of lime and both at 5 and 10 kg ha-1 Zn levels in Kundur (KUR) (pH= 5.2) and Telemong (TLM) (pH=7) soil series, whereas in Tepus (TEP) acid sulphate soil (pH=4), they increased in 5 kg ha-1 Zn and decrease at 10 kg ha-1. The grain per panicle(GPP), grain yield(GY), 1000grain weight(1000GW) and straw dry matter(SDW) significantly increased by application of Zn and increasing its levels. The highest increasing pattern were showed in Kundur (pH= 5.2) and Telemong (pH=7) soil series were recorded at 10 kg ha-1, whereas the highest and lowest values were obtained at 5 kg ha-1 and at 10 kg ha-1 in Tepus acid sulphate soil (pH=4). The highest grain and straw yield were obtained in TEP at 5 kg ha-1Zn level, which were 56 and 23% more than untreated Zn pots. The highest crude protein (CP) and grain Zn (GZn) were observed by 10 kg ha-1 applied Zn, 44% and 60% more than control, respectively. However, by lime addition CP and GZn decreased about 16 and 22% over the non-treated plots. The agronomic biofortification strategies such as Zn fertilization application and soil amendment addition improved rice MR219grain productivity and biofortification an average of 60%.

INTRODUCTION

Zinc (Zn) is the most limiting micronutrient that its deficiency, next to N and P is the widespread nutrient disorder in the rice paddy fields (Neue and Lantin 1994; Quijano-Guerta et al. 2002; Wissuwa et al. 2006). Zinc is required as a co-factor of more than 300 plant enzymes (Clemens 2010; White and Brown 2010) and has countless critical structural roles in regulation of transcription and translocation, the structural stability of proteins, and enzymes functional activities (Broadley et al. 2007). The macro scale Zn deficiency incidence in agricultural soil intensifies through soil erosion, leaching and off stream drainage water, imbalance proportions of manure and chemical fertilizer, high purity chemical fertilizers, marginal land cultivation and high demand improved varieties (Fageria et al. 2002; Khoshgoftarmanesh et al. 2009). In micro scale, Zn deficiency constraints are also accelerated by the soil limiting characters, such as high pH, excess amount of P, high calcium carbonate content (Alloway 2012). With respect of all reasons, the Zn deficiency is responsible for about 40% of rice yield reduction in paddy fields (Cakmak 2008; Dobermann and Fairhurst 2000), especially in tropic (Slaton et al. 2005a; Slaton et al. 2005b). Zinc deficiency in tropical Zn deficit lowland paddy soils of Malaysia has been presented

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(Habibah et al. 2011; Jamil et al. 2013; Jamil et al. 2011; Yin et al. 2012). Nearly all soils in Malaysia, are classified into three soil orders: Oxisols, and Ultisols (72%) and Entisols (Paramananthan 2000), which they are extremely leached, low pH (4-5), high Al activity and low basic cations (Ca and/or Mg) capacity. These soil characters can adversely affect the crop production of rice growing area in Malaysia (Shamshuddin and Anda 2012).

It has been estimated that in response to food demand of the rapid growth rate of population, crops production needs to rise up by 40% in 2020 annually (Khoshgoftarmanesh et al., 2010). Thus, sufficient Zn nutrient supply(Alloway 2012; Impa and Johnson-Beebout 2012) and sustainable modification of tropic soils condition (Shamshuddin et al. 2013) have played an important role in enhancing rice production. On the other hand, nowadays, higher crops production with more nutritional quality have been targeted as an agricultural policy to overcome growing malnutrition problems (about 40% of the world's population) (Khoshgoftarmanesh et al. 2009). Among the alleviate methods, liming, is a common way to control the tropical soils constraints. Lime application by rising up the acidic soil reaction and precipitation of toxic acidic cations, thereby reducing their phyto-availability, and preparing sufficient calcium and magnesium can improve the rice growth (Anda et al. 2009; Shamshuddin and Kapok 2010). But, on the other side, the uptake, translocation, metabolism, and plant use of essential micronutrients, such as Zn is inhibited by high pH and individual effect of $CaCO_3$ due to lime application.

In the field studies, several researches have addressed Zn application on rice plant growth (Cakmak 2008; Fageria 2010; Fageria et al. 2011; Kabeya and Shankar 2013) and also liming effect on soil conditions improvement in tropical soils (Anda et al. 2009; Shamshuddin et al. 2013; Shamshuddin and Kapok 2010), separately. But, the simultaneous application results of them were considered to be more conservative (Fageria and Stone 2008; Impa and Johnson-Beebout 2012) and have been exceeded in field conditions. Therefore, the present study was undertaken to investigate the effect of lime and Zn and their interactions on rice yield and yield components as well as rice quality in various Zn deficit tropical paddy soil types in Malaysia.

MATERIALS AND METHODS

The glasshouse experiment was conducted using two selected tropical soil orders (three soil series) that are deficient in soil Zn. The factorial experiments with three levels of Zn (0, 5 and 10 kg ha^{-1}) in the form of Zn sulphate, two levels of lime (0 and lime requirement for soil pH of 5.5) as calcium carbonate, and three types of soil series with different soil pH. The soils were sampled from the topsoil plough layer (0-30 cm) of distinctive puddle paddy fields in Kelantan and Kedah states, two major rice growing states of Malaysia. The soils were classified according to USDA Soil Taxonomy (Table 1). The soil samples were air-dried, ground and sieved through 2-mm metal sieve. The physicochemical properties of the soil samples were determined: pH, organic carbon (OC %), cation exchanges capacity (CEC), clay content, available Zn, Fe and Mn. A pipette method was used to determine soil texture (Gee and Bauder 1986). Soil pH and electrical conductivity (EC) were determined in a 1:2.5, soil to water ratio suspension. The CEC was measured by leaching and replacing NH_4 OAc method (Bower et al. 1952). The soil organic matter and available Zn were measured using the Walkley–Black (Jackson 1964) and double acid method (Amacher 1996) (Table 1), respectively. The MR219, moderately zinc efficient (Hafeezullah 2010), and the most popular rice variety in Malaysia was used as rice genotype. This experiment was carried out in randomized complete block design with three replications.

Fifty four pots (70×45×45 cm) were filled up with 20 kg of the prepared soil and applied the above mentioned treatments, except the Telemong soil series that did not receive lime, due to its neutral soil pH (7). The pot soil was fertilized with urea, triple supper phosphate (TSP) and muriate of potash (MOP) as the sources of N, P and K at the rates of 150 kg N, 70 kg P_2O_5 and 70 kg K_2O ha^{-1} respectively. The whole amount of One-third of urea, total TSP and MOP were applied as basal dose. The remaining 2/3rd were top dressed in two equal instalments at tillering and flowering stages. After puddling the soils, Four week-old MR219 rice seedlings were transplanted at the distance of of 20 cm × 20 cm. The water level is maintained constant at 5±0.5 cm above the soil surface throughout the period of the experiment by the periodic water supply. All the conventional managerial practices such as watering, fertilizers split application, weeding and pest control were performed on time as necessary. The soils and plant sampling and data were recorded at maximum tillering, flowering and harvesting stages. The whole plant sample was collected at each growth stage and washed carefully with tap water followed by 0.01 N HCl and rinsed with double distilled water in two times. They were separated into leaves, stems, panicles, roots and grains. Arial parts and roots were dried in the air and also oven at 65°C and total dry matter was recorded. The grains were dried at 45°C and adjusted to 12% moisture content. Rice plant samples were ground and stored for chemical analysis. The following morphological characters were measured: plant height, tillers number, number of panicles, grains/panicle, total 1000 grain weight, stem and leaves dry weight, yield and yield component and also rice quality parameters including: Zn in grain (Jones, 2001), protein, and protein profiles. Analysis of variance, correlation, and regression were used to explore the significance of treatment effects. Since the Telemong series did not receive any lime, thus to statistical analysis, combination (Comb) of soil and lime were used as a one treatment.

RESULTS AND DISCUSSION

Classification and soils properties

Based on the USDA soil taxonomy, selected soils, Telemong (TLM), and Kundur (KUR) soil series belong to Entisols and Tepus (TEP) soil series is classified as Ultisols. The parent material of all soils was recent alluvial. The results showed that the soil pH, ranged from acidic to neutral reactions (pH 3.9–7.0), OC content covered a narrow range (1.7- 2.6%), EC varied between 40 and 245 µs m^{-1}, particles size distributions (%) were clay: 16-45, silt: 28.2-57.9 sand: 0.6-55.7, CEC ranged from 6.4 to 17.6 $mmol_c$ kg^{-1} and concentrations of Ca, Mg, Mn and Fe were: 0.7-4.0, 0.03-0.06, 12.8-64 and 20-1752 $mgkg^{-1}$soil, respectively (Table 1). Phosphorus (P) concentration was ranged from 18 to 94 mg kg^{-1}, available Zn ranged from 0.56 mg kg^{-1} soil in Tepus acid sulphate soils, to 0.79 mg Zn kg^{-1} in Telemong soil series as a neutral soil. All Zn contents of soils series were showed less than the critical limit in paddy soils (2 mg kg^{-1}) (Dobermann and Fairhurst 2000). Lime application by 10 t $ha^{-1}$to reach the soil pH to 5.5 (the best root zone pH for rice growth), significantly increased the soil pH, especially in acid sulphate Tepus soil series. Furthermore, in Kundur soil series by application of 300 kg ha^{-1} calcium carbonate increased the soil reaction from 5.3 to 5.5. This results are in accordance with the findings of Shamshuddin and Anda (2012) and Shamshuddin et al. (2013), who reported that by applying of lime or liming products not only increased the soil pH but also raised the basic cations and both these improvement can help rice crop for better growth.

Morphological characters

Analysis of variance results of morphological characters at different rice growth stages were summarized in Tables 2 and 3. At maximum tillering and flowering stages, the tiller number (TN), plant height (PH) and straw dry matter (DW) were significantly affected with Zn levels and combination of soil and lime (Comb) at 0.01 confidence level. While, for the dry matter at maximum tillering stage, the interaction effect of applied treatments was not significant. Plant height, tillering capacity and dry matter are the most important morphological parameters for increasing rice production. An average data of two years trails indicated that Zn application all of them significantly increased tiller number(14%) and plant height(8%) over the control, although, increasing the applied Zn level more than 12 kg ha-1 has adversely effect on them (Khan et al. 2012). Furthermore, lime application in any rate significantly increased the rice morphological growth parameters such as: PL, PH. It is due to increasing the soil pH and prepare the proper amount of basic cations, thereby, influenced positively to the plant growth and development. Our results are in accordance with findings of (Rahman et al. 2002; Rosmini and Sarwani 1991; Shamshuddin and Anda 2012; Shamshuddin et al. 2013).

At harvesting stage, the plant height, tiller number, panicle length (PL), straw dry weight (DW), grain per panicle (GPP), 1000 grain weight (1000GW), grain yield (GY) were showed significantly affected by all treatments and their interactions, except immature grains that affected by Comb at 0.05 confidence level (Table 3). The PH, TN and PL at maximum tillering and flowering

Table 1. Physicochemical properties of selected soils

Soil series	EC×10^{-6}	pH	OC	CEC	Ca	Mg	K	Ava. Zn
	ds.m-1		%	———— $cmol_c kg^{-1}$ ————				mg.kg^{-1} soil
Kundur	40	5.46	2.63	17.57	3.43	0.05	0.01	0.50
Tupus	245	3.93	2.55	7.05	0.68	0.03	0.001	0.56
Telemong	142.3	7.00	1.73	6.40	3.98	0.06	0.003	0.79
Soil series	Mn	Fe	Clay	Silt	Sand	Texture	Soil order	Great groups
	meq.100 g^{-1} soil		--------------%------------------					
Kundur	13.44	1752	45	54.37	0.55	Si.C	Entisols	Fluvaquent
Tepus	64	19.95	35.6	57.86	6.41	Si.C. L	Ultisols	Kandiaquult
Telemong	12.75	292.4	16	28.17	55.73	Sa.L	Entisols	Udorthent

Table 2. Analysis of variances of morphological factors of rice MR219 at max tillering (1) and flowering stage (2)

	Mean square					
Sources	TN1	PH1	DW1	TN2	PH2	DW2
Comb	14.5**	156.24**	33.43**	29.14**	74.96**	35.55*
Zinc	4.8**	44.24**	1.93NS	0.38NS	36.90**	31.66*
Comb×Zinc	0.17NS	3.27NS	2.07**	1.25NS	8.64NS	6.60 NS

**, * and NS = Significant at 0.01, Significant at 0.05 and Non- Significant

stages also significantly increased by the application of lime and both at 5 and 10 kg ha^{-1} Zn levels in KUR (pH= 5.2) and TLM (pH=7) soil series, whereas increased in 5 kg ha^{-1} Zn and decreased at 10 kg ha^{-1} in TEP acid sulphate soil (pH=4). The highest PL was observed around 27 cm at 5 kg ha^{-1} with lime application for TEP, 27.5 cm at 10 kg ha^{-1} plus lime for KUR and 27.13 at 10 kg ha^{-1} for TLM which the difference between them were not significant. The highest TN and PH were 11.67, 13 and 13.3, and 117, 118.3 and 119.3 for TEP, KUR and TLM soil series, respectively. The two years trials results indicated that Zn application (9 kg ha^{-1}) significantly increased the morphological characters such as PH and TN about 14 and 8%, respectively. The lime application with elevation of the soil pH and basic cations concentration significantly increased the rice morphological growth parameters (Rahman et al. 2002; Rosmini and Sarwani 1991; Shamshuddin and Anda 2012; Shamshuddin et al. 2013). Liming to bring the acidic soil pH to 5.8 significantly influenced PL and GPP both at 1 t ha-1 and 2 t ha-1, but the highest grain yield was observed at 2 t ha-1, about 4700 kg ha-1 in comparison with control (3.54 t ha-1) (Rahman et al. 2002).

Grain and straw yield

The GPP, GY, 1000GW and SDW were significantly increased by application of Zn. The highest increasing pattern were observed in KUR (pH= 5.2) and TLM (pH=7) soil series at 10 kg ha^{-1}, whereas the highest and lowest values were obtained at 5 kg ha^{-1} and at 10 kg ha^{-1} over the control in in TEP acid sulphate soil (pH=4). The maximum GPP and 1000 GW, were achieved in TEP acid sulphate soil when 5 kg ha^{-1} applied Zn, which were 32.96 and around 10% greater than control, respectively. The highest grain and straw yield were obtained at 5 kg ha^{-1}Zn level in TEP, which were 56 and 23% more than untreated Zn pots. The GPP, 1000GW, GY and SDW were increased maximum in KUR and TLM at 10 kg ha^{-1} Zn application along about 60, 10, 68 and 25, and 43, 10, 63 and 33%, respectively (Figures. 1 and 2). The yield and yield components were showed significantly increased with the application of lime with different confidence levels in TEP acid sulphate (0.01), and KUR and TLM soil series (0.05) (Tables 1, 2, 3 and 4) (Figure 1). The GPP, 1000GW, GY and SDW were increased with 200, 10, 200 and 20%, respectively in TEP due to lime application, whereas in KUR and TLM soil series were less than 10% in all parameters. The interaction effect of lime and Zn on GPP, 1000GW, GY and SDW observed similar to single lime effect. The highest increasing values were recorded in TEP soil due to increasing its low soil pH to about 5.5, followed by KUR (pH=5. 3) and TLM soil series (Figure 2). Recommended Zn rates for lowland rice varied between 5 to 10 kg ha $^{-1}$ and strongly depended on soil types and pH, and rice varieties sensitivity (Fageria et al. 2011). Slaton et al. (2005a) were reported a wide range of increasing in grain yields (10-86%) due to Zn application. Zinc application increased the grain yields due to increasing of Zn content in the plant Zn application coupled with increased the active tiller number per hill and higher zinc uptake might have increased the grain yield (Jena et al., 2006). The highest rice yield, 7500 kg ha-1 was obtained by application of 7.5 t lime ha^{-1} in acid sulphate soils of the west coast states of Peninsular Malaysia that it is similar to the rice yield soils without problem in the granary areas (Shamshuddin et al. 2013). Soil liming is a serious amendment addition to rise up the soil pH of acidic soils as well as reducing Al and Fe toxicity to the growing crops and increasing the Ca and Mg content, which are

Table 3. Analysis of variances of morphological factors of rice MR219 at harvesting

Sources	Mean square							
	Gpp	PL	1000Gw	IMM	SDW3	PH3	TN3	GY
Comb	4764.96**	4.61 **	6.70 **	348.47 *	245.52 **	67.64 *	12.25**	398.66**
Zinc	11977.4**	6.58 **	8.41 **	130.19 NS	197.59 **	108.02 **	5.35 NS	700.23**
Comb×Zinc	2060.56**	3.46 **	3.15**	154.57 NS	64.17 **	66.32 **	2.15 NS	55.86**

**, * and NS = Significant at 0.01, Significant at 0.05 and Non- Significant

Table 4. Effect of lime and Zn on Straw and grain Yield and selected yield components at various tropical paddy soils

	Straw and grain Yield and selected yield components															
	Grain per panicle				1000 Grain weight				Grain yield per pot				Straw dry weight			
TRT	Zn0	Zn5	Zn10	LSD	Zn0	Zn5	Zn10	LSD	Zn0	Zn5	Zn10	LSD	Zn0	Zn5	Zn10	LSD
S1L1	123.34Cb	164.00Ca	97.67Bc	14.63	22.59Cb	24.48Aa	21.8Cb	1.52	15.63Db	24.34Da	13.63Ec	1.60	22.22Db	27.34Da	23.20Cab	4.2
S1L2	156.00Ac	183.67Ab	200.00Aa	11.43	23.00Cb	24.75Aa	24.08Ba	0.99	18.67Cc	26.45Cb	32.14Da	1.40	24.79Cc	32.12Cb	22.32Cc	1.67
S2L1	133.67Bb	173.00Bab	213.33Aa	43.15	23.06BCb	24.63Aa	24.85Ba	0.73	22.36Bc	33.13Bb	37.30Ca	1.35	27.38Bb	34.13Ba	34.2Ba	2.95
S2L2	135.33Bc	174.33Bb	213.33Aa	11.18	23.64ABb	24.07Aa	24.04Ba	0.21	24.00Acc	35.00Abb	38.35Baa	0.88	28.20Bb	37.46Aa	37.58ABa	2.26
S3L1	150.17Ac	180.00ABb	214.33Aa	6.84	24.00Ac	24.76Ab	26.39Aa	0.73	24.3Ac	33.47ABb	39.80Aa	1.05	31.45Ac	34.01Bb	41.53Aa	1.24
LSD	7.29	7.21	22.45		0.66	0.81	0.89		1.10	1.41	0.95		1.78	1.67	4.3	

Table 5. Analysis of variances of crude protein and grain total Zn of rice MR219

Sources	Mean square	
	Protein	Grain Zn
Comb	5.16**	81.24**
Zinc	19.68**	334.71**
Comb×Zinc	1.37**	37.65**

**, Significant at 0.01

necessary for crops in high amount (Shamshuddin and Kapok 2010).

Rice biofortification parameters

The rice quality characters, crude protein (CP) and grain Zn (GZn), significantly affected at harvesting stage by the application of lime or Zn separately and by their interaction at 0.01 confidences level (Tables 5, 6 and 7). The CP and GZn were increased by the application of lime and both at 5 and 10 kg ha^{-1} applied Zn in all studied soil series. The quality characters more increased significantly in 10 kg ha^{-1} Zn than 5 kg ha^{-1}. The highest values were obtained at 10 kg ha^{-1} over the control in Tepus acid sulphate soil series, which was 44% for CP and 60% for GZn. Whereas, lime and Zn interactions, the CP increasing pattern were showed dropped down to 16% and also GZn to 22%, although, the interaction effects are significantly over control. The highest CP and GZn for KUR were observed about 22 and 10% at 10 kg ha^{-1} plus lime and 65 and 45% for TLM, which the difference between them were significant (Figure 3). The agronomic bio-fortification strategies, such as Zn fertilization application and soil amendment addition, the efficient traditional method, still is quick solution to improve Zn deficiency in rice grain and addressed the human Zn disorders

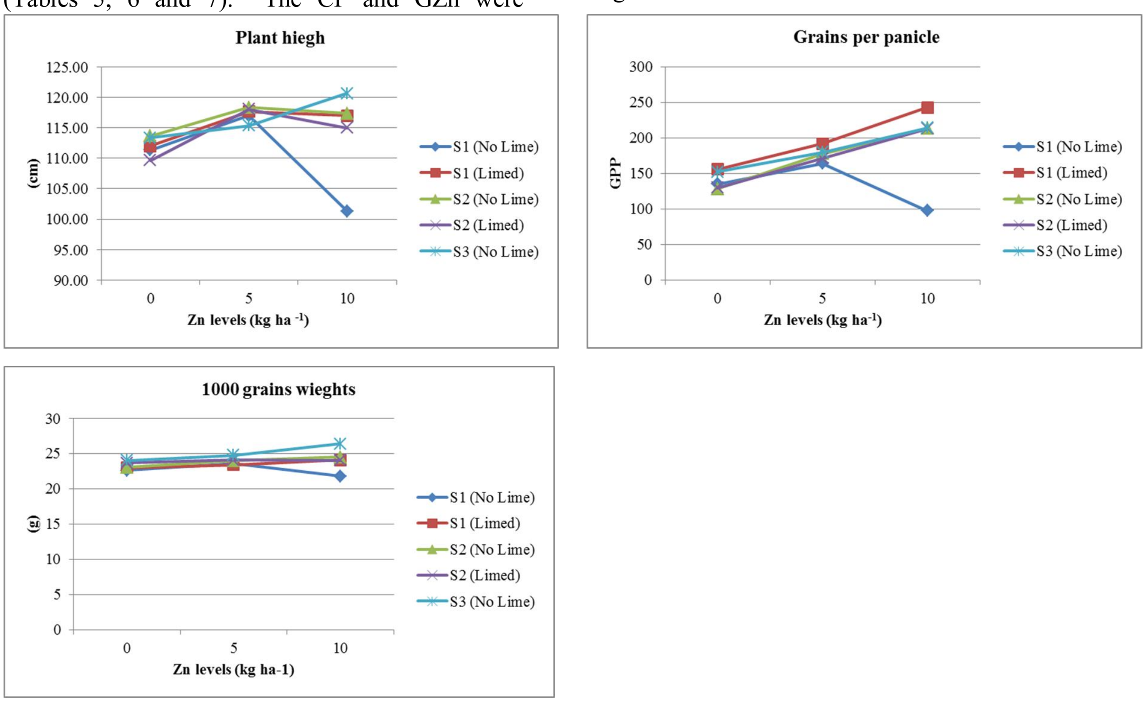

Figure 1. Effect of Zinc and lime application on PH, GPP, and 1000GW MR219 rice variety in tropical paddy soils

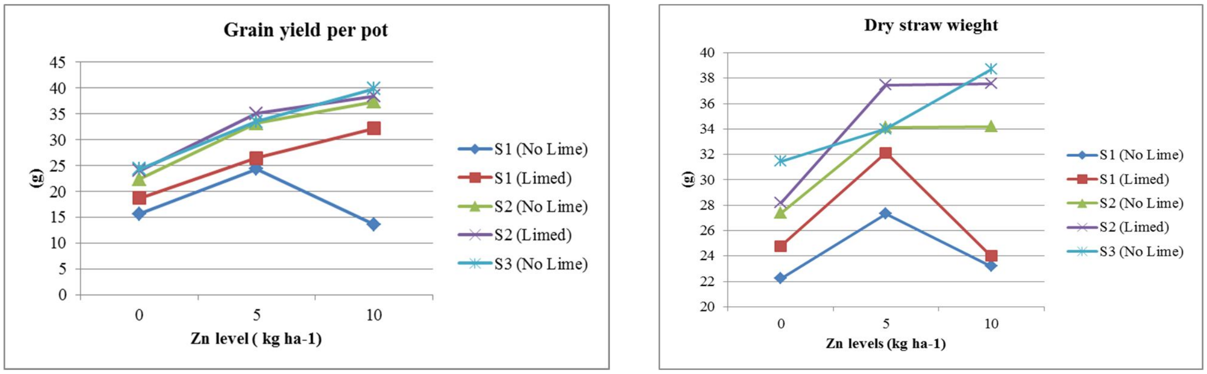

Figure 2. Effect of Zinc and lime application on grain per pot and straw dry weight of MR219 rice variety in tropical paddy soils

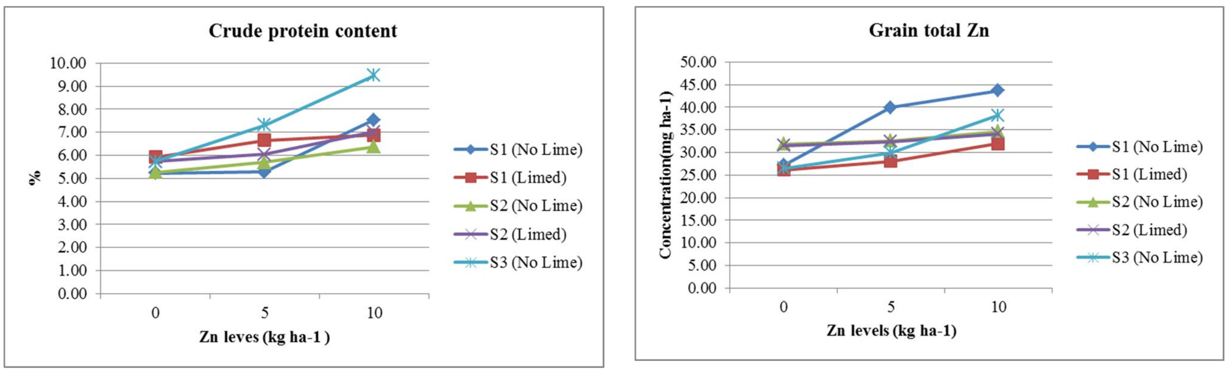

Figure 3. Effect of Zinc and lime application on grain total Zn and crude protein content of MR219 rice variety in tropical paddy soils

Table 6. Effect of lime and Zn interaction on MR219 Crude protein content and grain Zn

	Quality characters							
	Crude protein				Grain Zn			
TRT	Zn0	Zn5	Zn10	LSD	Zn0	Zn5	Zn10	LSD
S1L1	5.20Bb	5.30Be	7.54Ab	0.18	27.20Bbc	39.93Aa	43.67Aa	10.22
S1L2	5.91Ca	6.65Bb	6.87Acd	0.20	26.17Bc	28.07Bb	31.94Ad	3.36
S2L1	5.26Bb	5.70Bd	6.37Ad	0.51	31.87Aa	32.60Ab	34.63Ac	6.55
S2L2	5.70Ca	6.04Bc	7.01Abc	0.22	31.53Aab	32.43Ab	34.13Ac	3.16
S3L1	5.80Ca	7.00Ba	8.81Aa	0.62	26.07Bc	30.00Bb	38.20Ab	
LSD	0.313	0.28	0.56		4.46	6.7	1.5	

(Cakmak 2008). Rice quality parameters evaluation by Zn application in India indicated that improvement of the grain quality of rice was significantly over the control, and by soil application of ZnSO4, the protein content increase about 10% (Yadav et al. 2013). By applying four levels of Zn (0, 2.5, 5 and 7.5), the total Zn in grain increased significantly and the highest increased was observed at 7.5 kg ha^{-1} and about 45 mg ka^{-1}. Additionally, the increased in Zn concentration of rice grain varied from 22.9 mg kg-1 to 79.7 mg kg^{-1} with a mean value of 40.3 mg kg^{-1} due to Zn application. The soil Zn application increased the Zn concentration in brown rice about 17% over the control, whereas, soil plus foliar applied Zn increased more than 95% in comparison with non-treatment (Cakmak 2008).

Table 7. Effect of Zn on MR219 Crude protein content and grain Zn

	Quality characters	
TRT	Crude protein	Grain Zn
Zn0	5.60C	28.15C
Zn5	6.30B	32.29B
Zn10	7.680A	36.77A
LSD	0.17	0.11

CONCLUSION

The two tropical soil orders (three soil series) varied in soil pH from acidic to neutral reactions (pH 3.9–7.0) and deficient in available Zn (0.56 to 0.79 mg Zn kg^{-1}). The rice morphological characters at maximum tillering and flowering stages significantly affected by lime and Zn application and their interaction and both at 5 and 10 kg ha^{-1} Zn levels. At harvesting stage, also the grain per panicle(GPP), grain yield(GY), 1000grain weight(1000GW) and straw dry matter(SDW) significantly increased by application of Zn and increasing its levels. The biofortification characters were increased about 44% for crude protein (CP) and 60% for grain Zn (GZn) in Tepus, whereas in KUR and TLM were about 22 and 10% and 65 and 45% for TLM. In spite of clear results, still the question about selecting the appreciate Zn and lime sources and time strategies, soil properties effects and different varietal response need more focus.

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