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Lime and Zn application effects on soil and plant Zn status at different growth stages of rice in tropical acid sulphate paddy soil

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ABSTRACT

The acid sulphate soils in tropics are characterized with low pH (<4), high Al^{3+} and Fe^{2+} content, low basic cations and low phyto-available Zn concentration that can adversely affect the rice growth. A two year field experiment was conducted to explore the Zn and lime application and their interaction effects on soil and rice tissues Zn status in Zn deficit tropical acid sulphate paddy soils. The maximum increase in available Zn at no limed plots was obtained at 10 kg ha^{-1} Zn level about an average of 12 folds and lime application decreased it about 20% compared to control. The average increase in leaves, stems and grains Zn concentration due to Zn application at maximum tillering was 60%, 35.5% and 200% respectively at 10 kg ha^{-1} Zn level. The highest correlation coefficient between grain Zn concentration and available Zn, root Zn, panicle Zn and stem Zn was 0.96^{**}, 0.92^{**}, 0.92^{**}, and 0.97^{**}, respectively. The Zn concentration of grain had positive significant correlation with bran Zn (0.93^{**}) and white rice Zn (0.91^{**}). The highest increased percentage of Zn uptake in limed plots was 2.11% and 1.59%, 1.465 and 1.23% with 10 and 5 kg ha^{-1} Zn application, respectively. The highest Zn concentration in rice tissues at maximum tillering was recorded in roots; followed by stems, and leaves. Whereas, the order at flowering stage was as follows: root> stem> panicle>leave. Finally, at harvesting stage this order of Zn concentration in roots, stems, grains, panicles and leaves was observed.

INTRODUCTION

Zinc (Zn) is the most important micronutrient that its deficiency considered to be a serious widespread nutritional disorder of the world's wetland rice (Neue and Lantin 1994; Wissusa et al. 2006). To sufficient supplying of Zn for proper crop growth, two Zn sources are used: the outer sources i.e. of soil and foliar Zn uptake and the inner sources i.e. of remobilization Zn (Palmgren et al. 2008). The first source is improved by agronomic strategies, especially increasing Zn phyto- availability through soil amendments addition (Graham et al. 2007; White and Broadley 2009; Bouis and Welch 2011). The second bioavailable Zn reservoir is remobilization of the pre-anthesis Zn source tissues in plant that its dynamics in rice tissues are based on the relationships among soil available Zn, total plant Zn and the Zn concentration of individual rice plant parts (Jiang et al. 2008; Stomph et al. 2009). Zinc is unequally partitioned within the crop tissues. Crops are able to absorb soluble micronutrients through roots and aerial parts (Broadley et al. 2007), and store a high portion of their soluble forms in organic complexed constituents. When crops are given Zn through root zone, Zn concentration in tissues commonly accumulate in the order of root ≈ stem> leave > grain. Consequently, Zn concentration in root generally are higher than shoot and grain (Pfeiffer and McClafferty 2007; White and Broadley 2009).

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In Asian countries, low fertile acid sulphate soils have been goaled to expand agricultural arable land especially paddy fields where immense acres of it be found in tropical climate conditions, particularly in coastal regions with no limitation of irrigation water supply (Enio et al. 2011). Generally, the most important characters of acid sulphate soils in tropic regions are low pH (< 4), and high Al^{3+} and Fe^{2+} concentration that can effect rice growth adversely (Elisa et al. 2011; Shamshuddin et al. 2013; MahmoudSoltani et al., 2016). In Malaysia, these constraints combined with high weathering and leaching processes (Somani 2008) and low phyto-available Zn (Hafeez et al. 2009; Khairiah et al. 2009 a,b; Habibah et al. 2011). The acid sulphate soil's low in fertility and toxicity problems and improvement of rice growth can be alleviated by Zn fertilizers and lime application (Anda et al. 2009; Shamshuddin and Kapok 2010). However, lime application restricted the Zn uptake, translocation, and use efficiency due to increase in pH and negative effect of $CaCO_3$.

A great number of agricultural researches have addressed the Zn application for optimum rice growth and development, nutritional quality in rice (Cakmak 2009; Fageria et al. 2011; Kabeya and Shankar 2013; MahmoudSoltani et al. 2016), Zn partitioning in different parts of rice tissues (Pfeiffer and McClafferty 2007; White and Broadley 2009). Furthermore, the effects of lime application to improvements of soil characters especially soil reaction and reduction in metal ions toxicities in tropics (Anda et al. 2009; Shamshuddin and Kapok 2010; Shamshuddin et al. 2013). But, combined effects of lime and Zn application results were seemed to be rare (Fageria and Stone 2008; Impa and Johnson-Beebout 2012) and need to exceed in researches. To fulfil these research gaps, the present two years study was attempted to explore the lime and Zn application and their interaction effects on soil Zn status, Zn uptake, use efficiency, translocation and partitioning in different rice growth stages in acid sulphate paddy soil.

MATERIALS AND METHODS

This experiment was carried out in the acid sulphate research field of Long-term Research Grant Scheme (LRGS), Food Security Project, during 2013-2014 rice growing seasons in Kelantan state of Malaysia. Bulk surface (0-30 cm) paddy soil samples in composite method (3 samples per location) were collected, air dried under glass-house shade, grounded with a mechanical pestle and mortar, and passed through 2 mm metal sieve. The grounded, fine soil particles were kept in polyethylene bags for further works.

A pipette method was used to determine soil particle-size (Gee and Bauder 1986). A 1:2.5 (weight (w): volume (v)) soil to water suspension was used to determine soil pH. The oxidizable organic carbon (OC %) was measured by using the Walkley–Black wet oxidation method, where organic matter concentration of the fine soil particle was oxidized by chromic acid through the heat of dilute sulphuric acid (Jakson 1964). Soil electrical conductivity (EC) was determined by a 1:2 (w: v) soil to water suspension with a conductivity meter. The cation-exchange capacity (CEC) and basic cation concentration were measured by leaching, replacing and titration procedures (Bower et al. 1952) and determined by the atomic absorption spectrophotometer. Acidic cations were measured by double acid method (extracting by mixture of 0.05 N HCl and 0.025 N H_2SO_4) and reading supernatant solution by an atomic absorption spectrophotometer (Amacher 1996). Also, phosphorus (P) was measured by Bary and Kurtz (1945) method. The total Zn concentration in soil samples was determined by dry ashing, thermal digestion with Aqua Regia (Hydrochloric acid, 37%, Nitric acid, 65%, and Sulfuric acid, 98% mixture), and finally dilute nitric acid solution (Jones 2001). Available Zn was extracted by double acid method (extracting by mixture of 0.05 N HCl and 0.025 N H_2SO_4) and determined by atomic absorption spectrophotometer in supernatant solution (Amacher 1996). According to rice growth stages, the whole plant was sampled intact and washed carefully with tap water and then by 0.01 N HCl and rinsed two times with double distilled water. They were separated into leave, stem, panicle, root and grain. The aerial parts, roots, and grains were first air-dried and then oven-dried at 65^{o}C, except grains at 45 ^{o}C. Rice plant tissues were powdered (less than 0.1 mm) and stored for chemical analysis. Prepared tissue samples (0.5 g) were placed in the cool muffle furnace, heated at 300 ^{0}C for 3 h. After that, the temperature was increased to and held at 500 ^{0}C for 8 h to achieve clean white to gray color ash (Kalra 1997). The furnace was allowed to cool down slightly, removed crucibles, and in accordance with the method, 2 ml of 69-70% concentrated hydrochloride acid was added to the crucibles and heating was continued on the hot plate to evaporate the added HCl completely. The procedure was followed by adding 10 ml HNO_3 20% and the crucibles were placed in the water bath for 1 h. In the last step, the solutions were filtered with ash-free filter papers and the volume was made up to 100 ml in a volumetric flask. Total Zn concentration in final solutions was measured by an atomic absorption spectrophotometer (AAS).

Due to long time follow, weeds control was done three times before ploughing and puddling.

The common Malaysian and moderately zinc efficient rice variety, MR219 (Hafeez et al. 2010) was transplanted in the experimental plots (with dimension of 30×30 cm and 3 seedlings per hills). Two- factor experiment was conducted in split-plot design with lime requirement as main plot and Zn levels as sub-plot with 3 replications. Two levels of lime requirement (0 and LR to reach the soil pH 5.5) as calcium carbonate, three levels of Zn (0, 5 and 10 kg ha^{-1}) in the form of Zn sulphate were applied. Nitrogen fertilizer was applied as urea at the rate of 150 kg ha^{-1} (50 basal, 50 top dressing at the start of tillering, 50 top dressing at the start of flowering stage) to each plot. Potassium as muriate of potash (MOP) and P as a KH_2PO_4 in the rate of 70 kg ha^{-1} were applied to each plot as basal to maintain a constant level of K in all P treatments, taking into consideration the amount of K in KH_2PO_4 was used as a P source. The standing water level was maintained constant at 5±0.5 cm above the soil surface throughout the period of experiment by regular water application. All conventional managerial practices such as watering, split application of fertilizers, weeding and pest control were run on time and if necessary. The soil and plant sampling, and data recording were started at vegetative stage, and continued at flowering and harvesting time. Zinc concentration in soils and leaves, stems, panicles, roots and grains were measured by dry ashing method follow by atomic absorption spectrophotometry (Jones, 2001). Agronomic efficiency (AE), physiological efficiency (PE), agro-physiological efficiency (APE), apparent recovery efficiency (ARE) and utilization efficiency (UE) were calculated by formulas proposed by (Fageria 2016).

The SAS program was used to explore the analysis of variance (ANOVA) of all data collected. The correlation analysis was performed by using SPSS software package (IBM version 22.1). The correlation coefficient was used to explore the relationships between variables.

RESULTS

Available soil Zn status at different rice growth stages

The available Zn contents of soil (0.56 mg kg^{-1}) showed less than the critical limit in paddy soils (2 mg kg^{-1}) (Dobermann and Fairhurst 2000). Furthermore, the soil suffered from low pH (3.96) and lack of basic and acid actions toxicity (Table 1). Rice cultivation in acid sulphate soil (pH<4.0) experiences the relative to severe biotic and abiotic stresses. The high concentration of H^+ due to low pH soils causes basic cations (Ca, Mg, and K) deficiency, acidic cations toxicity (Al and Mn) and lack of P and Zn in paddy soils. Lime application at 10 ton ha^{-1} to reach the soil pH to 5.5 (the best root zone pH for rice growth), significantly increased the soil pH in all rice growth stages samples analysis (Tables 2 and 3). Despite being a few differences among plots, the limed plots showed the soil pH increased to an average of 5.7. Although, the soil pH difference among the rice growth stage was not significant, but its absolute amount increased with time (Figure 1).

The concentration of soil available Zn positively and significantly was affected by Zn levels, combination of lime, and their interactions at 0.01 confidence level at different growth stages (Table 2). The available Zn concentration of soil increased by increasing the Zn levels and decreased by lime application at different rice growth stages. The maximum increase in available Zn at no limed plots was obtained at 10 kg ha^{-1} Zn level at different rice growth stages, 13.32 folds in harvesting stage, 12.50 folds in flowering, and 11.60 times in maximum tillering more than control. These values at 5 kg ha^{-1} applied Zn were approximately 80% of 10 kg ha^{-1} applied Zn level. At limed plots, the obtained data decreased about 17% at maximum tillering, 23% at flowering and 27% at harvesting stage compared to no limed plots. Among the Zn levels, 10 kg ha^{-1} produced significantly highest increased in both limed and no limed plots by an average of 12 folds (Figure 2). Whereas, in 5 kg ha^{-1} applied Zn, the decrease in available Zn due to lime application was averagely about 55% in comparison with no limed plots. Furthermore, the available Zn concentration in limed and no limed plots decreased significantly from maximum tillering to harvesting stages due to rice plant uptake.

Zn concentration of rice plant tissues and its partitioning

The Zn concentration of rice tissues in the studied acid sulphate soil series were significantly affected with Zn, lime levels and their interactions

Table 1. Physico-chemical properties of selected acid sulphate soil

Soil series	EC×10^{-6}	pH	OC	CEC	Ca	Mg	K	Ava. Zn
	ds m^{-1}		%	–––––––––––––	cmol$_c$ kg^{-1}	–––––––		mg kg^{-1} soil
Tupus	0.245	3.96	2.48	7.15	0.66	0.03	0.001	0.56
Soil series	Mn	Fe	Clay	Silt	Sand	Texture	Soil order	Great group
	meq.100 g^{-1} soil		------------	%-------------				
Tupus	63	19.84	35.6	57.86	6.41	Si. C. L	Ultisols	Kandiaquult

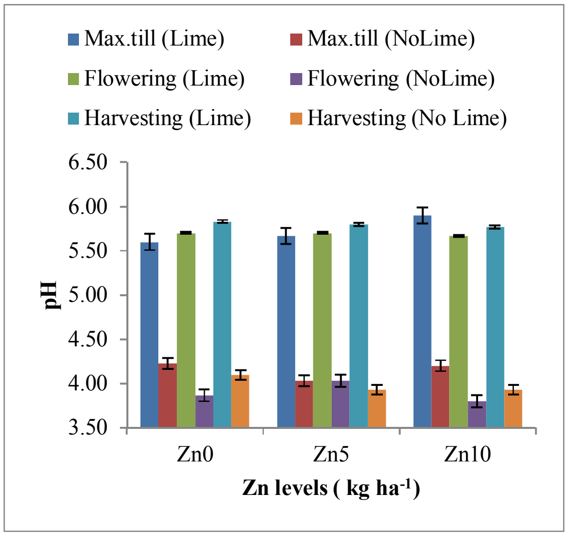


Figure 1. Effect of lime and Zn application on soil reaction at different rice growth stages

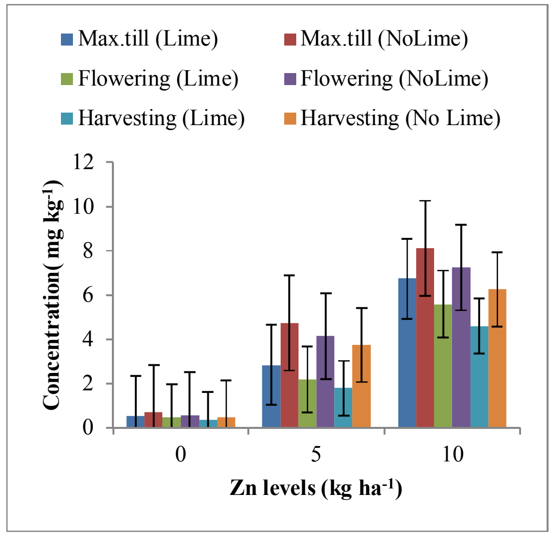


Figure 2. Effect of lime and Zn application on soil available Zn at different rice growth stages

at 0.01 confidence level at different growth stages (Table 3). The Zn concentration in rice tissues (roots, stems, leaves, and panicles) at different rice growth stages and in grain increased by increasing the Zn levels and decreased by lime application.

In case of roots, the maximum increased percentage of Zn concentration due to applied Zn was recorded about 2.40% in 10 kg ha^{-1} at maximum tillering, and 1.84% at harvesting stage over the control in no limed plots. In limed plots the highest increasing percentage was occurred about 2.34% in 10 kg ha^{-1} at maximum tillering and 2.33% at harvesting stage. Therefore, lime application decreased the Zn concentration of root about 30% (Figure 3A). The increasing order by Zn application and decreasing order by applied lime at different rice growth stage were as follow: maximum tillering> harvesting> flowering stages.

Across the Zn rates, the highest increase in Zn concentration in stems was recorded at flowering stage followed by harvesting and maximum tillering stage. Furthermore, with same pattern, lime application decreased the Zn concentration of stems. Whereas, the highest percentage of stem Zn concentration were obtained at maximum tillering, followed by harvesting and flowering stage about 2.36, 2.3 and 1.78% at 10 kg ha^{-1}, respectively. In 5 kg ha^{-1} applied Zn, the stem Zn concentration averagely increased half of 10 kg ha^{-1}level (Figure 3B).

The total Zn concentration of leaves increased at each levels of applied Zn, and all rice growth stage in comparison with the control plots, and Zn concentrations of leaves generally increase in the following order: maximum tillering> flowering> harvesting stage. On the other hand, the decreasing of Zn concentration in leaves due to lime application was in order flowering > maximum tillering > harvesting stage. The average increase in leaves Zn concentration due to Zn application at maximum tillering was obtained about 20% at 5 kg ha^{-1} and 60% in 10 kg ha^{-1} Zn level, whereas the mean reduction rate due to liming occurred about 35.5% in comparison with no limed plots (Figure 3C).

Across the Zn rates, maximum increased percentage of Zn concentration in panicle was recorded about 25 % with 10 kg ha^{-1} and 11% in 5

Table 2. Analysis of variances of soil Zn and pH at various growth stages

Sources	Mean square					
	Soil Zn1	Soil pH1	Soil Zn2	Soil pH2	Soil Zn3	Soil pH3
	mg kg^{-1}		mg kg^{-1}		mg kg^{-1}	
Lime	5.84**	11.360**	6.90**	14.76**	6.99 **	14.76*
Zn	69.75**	0.12^{ns}	52.34**	0.02^{ns}	37.6**	0.02^{ns}
Lime × Zn	1.20**	0.057^{ns}	1.49**	0.007^{ns}	1.469**	0.01^{ns}

Note: **, * and ns= Significant at 0.01, 0.05 and non- significant; 1=Maximum tillering, 2= flowering and 3= Harvesting stages

Table 3. Analysis of variances of Zn in soil and rice tissues at various growth stages

Sources	Mean square										
	Leaf			Stem			Root			Panicle	
	Zn1	Zn2	Zn3	Zn1	Zn2	Zn3	Zn1	Zn2	Zn3	Zn2	Zn3
	mg kg^{-1}										
Lime	4380.48**	482.57**	1796.00**	3488.90**	3669.38**	7654.96**	350.24**	32.00**	113.50**	107.55**	118.58**
Zinc	2073.49**	1800.22**	1825.38**	5584.22**	4425.92**	4380.64**	415.84**	289.10**	181.68**	283.01**	523.94**
Lime × Zinc	949.80**	85.90**	117.54**	250.14**	133.48**	444.24**	28.01**	9.73NS	18.22NS	9.28NS	32.72**

Note: **, * and ns= Significant at 0.01, 0.05 and non- significant; 1= Maximum tillering, 2= Flowering stage and 3= Harvesting stages

kg ha^{-1} applied Zn over the control in no limed plots. In limed plots the highest increasing percentage occurred about 44% in 10 kg ha^{-1} and 17% at 5 kg ha^{-1} applied Zn over the control. Although, the Zn concentration difference at flowering and harvesting stages were not significant. But, lime application decreased the panicles Zn concentration averagely about 10%. The increasing order by Zn application and decreasing order by applied lime at different rice growth stage were as followed: flowering > harvesting stages (Figure 3D).

The Zn concentration in grain, bran and white rice were significantly affected by the Zn, lime levels and their interactions at 0. 01 confidence level (Table 4). The highest increased in Zn concentration of grain, bran and white rice due to Zn application were obtained at 10 kg ha^{-1} and about 45% in no limed, whereas it was 30% in limed plots compared to control (Figure 4).

The accumulated Zn concentration in rice varied among different tissues and growth stages. Overall, the highest Zn concentration in rice tissues at maximum tillering was recorded at roots, followed by stems, and leaves. Whereas, the order at flowering stage was as follows: roots> stems> panicles>leaves. Finally, at harvesting stage was observed in roots, stems, grains, panicles and leaves, respectively (Figure 3 and 4).

The highest correlation coefficient among grain Zn concentration and available Zn (0.96**), root Zn (0.92**), panicle Zn (0.92**) and stem Zn (0.97**). The soil available Zn had the highest correlation with root (0.93**), stem (0.96**), and panicle Zn (0.95**) concentration. The leaves Zn concentration significantly correlated with root Zn (0.94**), stems (0.0.935**) and, panicle Zn (0.94**) (Table 5). The Zn concentration of grain had positive significant correlation with bran Zn (0.93**) and white rice Zn (0.91**) (Table 6).

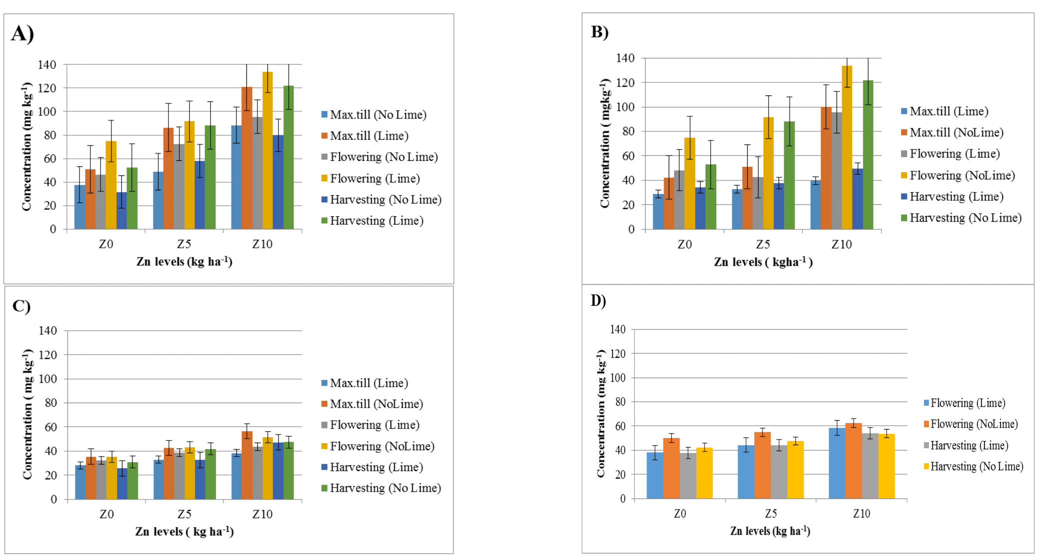
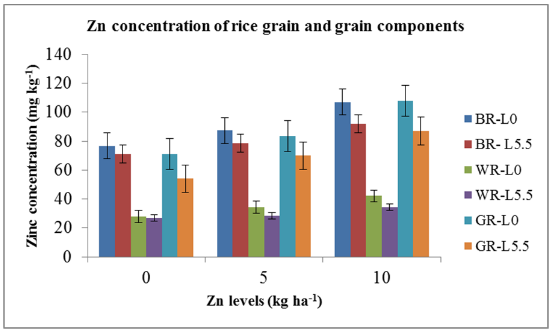
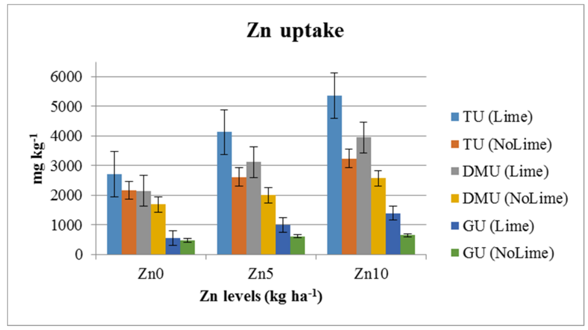


Figure 3. Effect of lime and Zn application on Zn concentration in roots (A), stems (B), leaves (C) and panicles (D) of MR219 rice tissues



Note: BR, WR, GR, Lo and L5.5= Bran, white rice, grain, zero lime and limed for soil pH of 5.5

Figure 4. Effect of lime and Zn on Zn concentration of grain and its components



Note: TU, DMU, GU= Total, Straw and Grain uptake, respectively

Figure 5. Effect of lime and Zn levels on Zn total, grain and shoot uptake

Zinc uptake

Zinc uptake as well as concentration was greater in the straw than grain. Whereas, increased percentage of Zn uptake in the grain was more than the straw. At 10 and 5 kg ha $^{-1}$ applied Zn, the grain Zn uptake were 36% and 23% more than the straw Zn uptake. Across the Zn rates, the highest increased percentage of Zn uptake in limed plots was 2.11% and 1.59% in 10 and 5 kg ha^{-1} Zn application, respectively, but in no limed plots, with 1.465 and 1.23%. Also, Zn uptake indicated same trend due to lime application as well as Zn concentration in soils and plant tissues (Table 7, Figure 5).

Zinc use efficiency

Agronomic, physiological, and agro-physiological efficiency significantly decreased by increasing the applied Zn levels, whereas, apparent recovery and utilization efficiency increased with increasing the Zn rate (Table 9). Furthermore, lime application and its interaction with Zn were significantly affected on various Zn use efficiency. Due to negative significant effect of 10 kg Zn ha^{-1} on rice grain and straw yield at no limed plots, the both yield characters were less than control (Table 8).

DISCUSSION

Some of the paddy fields in tropics are located in acid sulphate soils, which are not only low in pH (< 3.5), but also contain high amounts of Al^{3+} and Fe^{2+} and low phyto-available Zn concentration due to high weathering and leaching processes that can adversely affect the rice plant growth and development (Elisa et al. 2011; Shamshuddin and Anda 2012; Shamshuddin et al. 2013; Somani 2008). The results of numerous works in acid sulphate soils indicated that liming addition at 1 t ha^{-1} (Shamshuddin et al. 1991), 2 ton ha^{-1} (Shamshuddin and Anda 2012; Cristancho et al. 2013) and 4 ton ha^{-1} (Shamshuddin et al. 2013) increased the soil pH, basic cations and thereby, can improve rice yield and yield components closed to good soil condition. The soil available Zn, -with and without lime application was significantly affected by all applied Zn levels. In Ultisols paddy fields, Zn application not only significantly increased the available soil Zn, especially at maximum tillering, but also, it increase to sufficient level (0.98 - 1.08 mg kg^{-1}) for rice growing (Bandara and Silva 2001). Also, soil application of Zn significantly affected the DTPA extractable Zn at harvesting stage over the control (Abbas et al. 2009). The results of Zn application (two levels of Zn, 5 and 10 mgkg^{-1} as $ZnSO_4.7H_2O$)

Table 4. Effect of lime, Zn and their interaction on Zn concentration of grain and its components

Treatments	Zn content								
	——––Whole grain——––			——————Bran——————			————White rice———		
	L0	L5.5	LSD	L0	L5.5	LSD	L0	L5.5	LSD
	——————————mg kg^{-1}——————————								
Zn0	54.06Cb*	71.20Ca	4.97	71.20Ca	76.73Ca	6.6	26.73Ca	27.86Ca	12.42
Zn5	70.00Bb	78.60Ba	3.94	78.60Bb	87.33Ba	5.54	28.48Ba	34.46Ba	8.89
Zn10	87.06Ab	91.93Aa	2.29	91.93Ab	107.06Aa	0.28	34.2Ab	42.13Aaa	3.73
LSD (5%)	5.76	5.93		3.9	1.69		6.7	4.41	

Note: *Capital and small letters = Mean comparisons of lime across Zn levels and Zn across lime levels, respectively

Table 5. Correlation between Zn concentration in soil and plant tissues at different growth stages

	Available Zn			Plant tissues total Zn											
	Soil 1	Soil 2	Soil 3	Leaf 1	Leaf 2	Leaf 3	Stem 1	Stem 2	Stem 3	Root 1	Root 2	Root 3	Pani 2	Pani 3	Grain 3
Soil 1	1	0.99**	0.99**	0.72**	0.92**	0.85**	0.94**	0.90**	0.42**	0.87**	0.93**	0.84**	0.93**	0.95**	0.94**
Soil 2		1	0.99**	0.76**	0.92**	0.86**	0.96**	0.91**	0.87**	0.87**	0.93**	0.90**	0.93**	0.95**	0.96**
Soil 3			1	0.78**	0.91**	0.86**	0.96**	0.92**	0.87**	0.89**	0.93**	0.90**	0.94**	0.95**	0.96**
Leaf 1				1	0.71**	0.75**	0.86**	0.90**	0.92**	0.76**	0.63**	0.85**	0.86**	0.94**	0.90**
Leaf 2					1	0.95**	0.90**	0.93**	o.86**	0.93**	0.94**	0.83**	0.89**	0.94**	0.91**
Leaf 3						1	0.90**	0.935*	0.90**	0.93**	0.88**	0.82**	0.87**	0.93**	0.88**
Stem 1							1	0.95**	0.96**	0.92**	0.88**	0.91**	0.92**	0.93**	0.97**
Stem 2								1	0.96**	0.93**	0.93**	0.91**	0.94**	0.89**	0.97**
Stem 3									1	0.93**	0.91**	0.91**	0.90**	0.94**	0.96**
Root 1										1	0.89**	0.83**	0.86**	0.94**	0.90**
Root 2											1	0.79**	0.84**	0.95**	0.87**
Root 3												1	0.87**	0.83**	0.92**
Panicle 2													1	0.89**	0.92**
Panicle 3														1	0.91**
Grain 3															1

Note: **, and * = Significant at 0.01 and 0.05; 1, 2 and 3 are symbols of maximum tillering, flowering and harvesting stages, respectively; 4=Panicle

in the acidic paddy soil at Jhargram (Alfisols) in West Bengal state indicated that the available Zn concentration significantly increased about 2 folds at 10 mg kg^{-1}level (Naik and Das 2007). The soil broadcasting of Zn fertilizers was more effective than other application methods and significantly increased the soil available Zn. The maximum increase in available Zn concentration was observed at 2.5 kg Zn ha^{-1} (the highest applied level) and about 10.2% over the control in rice paddy fields (Srivastava et al. 2014). Also, soil application of Zn fertilizers significantly increased the DTPA extractable Zn (available Zn) at harvesting stage (Abas et al. 2009).

Table 6. Correlation between Zn concentration of grain and grain components

	Whole grain Zn	Bran Zn	White rice Zn
Whole grain Zn	1	0.93**	0.91**
Bran Zn		1	0.92**
White rice Zn			1

Note: ** = Significant at 0.01

Although, liming across the all Zn levels, significantly decreased the available Zn in soil at all rice growth stages. The highest rate of decrease was recorded at 10 kg ha^{-1} level and at maximum tillering stage. The Zn^{2+} activity in soils strongly related to the square of proton activity; therefore, by increasing the soil pH and H^+ concentration, the solubility and availability of Zn decreases sharply (Impa and Johnson-Beebout 2012). Lime application by any amendments increases the soil pH and basic cations and consequently could double the Zn- calcite bonding strength 7 fold over the control. Therefore, fixed Zn with $CaCO_3$ crystals, decreased the soil available Zn for rice uptake (Uygur and Rimmer 2000). Although, liming of Zn deficit tropical soils is a common method to enhance growth of high yielding varieties of cereal crops, but applied lime decreased the Zn availability clearly (Cakmak 2008; Fageria et al. 2011). Lime application could decrease the more Zn availability by increasing the soil pH and basic cations content. The reduction of Zn^{2+} activity in soils highly depend on the square of proton activity; thus, the increase in pH could decrease the proton activity. Consequently, the Zn solubility and availability reduced with elevation of the soil pH values (Zhang et al. 2006; Xu et al. 2007; Impa and Johnson-Beebout 2012). On the other hand, calcite minerals individual effects could double the Zn- calcite bonding strength 7 fold over the control. Therefore, coated Zn with $CaCO_3$, decreased the soil available Zn for plant (Uygur and Rimmer 2000). Also, Naik and Das (2007) and reported that lime application in rate of full lime requirement significantly decreased the available Zn about 107% at 5 and 10 kg ha^{-1}.

Simmons et al. (2003); Cakmak et al. (2008); Hussain et al. (2012) and Rehman et al. (2012) reported that the Zn application significantly increased the rice straw Zn content. The rice straws Zn concentration in the tropical soils were significantly affected by applied Zn levels and the maximum increase in shoot Zn concentration (2 folds) was observed at the 10 kg Zn ha^{-1} Zn level. The mean concentrations of total Zn in the rice straw was in the following order: stems > leaves > grains (Simmons et al. 2003).

The stems zinc concentration significantly influenced by applied Zn in both sufficient and insufficient rice varietal genotypes, and the highest increased Zn concentration was obtained in the highest applied Zn level over control (Kabeya and Shankar 2013). Also, Fageria and Baligar (2005) reported that by Zn application in acidic Oxisols (Typic Hapludox), the shoot Zn concentration significantly increased about 2 times. Whereas, it decreased by lime application about 40, 70 and 41% at maximum tillering, flowering and harvesting stages over the control plots, respectively. The decreased pattern significantly related to applied Zn levels. It means that the highest decrease was recorded at low Zn level (averagely 68, 64 and 40% in Zn0, Zn 5, and Zn 10, respectively). Although, lime addition alleviate Al^{3+} toxicity and thereby enhance crop growth but the significant decrease in soil Zn concentration and concentration crop tissues, therefore, liming

Table 7. Effect of lime and Zn levels on Zn total, grain and shoot uptake

	Zn uptake								
	------Total------			------Grain------			------Straw------		
Treatments	L0	L5.5	LSD	L0	L5.5	LSD	L0	L5.5	LSD
Kg ha^{-1}	------------------------mgkg^{-1}------------------------								
Zn0	7.16Ca*	7.50Ca	0.33	2.15Ba	1.69Cb	0.31	2.71Ca	2.16Cb	0.28
Zn5	7.58Ba	8.32Ba	1.29	2.62Ab	3.12Ba	0.32	3.23Bb	4.13Ba	0.27
Zn10	8.13Ab	9.53Aa	0.98	2.57Ab	3.96Aa	0.58	3.57Ab	5.35Aa	0.68
LSD (5%)	0.13	1.02		0.16	0.43		0.87	0.47	

Note: *= Capital and Small letters for mean comparisons of lime across Zn levels and Zn across lime levels, respectively; L0 and L5.5 are equal to no lime and lime for bring soil pH to 5.5

combined with higher zinc requirements due to enhanced shoot growth requires the additional supply of zinc to prevent a reduction in growth lime supply (Alloway 2004).

In this study to improve Zn concentration in different tissues of rice, the results indicated significant differences between roots Zn concentration at various Zn levels. The maximum root Zn concentration was obtained by over than 6 kg ha^{-1} Zn applications (Ahmad et al. 2012). The results of Zn concentration at different parts of rice plant indicate that the roots Zn concentration were significantly more than other tissues. Applied Zn can increase of root Zn due to Zn stored in the root cell walls, as results of decreasing in Zn transportation to the aerial parts of rice crops (Ahmad et al. 2012).

As expected, the Zn was uniformly accumulated within the grain components and bran (BR) Zn concentration averagely was 3 times more than white rice (WR). When crops take up Zn through the root zone, the higher Zn and the lower concentrations in plant tissues generally stored in root and edible parts, respectively (White and Broadley 2009, 2011; White and Brown 2011). Within crops tissues, adsorbed Zn is preferentially stored within particular cell types. In cereal grains, Zn is selectively accumulated in outer layer or bran including the husk, aleurone layers or embryo (Cakmak et al. 2010; Lombi et al. 2011; Stomph et al. 2011). The distribution patterns of Zn within the crop may relate to local translocation and/or long-distance Zn transport (Broadley et al. 2007; Stomph et al. 2011). Consequently the distribution patterns of Zn within cereal grain will reduce its dietary intakes when polished grains are consumed.

The increase in Zn due to 5 kg ha^{-1}Zn application was half of 10 kg ha^{-1} in all plots. At acidic soils of Bangalore, the Zn concentration in grains were significantly affected by Zn levels in both sufficient and insufficient rice genotypes, and the highest response was recorded with medium Zn level (Kabeya and Shankar 2013). Furthermore the mean concentration of grain Zn was lower than shoot Zn concentration (Fageria and Baligar 2005; Fageria et al. 2002). In Zn deficit low humid gely soils of India, the grain Zn concentration was increased by application of 2.5 kg ha^{-1} Zn (2.5 tonnes)in two year rice cultivation (Bandara and Silva 2001).

By increasing the soil Zn concentration and thereby increasing its phytoavailability and accessibility, the uptake of Zn will increase significantly. The high correlation between soil and plant tissues Zn concentration of grain and straw in this study is corresponds with the results of Mandal et al. (2000); Chaudhary and Singh (2007); Fageria et al. (2011) and Muthumaraja and Sirramchandrasekharan (2012).

The Zn uptake significantly increased by Zn application in rice crop from the soil irrespective of soil pH (Kabeya and Shankar 2013). The results are in line with Navas and Lindhorfer (2003); Hussain et al. (2012); Fageria et al. (2012) and Muthumaraja and Sirramchandrasekharan (2012). In acidic Inceptisols of Brazil, Zn concentrations and uptakes rice were significantly affected by application of 0, 5, 10 20, 40, 80, and 120 mg Zn kg^{-1}. Furthermore, concentration of Zn and its uptake in shoot grain significantly increased by increasing Zn concentration in the soil solution. Zn

Table 8. Effect of lime and Zn application on Zn use efficiency of MR219 rice in acid sulphate lowland

	---AE---		---PE---		---APE---		---UE---		---ARE---	
	Z5	Z10	Zn5	Zn10	Zn5	Zn10	Zn5	Zn10	Zn5	Zn10
	------------------------μg $μg^{-1}$------------------------									%
L1	382	289	4593.14	3615.58	3396.00	2290.93	407.94	283.60	112.60	127.48
L0	395.33	0	5583.26	0	3496.74	0	491.90	0	113.50	20.921

Note: AE, PE, APE, UE and ARE= Agricultural, Physiological, Agro-physiological, Utilization efficiencies and Apparent recovery concentration and Zn uptake of rice straw rise sharply at the highest level of applied Zn due to high increase in available Zn in soil solution phase (Fageria et al. 2011).

The soluble and insoluble Zn forms can be adsorbed by rice plant tissues (Broadley et al. 2007), and consequently accumulate a large portion of soluble Zn in organic complexed component at different tissues. Generally, Zn distribution in crop tissues is unevenly and commonly partitioned as follows: roots> shoots> fruits, grains, tubers (White and Broadley 2011; White and Brown 2010). Therefore, Zn concentration of roots is often higher than shoots and the lowest concentration store in grains (White and Broadley 2005; White and Broadley 2009; Pfeiffer and McClafferty 2007).

Therefore, all Zn use efficiency parameters were zero. The highest Zn use efficiency at a low Zn level is due to Zn efficient utilization at lower Zn level (Fageria et al. 2011; Muthumaraja and Sirramchandrasekharan 2012). Also, the reduction of Zn use efficiency with increasing the Zn levels is referred to larger decreases in straw and yield dry matter due to the higher Zn rate in Zn deficit soils, where crop response to Zn application is more progressive (Fageria et al. 2011; Muthumaraja and Sirramchandrasekharan 2012).

CONCLUSION

Soil incorporated lime and Zn application (separately) promote rice growth and development at acid sulphate soils, but a few works have addressed on their effects (separately and in combination) on soil Zn content and Zn partitioning at rice plant tissues at different growth stages. The current experiments was done to fulfil these gaps. Although all of Zn treatments increased the Zn content of soil samples and plant tissues in limed and no-limed plots, the increasing and decreasing order of Zn content at different rice growth stages were different and as follow: maximum tillering> harvesting> flowering stages. Among the Zn levels, the 10 kg ha-1 produced significantly highest increased in Zn concentration of soil samples and rice tissues at limed and no limed plots at all growth stages. The highest Zn concentration in rice tissues at maximum tillering was recorded in roots; followed by stems, and leaves. Whereas, the order at flowering stage was as follows: root> stem> panicle>leaves. Finally, at harvesting stage this order of Zn concentration in roots, stems, grains, panicles and leaves was observed. These behaviours should be answered through time and sources of Zn and lime application in future works.

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