Status of Zinc Content in Soils and Rice Genotypes and its Relationship with Soil Chemical Properties across different Agro-Climatic Zones of Karnataka, South India

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Received:- 03 October 2025/ Revised:- 09 October 2025/ Accepted:- 15 October 2025/ Published: 31-10-2025

Abstract—

Background and Aims: *Billions of people suffer from Zn deficiency globally. Rice, being an important source of Zn in the diet, a study was carried out to access the status of Zn in soils and rice genotypes and also study the relationship of soil pH, OC and DTPA-Zn with Zn content in grain and straw of rice.*

Methods: *A total of 244 rice and soil samples comprising 64 different rice genotypes were collected from eight agro-climatic zones of Karnataka. The status of Zn in rice and soils were analyzed.*

Results: *The results revealed that DTPA-Zn content in soil ranged from 0.2 to 4.5 mg kg^{-1} across eight ACZ. The grain and straw Zn content of 244 rice samples comprising of 64 rice genotypes ranged from 7.8 to 51.3 mg kg^{-1} and 16.6 to 284.0 mg kg^{-1}, respectively. The Zn content of grain and straw was positive significantly correlated with OC and DTPA-Zn whereas negative significantly correlated with soil pH.*

Conclusion: *The problem of low Zn content in rice may be overcome through proper understanding of the relationship between the rice plant and soil chemical properties such as soil pH, DTPA-Zn and OC and adoption of proper management practices accordingly.*

Keywords— Rice genotypes, grain and straw Zn content, soil pH, organic carbon, DTPA-Zn.

Abbreviation

ACZ – Agro-climatic zone; AAS – Atomic Absorption Spectrophotometer; DTPA-Zn – Diethylene Triamine Penta Acetic Acid Extractable Zn.

I. INTRODUCTION

Micronutrient malnutrition has affected lives of billions as evident by 2.7 billion suffering from Zn deficiency all over the world (Anon 2004). In India, 27 per cent of total population is affected by Zn deficiency related disorders such as poor immune system, diarrhoea, poor physical and mental health (WHO 2007). Zn deficiency claims about 4.4 per cent of the total child deaths in the world (Black 2003).

Rice is the important staple food for more than half of the world population and provides 60 to 70 per cent body calorie intake to the consumers and is consumed in large amounts. Rice is the staple food of nearly 65 per cent of the total population in India (Barah 2005). Because of the high consumption of rice in developing countries and its inherent low Zn content, the extra Zn would have meaningful impact on human nutrition and health. A little increase in grain nutritive value of rice will produce a cumulative effect on total nutrient intake (Chandel et al. 2010).

Nutritional requirement of micronutrient should be met from micronutrient output of modern agricultural systems. Accordingly, knowledge on micronutrient status in soil and crop edible tissues is necessary. Katyal and Sharma (1991) indicated the variation in Zn content of different major soils forming rocks of India. Available Zn content in surface soils of India ranged from 0.08 to 20.5 ppm. There is a wide variation in agricultural soils across the globe in Zn content and their capacity to supply Zn for optimal crop growth (White and Zasoki 1999). Alloway (2008) reported worldwide deficiency of Zn in soils. Zinc deficiency was reported in the soils of Turkey (Cakmak 2002), China (Liu 1991), Java (Soepardi 1982), Australia (Sillanpaa 1990) and in India (Takkar 1996; Singh 2001; Behera et al. 2009). About 48 per cent of Indian soils are deficient in Zn (Sakal 2001). Zn deficiency in soils of Karnataka is up to the extent of 78 per cent (Singh and Saha 1995). It is generally prevalent in high pH calcareous soils (Liu et al. 1983; Katyal and Vlek 1985). But it has also been reported in acid soils which are leached and heavily weathered (Alloway 2008 and Behera 2011).

Plant availability of Zn in soils is influenced by many factors (Shuman 1986). Besides soil organic carbon (OC) content, one of the most important soil properties influencing Zn availability in soil is soil pH (Anderson and Christensen 1988). Usually extractable Zn decreases with an increase in soil pH due to increased absorptive capacity, the formation of hydrolyzed forms of Zn, possible chemisorptions on calcium carbonate and co-precipitation as iron oxides (Cox and Kamprath 1972; Alloway 2008).

The incidence of Zn deficiencies in crops has increased markedly in recent years due to intensive cropping, loss of top soils by erosion, losses of micronutrients through leaching, liming of acid soils, decreased proportions of farmyard manure compared to chemical fertilizers, increased use of high analysis NPK fertilizers coupled with use of Zn free fertilizers and use of marginal lands for crop production. Micronutrient deficiency problems are also aggravated by the high demand of modern crop cultivars (Fageria et al. 2002). As a result, Zn content in plant dry matter is low particularly in grain. Since all of the micronutrients that human consume are derived from the soil-plant system. Therefore, identification of high grain Zn containing rice genotypes is needed to ensure adequate attainment of mineral element in daily diet.

In the context of the above facts, the present study was carried out to (i) access the status of Zn in soils and rice genotypes (ii) study the relationship of selected soil chemical properties such as soil pH, OC and DTPA-Zn with Zn content in grain and straw of rice.

II. MATERIALS AND METHODS

2.1 Sampling location:

A survey work was conducted to determine the status of Zn content in different rice genotypes and rice growing soils under various rice growing agro-climatic zones (ACZ) of Karnataka. The state of Karnataka has been classified into ten ACZ (Zone 1 to 10) which was categorized based on soil type, cropping pattern, rainfall and soil parent material.

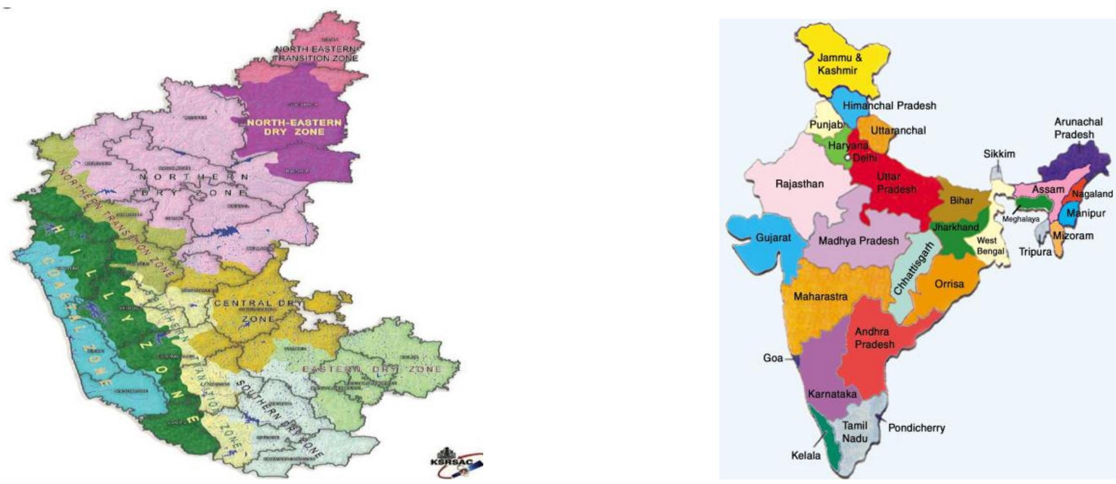

FIGURE 1: Soil and plant sampling sites representing different ACZ of Karnataka, India

Out of ten zones, samples were collected from eight ACZ viz. North Eastern Dry Zone (Zone 2) denoted by NEDZ, Northern Dry Zone (Zone 3) denoted by NDZ, Central Dry Zone (Zone 4) denoted by CDZ, Southern Dry Zone (Zone 6) denoted by SDZ, Southern Transition Zone (Zone 7) denoted by STZ, Northern Transition Zone (Zone 8) denoted by NTZ, Hilly Zone

(Zone 9) denoted by HZ and Coastal Zone (Zone 10) denoted by CZ as shown in Fig.1. The rice plant (grain and straw) and soil samples were collected from farmers' field. Effort was made to collect as many rice genotypes as possible from each zone to know the variations in Zn content in plant and soil samples. This study was conducted in the following steps:

1) Representative soil, rice grain and straw samples were collected at the time of harvest from different farmers' fields representing eight ACZ of Karnataka. The soil samples were collected from the same field where the plant samples had been collected.

2) From each zone, more than two prominent genotypes were collected depending on the availability. For each genotype, a minimum of two different farmers' field was selected for sampling from each zone. In some of the ACZ, single rice genotype was also collected to make representation of the zone.

3) Plant and soil sampling, and analytical methods for soil pH, Electrical Conductivity (EC), OC, Zn content in soil (DTPA extractable) and plant (grain and straw) are given below

2.2 Soil sampling and processing:

The soil samples were collected from rice fields of eight ACZ of Karnataka. The composite soil samples were prepared for all the soil samples collected and allowed to air dry in shade. The air dried soil samples were pounded with wooden plank and sieved in 2 mm and 0.2 mm (for OC estimation) mesh sieve. The soil samples were stored in plastic container with proper labeling for further use.

2.3 Plant sampling and its preparation:

The collected rice samples from different ACZ of Karnataka were separated into grain and straw. Rice straw was first washed in tap water followed by 0.1 *N* HCl to remove any surface contaminants. It was again washed twice in glass double distilled water (DDW) immediately to remove any acid residues. The rice straw and grain was dried in the hot-air oven at 65° C for 48 and 72 hours respectively. The dried straw samples were cut into smaller pieces and powdered in stainless steel grinder. The stainless-steel jar was cleaned thoroughly and wiped with distilled alcohol after each and every sample to avoid any contamination.

The dried rice grain was de-husked manually by hand to avoid any kind of contamination. Washing of hand was followed for each and every sample with distilled alcohol to prevent sample to sample contamination. The de-husked grains were washed first in DDW and followed by 0.1 *N* HCl. It was washed thrice in DDW immediately to remove the acid residues from the surface of grain and dried in the hot-air oven at 65° C for 24 hours.

2.4 Routine soil analysis:

Determination of soil chemical properties like soil pH and EC was conducted on 1:2.5 soil water ratio (w/v) suspension using pH meter and EC meter following half an hour equilibration (Jakson 1973). Soil organic carbon content was estimated by the Walkley and Black (1934) method.

The extracting solution used for extracting Zn from soil consisted of 0.005 *M* Diethylene triamine penta acetic acid (DTPA) + 0.001 *M* $CaCl_2.2H_2O$ + 0.1 *N* Triethanolamine buffered at pH 7.3 (Lindsay and Norwell 1978). Ten grams of soil was shaken with 20 ml of extracting solution for 2 hours and the soil solution was further filtered. Zn content was determined from the extract using AAS (Perkin Elmer, Analyst 400)

2.5 Zinc content in soil:

A known quantity of sample (grain and straw) was treated with 3 ml of H_2O_2 and later with 7 ml of HNO_3 and digested using microwave digestion system (Milestone - Start D) programmed with following steps: 1000 watts for 20 minutes at 150ºC (Ramping) and 1000 watts for 10 minutes at 150ºC (Holding) followed by 10 minutes of venting. The digested sample was made up to 50 ml volume and analyzed for Zn content in grain and straw samples with the help of AAS.

2.6 Zinc content in plant:

A correlation coefficient matrix was established by using SPSS software version 20.0 taking all samples together to study the effect of selected soil chemical properties such as soil pH, EC, OC and DTPA-Zn on the occurrence of Zn content in grain and straw.

III. RESULTS

3.1 Status of Zn in soils and rice genotypes:

The details of the genotypes and the GPS coordinates of the sampling sites are given in Table 1. Table 2 shows the analytical results of chemical properties of soil (soil pH, EC and OC), Zn content in rice (grain and straw) and soil samples (DTPA extractable) collected from eight ACZ of Karnataka.

The soil pH ranged from 5.9 to 8.8 (mean of 7.9), 5.0 to 7.5 (mean of 6.3), 4.9 to 8.5 (mean of 6.4), 5.1 to 8.8 (mean of 6.9), 4.7 to 7.5 (mean of 5.5), 4.8 to 6.9 (mean of 5.8), 4.7 to 7.6 (mean of 5.4) and 4.5 to 6.4 (mean of 5.7) in the soils of NEDZ, NDZ, CDZ, SDZ, STZ, NTZ, HZ and CZ, respectively (Table 2). Similarly, EC ranged from 0.08 to 1.71 dSm^{-1} (mean of 0.64 dSm^{-1}), 0.07 to 0.57 dSm^{-1} (mean of 0.19 dSm^{-1}), 0.06 to 0.84 dSm^{-1} (mean of 0.24 dSm^{-1}), 0.07 to 1.48 dSm^{-1} (mean of 0.39 dSm^{-1}), 0.06 to 0.59 dSm^{-1} (mean of 0.21 dSm^{-1}), 0.04 to 0.63 dSm^{-1} (mean of 0.26 dSm^{-1}), 0.02 to 0.4 dSm^{-1} (mean of 0.1 dSm^{-1}), 0.04 to 0.73 dSm^{-1} (mean of 0.21 dSm^{-1}) in the soils of NEDZ, NDZ, CDZ, SDZ, STZ, NTZ, HZ and CZ, respectively (Table 2).

The OC content ranged from 0.11 to 0.35 per cent (mean of 0.19 per cent), 0.17 to 0.39 per cent (mean of 0.30 per cent), 0.19 to 0.55 per cent (mean of 0.33 per cent), 0.21 to 0.55 per cent (mean of 0.36 per cent), 0.25 to 0.62 per cent (mean of 0.39 per cent), 0.24 to 0.64 per cent (mean of 0.41per cent), 0.28 to 0.74 per cent (mean of 0.49 per cent) and 0.17 to 0.54 per cent (mean of 0.35 per cent) in the soils of NEDZ, NDZ, CDZ, SDZ, STZ, NTZ, HZ and CZ, respectively (Table 2).

The DTPA-Zn content ranged from 0.3 to 1.0 mg kg^{-1} (mean of 0.6 mg kg^{-1}), 0.3 to 1.0 mg kg^{-1} (mean of 0.7mg kg^{-1}), 0.3 to 3.2 mg kg^{-1} (mean of 0.9 mg kg^{-1}), 0.3 to 2.4 mg kg^{-1} (mean of 0.9 mg kg^{-1}), 0.3 to 3.5 mg kg^{-1} (mean of 1.0 mg kg^{-1}), 0.2 to 1.2 mg kg^{-1} (mean of 0.7 mg kg^{-1}), 0.3 to 4.5 mg kg^{-1} (mean of 1.4 mg kg^{-1}) and 0.4 to 1.2 mg kg^{-1} (mean of 0.7 mg kg^{-1}) in the soils of NEDZ, NDZ, CDZ, SDZ, STZ, NTZ, HZ and CZ, respectively (Table 2).

The Zn content of grain ranged from 12.5 to 24.5 mg kg^{-1} (mean of 16.0 mg kg^{-1}), 11.4 to 26.9 mg kg^{-1} (mean of 16.8 mg kg^{-1}), 12.3 to 25.8 mg kg^{-1} (mean of 18.1 mg kg^{-1}), 7.8 to 21.2 mg kg^{-1} (mean of 14.2 mg kg^{-1}), 10.1 to 39.6 mg kg^{-1} (mean of 22.4 mg kg^{-1}), 18.1 to 28.8 mg kg^{-1} (mean of 23.8 mg kg^{-1}), 12.7 to 45.4 mg kg^{-1} (mean of 24.0 mg kg^{-1}) and 16.5 to 51.3 mg kg^{-1} (mean of 27.9 mg kg^{-1}) in the grain samples collected from NEDZ, NDZ, CDZ, SDZ, STZ, NTZ, HZ and CZ, respectively (Table 2). Whereas, the Zn content of straw ranged from 22.3 to 46.5 mg kg^{-1} (mean of 34.4 mg kg^{-1}), and 24.3 to 64.8 mg kg^{-1} (mean of 45.9 mg kg^{-1}), and 30.5 to 58.0 mg kg^{-1} (mean of 42.9 mg kg^{-1}), and 16.6 to 102.3 mg kg^{-1} (mean of 43.6 mg kg^{-1}), and 20.8 to 284.0 mg kg^{-1} (mean of 58.6 mg kg^{-1}), and 33.3 to 72.3 mg kg^{-1} (mean of 53.3 mg kg^{-1}), and 36.3 to 94.5 mg kg^{-1} (mean of 62.1 mg kg^{-1}) and 40.5 to 90.3 mg kg^{-1} (mean of 60.6 mg kg^{-1}) in the straw samples collected from NEDZ, NDZ, CDZ, SDZ, STZ, NTZ, HZ and CZ, respectively (Table 2).

It was observed that Zn was applied in 67, 21, 57, 28, 14, 36 and 38 per cent of the soil samples collected from farmers' field representing NEDZ, NDZ, CDZ, SDZ, STZ, HZ and CZ, respectively (Table 2). In overall, 34 per cent of the collected soil samples were below the critical limit of Zn in soil.

In general, soil pH, EC, OC, DTPA-Zn, grain Zn and straw Zn ranged from 4.5 to 8.8 (mean of 6.3), 0.02 to 1.71 dSm^{-1} (mean of 0.29 dSm^{-1}), 0.11 to 0.74 per cent (mean of 0.36 per cent), 0.2 to 4.5 mg kg^{-1} (mean of 0.9 mg kg^{-1}), 7.8 to 51.3 mg kg^{-1} (mean of 19.8 mg kg^{-1}) and 16.6 to 284.0 mg kg^{-1} (mean of 50.8 mg kg^{-1}), respectively in all the collected soil and plant samples.

3.2 Variation among the rice genotypes in Zn content of grain and straw:

A total of 244 rice samples (grain and straw) were collected comprising of 64 rice genotypes from eight ACZ of Karnataka, India. Among the different rice genotypes, five commonly grown genotypes were selected for studying the variation in Zn content of rice grain and straw. The Sona was collected as the largest number of samples (n=50) among the different rice genotypes followed by JGL (n=17), MTU-1001 (n=15), Jyothi (n=15) and MTU-1010 (n=11) as presented in Table 3.

The grain and straw Zn content of Sona genotype was ranged from 12.5 to 36.1 mg kg^{-1} and 22.3 to 90.3 mg kg^{-1} with a mean of 18.1 mg kg^{-1} and 40.2 mg kg^{-1}, respectively (Table 3). For JGL genotype, Zn content for grain and straw was ranged from 7.9 to 33.3 mg kg^{-1} and 25.2 to 75.7 mg kg^{-1} with a mean of 19.1 mg kg^{-1} and 44.5 mg kg^{-1}, respectively. The grain and straw Zn content of MTU-1001 genotype was ranged from 8.9 to 27.9 mg kg^{-1} and 24.3 to 75.3 mg kg^{-1} with a mean of 17.3 mg kg^{-1} and 45.1 mg kg^{-1}, respectively. In case of Jyothi genotype, the Zn content of grain and straw was ranged from 10.5 to 51.3 mg kg^{-1} and 17.5 to 90.7 mg kg^{-1} with a mean of 22.4 mg kg^{-1} and 52.6 mg kg^{-1}, respectively. For MTU-1010 genotype, the Zn content of grain and straw was ranged from 11.4 to 26.0 mg kg^{-1} and 33.8 to 79.8 mg kg^{-1} with a mean of 20.4 mg kg^{-1} and 57.5

mg kg^{-1}, respectively. In general, the grain and straw Zn content across 64 rice genotypes ranged from 7.9 to 51.3 mg kg^{-1} and 16.6 to 284.0 mg kg^{-1} with a mean of 19.8 mg kg^{-1} and 50.8 mg kg^{-1}, respectively (Table 3).

3.3 Categorization of rice growing soils and rice genotypes based on their Zn content:

An attempt has been made to categorize the collected 244 soil and plant samples comprising of 64 rice genotypes from eight ACZ of Karnataka based on the Zn content in soils, grain and straw as shown in Table 2 and 4.

TABLE 1
DETAILS OF THE GENOTYPES COLLECTED FROM DIFFERENT ACZ OF KARNATAKA, INDIA AND GPS COORDINATES OF THE SAMPLING SITES

Sl. no.	Agro-climatic zones	*n	Latitude	Longitude	No. of genotypes	Genotypes collected
1	North Eastern Dry Zone (NEDZ)	30	N 15°32’10.9” – N 16°35’11.5”	E 75°46’27.8” – E 76°47’08.9”	1	Sona
2	Northern Dry Zone (NDZ)	14	N 14°36’10.0” – N 14°39’23.8”	E 75°11’54.8” – E 75°15’49.1”	5	MTU-1001, MTU-1010, JGL, Sona and Jyothi
3	Central Dry Zone (CDZ)	14	N 14°16’37.2” – N 14°28’5.6”	E 75°44’47.3” – E 75°57’53.5”	2	JGL and Sona
4	Southern Dry Zone (SDZ)	48	N 12°03’27.4” – N 12°52’28.8”	E 75°54’45.0” – E 77°05’12.9”	22	Rajamudi, Aryza-6444, KRH-2, MTU-1001, BR-2655, Jaya, Rasi, Thanu, Prakash, Nagamani, GK-5003, Sona, Ankush, Gagana, KMP-149, KMP-150, KCP-1, Jyothi, IR-64, NLR, Raksha and JGL
5	Southern Transition Zone (STZ)	50	N 13°43’39.8” – N 14°36’39.0”	E74°50’43.5” – E 075°44’27.8”	21	MTU-1001, Sanabatta, Jaya, Sona, Jyothi, JGL, MO-4, MTU-1010, Sonalam, Abhilashu, Lokanatha, Thunga, Jeerge Sanna, Siri-1253, Basmati, Intaan, Hemavati, Siddhagiri-2, IET-9926 and Warangal Batta
6	Northern Transition Zone (NTZ)	17	N 14°59’1.9” – N 15°02’8.7”	E 75°03’33.8” – E 75°09’33.3”	5	Jaya, Sona, MTU-1010, Intaan, and Doddige
7	Hilly Zone (HZ)	45	N 12°08’41.6” – N 13°21’53.8”	E 75°38’29.8” – E 75°56’29.8”	32	IR-20, Intaan, Annekal Batta, Holesalu, IR-64, Uddara Mallige, Kesari Batta, Kirwana, Billi Batta, PUBM-8, Sharavati, KHP-9, BKBM-23, Hemavati, KHP-2, Thunga, KHP-5, IET-7191, Abhilasu, Putta Batta, AVT-2, KHRS-28, Thirthalli, CTH-1, CTH-3, BR-2655, Jyothi, JGL, KHP-10, KMP-148, Doddi and BKV
8	Coastal Zone (CZ)	16	N 13°25’53.3” – N 13°49’09.1”	E 74°38’53.0” – E 74°46’10.3”	6	MO-4, KCP-1, Phalguna, Champaka, Thunga and Jyothi
	Total	244			64	

n= number of plant sample

3.3.1 Rice growing soils:

The results of the present investigation revealed that 26.7 (NEDZ), 35.7 (NDZ), 35.7 (CDZ), 13.8 (SDZ), 26.0 (STZ), 35.3 (NTZ), 20.0 (HZ) and 50 (CZ) per cent of the collected soil samples were found to be deficient in available Zn which is below the general soil critical limit of 0.6 mg kg^{-1} Zn in soil as given by Katyal and Rattan (2003). In general, 34 per cent out of 244 soil samples collected from eight ACZ of Karnataka were found below the critical limit of Zn in soil (Table 2).

TABLE 2
SOIL pH, EC, Zn CONTENT OF SOILS, GRAIN AND STRAW OF RICE ACROSS DIFFERENT ACZ OF KARNATAKA, INDIA

ACZ	*n		pH	EC (dSm^{-1})	OC (%)	DTPA-Zn ($mg\ kg^{-1}$)	Grain ($mg\ kg^{-1}$) Zn	Straw ($mg\ kg^{-1}$) Zn	Zn deficiency (%)	Zn application (%)
NEDZ	30	Mean	7.9	0.64	0.19	0.6	16	34.4	26.7	67
		Range	5.9-8.8	0.08 - 1.71	0.11 – 0.35	0.3-1.0	12.5-24.5	22.3-46.5		
		SD	0.25	0.02	0.05	0.03	0.99	1.58		
NDZ	14	Mean	6.3	0.19	0.3	0.7	16.8	45.9	35.7	21
		Range	5.0-7.5	0.07-0.57	0.17-0.39	0.3-1.0	11.4-26.9	24.3-64.8		
		SD	0.45	0.06	0.03	0.1	1.3	2.2		
CDZ	14	Mean	6.4	0.24	0.33	0.9	18.1	42.9	35.7	57
		Range	4.9-8.5	0.06-0.84	0.19-0.55	0.3-3.2	12.3-25.8	30.5-58.0		
		SD	0.5	0.04	0.07	0.08	1.7	2		
SDZ	48	Mean	6.9	0.39	0.36	0.9	14.2	43.6	13.8	28
		Range	5.1-8.8	0.07-1.48	0.21-0.55	0.3-2.4	7.8-21.2	16.6-102.3		
		SD	0.65	0.01	0.04	0.25	0.75	1.3		
STZ	50	Mean	5.5	0.21	0.39	1	22.4	58.6	26	14
		Range	4.7-7.5	0.06-0.59	0.25-0.62	0.3-3.5	10.1-39.6	20.8-284.0		
		SD	0.3	0.03	0.05	0.2	0.65	1.65		
NTZ	17	Mean	5.8	0.26	0.41	0.7	23.8	53.3	35.3	0
		Range	4.8-6.9	0.04-0.63	0.24-0.64	0.2-1.2	18.1-28.8	33.3-72.3		
		SD	0.35	0.1	0.03	0.12	1.1	0.9		
HZ	45	Mean	5.4	0.1	0.49	1.4	24	62.1	20	36
		Range	4.7-7.6	0.02-0.4	0.28-0.74	0.3-4.5	12.7-45.4	36.3-94.5		
		SD	0.4	0.04	0.08	0.3	2	0.6		
CZ	16	Mean	5.7	0.21	0.35	0.7	27.9	60.6	50	38
		Range	4.5-6.4	0.04-0.73	0.17-0.54	0.4-1.2	16.5-51.3	40.5-90.3		
		SD	0.2	0.07	0.04	0.14	2.8	1.15		
Total	244	Mean	6.3	0.29	0.36	0.9	19.8	50.8	34	30
		Range	4.5-8.8	0.02-1.71	0.11-0.72	0.2-4.5	7.8-51.3	16.6-284.0		
		SD	0.95	0.11	0.08	0.4	1.25	1.95		

n= number of soil and plant sample

TABLE 3
VARIATION IN Zn CONTENT OF GRAIN AND STRAW OF DIFFERENT RICE GENOTYPES

Sl. No.	Genotypes	n*	Zn ($mg\ kg^{-1}$) Grain Mean	Grain Range	Straw Mean	Straw Range
1	Sona	50	18.1	12.5-36.1	40.2	22.3-90.3
2	JGL	17	19.1	7.9-33.3	44.5	25.2-75.7
3	MTU-1001	15	17.3	8.9-27.9	45.1	24.3-75.3
4	Jyothi	15	22.4	10.5-51.3	52.6	17.5-90.7
5	MTU-1010	11	20.4	11.4-26.0	57.5	33.8-79.8
6	Intaan	10	19.8	14.4-27.3	58.4	39.8-87.5
7	Jaya	9	22.7	13.8-29.3	61.8	41.8-85.0
8	BR-2655	8	16.8	12.9-26.2	45.4	22.8-89.5
9	Rajamudi	7	14.6	12.2-17.6	53.9	40.3-75.5

Table 3 Continues. . . .

Sl. No.	Genotypes	n*	Zn (mg kg^{-1})			
			Grain		Straw	
			Mean	Range	Mean	Range
10	Thanu	7	16	9.1-29.4	46.3	24.8-66.3
11	IR-64	6	15.4	11.5-18.5	27.8	16.6-37.6
12	MO-4	6	33.2	25.2-39.2	70.4	55.1-90.3
13	Doddige	6	22.1	18.1-24.8	49.7	33.3-65.8
14	Thunga	6	21.3	16.3-25.8	55.5	46.8-62.8
15	Champaka	5	23.5	16.5-30.8	48.5	40.5-60.8
16	Sana Batta	3	13.1	12.2-14.0	56.2	51.8-61.3
17	Abhilashu	3	22	16.2-25.8	45.3	38.8-50.5
18	KRH-2	3	14.4	11.2-16.4	50.7	41.3-62.1
19	Rasi	2	17.6	16.5-18.8	83.4	68.3-98.6
20	Ankush	2	11.1	9.0-13.2	34.8	24.7-44.8
21	KCP-1	2	21.4	15.4-27.5	57.6	25.6-89.5
22	KMP-150	2	12.8	12.0-13.5	19.4	18.5-20.3
23	Hemavati	2	22	20.1-23.9	45.8	36.0-55.5
24	Annekal Batta	2	17.6	17.3-17.8	48.8	40.8-56.8
25	PUBM-8	2	27.5	20.7-34.4	62.5	38.7-86.3
26	Sharavati	2	28.7	24.1-33.3	74.4	54.3-94.5
27	IET-7191	2	31.5	27.5-35.5	81.5	78.8-84.3
28	CTH-1	2	18.7	12.7-24.8	53.8	36.3-71.3
29	CTH-3	2	18.9	14.3-23.6	72.1	68.1-76.0
30	Aryza-6444	1	12.3	-	102.3	-
31	Sonalam	1	18	-	39.3	-
32	Lokanatha	1	10.1	-	20.8	-
33	Jeerge Sanna	1	39.6	-	63.8	-
34	Siri 1253	1	24.8	-	56	-
35	Basmati	1	27.8	-	80.2	-
36	Siddhagiri-2	1	26.6	-	59.3	-
37	IET-9926	1	22.8	-	63.5	-
38	Warangal	1	14.3	-	65.3	-
39	IR-20	1	13.6	-	49.5	-
40	Holesalu	1	22	-	42.3	-
41	Uddara	1	16.6	-	43.3	-
42	Kesari Batta	1	13.6	-	59.3	-
43	Kirwana	1	27.6	-	47.1	-
44	Billi Batta	1	16.8	-	55.3	-
45	NLR	1	11.6	-	18.9	-
46	Raksha	1	7.8	-	30.2	-
47	KHP-9	1	21.4	-	40.8	-
48	BKBM-23	1	23.4	-	41.4	-
49	KHP-2	1	24.5	-	46.8	-
50	KHP-5	1	25.9	-	70.8	-
51	Prakash	1	21.2	-	38.6	-
52	Nagamani	1	13.3	-	55.3	-
53	GK-5003	1	15.8	-	48.3	-
54	Putta Batta	1	45.4	-	73.5	-
55	AVT-2	1	20.5	-	59.8	-
56	KHRS-28	1	19.2	-	73.7	-
57	Thirthalli	1	21	-	60.3	-
58	KHP-10	1	23	-	80	-
59	KMP-148	1	31.6	-	81.8	-
60	BKV	1	33.5	-	85.3	-
61	Phalguna	1	37.4	-	74.3	-
62	Gangana	1	10.3	-	24.3	-
63	KMP-149	1	18.2	-	16.2	-
64	Doddi (Red)	1	37.9	-	79.5	-
	Total	**244**	**19.8**	**7.9-51.3**	**50.8**	**16.6-284.0**

**** n =Number of sample***

TABLE 4
CATEGORIZATION OF RICE GENOTYPES BASED ON ITS ZN CONTENT IN GRAIN AND STRAW

Sl. no.	Grain						Straw					
	< 20 mg Zn kg^{-1}		20-30 mg Zn kg^{-1}		> 30 mg Zn kg^{-1}		< 50 mg Zn kg^{-1}		50-80 mg Zn kg^{-1}		> 80 mg Zn kg^{-1}	
	Genotype	mg kg^{-1}	Genotype	mg kg^{-1}	Genotype	mg kg^{-1}	Genotype	mg kg^{-1}	Genotype	mg kg^{-1}	Genotype	mg kg^{-1}
1	Raksha	7.8	MTU-1010	20.4	IET-7191	31.5	KMP-149	16.2	KRH-2	50.7	Basmati	80.2
2	Lokanatha	10.1	AVT-2	20.5	KMP-148	31.6	NLR	18.9	Jyothi	52.6	IET-7191	81.5
3	Gangana	10.3	Thirthalli	21	MO-4	33.2	KMP-150	19.4	CTH-1	53.8	KMP-148	81.8
4	Ankush	11.1	Prakash	21.2	BKV	33.5	Lokanatha	20.8	Rajamudi	53.9	Rasi	83.4
5	NLR	11.6	Thunga	21.3	Phalguna	37.4	Gangana	24.3	Billi Batta	55.3	BKV	85.3
6	Aryza-6444	12.3	KCP-1	21.4	Doddi (Red)	37.9	IR-64	27.8	Nagamani	55.3	Aryza-6444	102.3
7	KMP-150	12.8	KHP-9	21.4	Jeerge Sanna	39.6	Raksha	30.2	Thunga	55.5		
8	Sana Batta	13.1	Abhilashu	22	Putta Batta	45.4	Ankush	34.8	Siri 1253	56		
9	Nagamani	13.3	Hemavati	22			Prakash	38.6	Sana Batta	56.2		
10	IR-20	13.6	Holesalu	22			Sonalam	39.3	MTU-1010	57.5		
11	Kesari Batta	13.6	Doddige	22.1			Sona	40.2	KCP-1	57.6		
12	Warangal	14.3	Jyothi	22.4			KHP-9	40.8	Intaan	58.4		
13	KRH-2	14.4	Jaya	22.7			BKBM-23	41.4	Siddhagiri-2	59.3		
14	Rajamudi	14.6	IET-9926	22.8			Holesalu	42.3	Kesari Batta	59.3		
15	IR-64	15.4	KHP-10	23			Uddara	43.3	AVT-2	59.8		
16	GK-5003	15.8	BKBM-23	23.4			JGL	44.5	Thirthalli	60.3		
17	Thanu	16	Champaka	23.5			MTU-1001	45.1	Jaya	61.8		
18	Uddara	16.6	KHP-2	24.5			Abhilashu	45.3	PUBM-8	62.5		
19	BR-2655	16.8	Siri-1253	24.8			BR-2655	45.4	IET-9926	63.5		
20	Billi Batta	16.8	KHP-5	25.9			Hemavathi	45.8	Jeerge Sanna	63.8		
21	MTU-1001	17.3	Siddhagiri-2	26.6			Thanu	46.3	Warangal	65.3		
22	Rasi	17.6	PUBM-8	27.5			KHP-2	46.8	MO-4	70.4		
23	Annekal Batta	17.6	Kirwana	27.6			Kirwana	47.1	KHP-5	70.8		
24	Sonalam	18	Basmati	27.8			GK-5003	48.3	CTH-3	72.1		
25	Sona	18.1	Sharavati	28.7			Champaka	48.5	Putta Batta	73.5		
26	KMP-149	18.2					Annekal Batta	48.8	KHRS-28	73.7		
27	CTH-1	18.7					IR-20	49.5	Phalguna	74.3		
28	CTH-3	18.9					Doddige	49.7	Sharavati	74.4		
29	JGL	19.1							Doddi (Red)	79.5		
30	KHRS-28	19.2							KHP-10	80		
31	Intaan	19.8										

3.3.2 Grain Zn content:

Based on Zn content of rice grain, sixty four rice genotypes were categorized as <20 mg Zn kg^{-1}, 20-30 mg Zn kg^{-1} and >30 mg Zn kg^{-1}. The rice genotypes Raksha, Lokanatha, Gangana, Ankush, NLR, Aryza-6444, KMP-150, Sana Batta, Nagamani, IR-20, Kesari Batta, Warangal, KRH-2, Rajamudi, IR-64, GK-5003, Thanu, Uddara, BR-2655, Billi Batta, MTU-1001, Rasi, Annekal Batta, Sonalam, Sona, KMP-149, CTH-1, CTH-3, JGL, KHRS-28 and Intaan has been categorized under <20 mg Zn kg^{-1} grain (Table 4). Whereas MTU-1010, AVT-2, Thirthalli, Prakash, Thunga, KCP-1, KHP-9, Abhilashu, Hemavati, Holesalu, Doddige, Jyothi, Jaya, IET-9926, KHP-10, BKBM-23, Champaka, KHP-2, Siri-1253, KHP-5, Siddhagiri-2, PUBM-8, Kirwana, Basmati and Sharavati were categorized under 20-30 mg Zn kg^{-1} grain. The rice genotypes IET-7191, KMP-148, MO-4, BKV, Phalguna, Doddi (Red), Jeerge Sanna, and Putta Batta were categorized as >30 mg Zn kg^{-1}.

Among 64 rice genotypes collected from eight ACZ of Karnataka, the highest grain Zn content was observed in Putta Batta (45.4 mg kg^{-1}) while the lowest was observed in Raksha (7.8 mg kg^{-1}) as presented in Table 4.

3.3.3 Straw Zn content:

Based on Zn content of rice straw, sixty four rice genotypes were categorized as <50 mg Zn kg^{-1}, 50-80 mg Zn kg^{-1} and >80 mg Zn kg^{-1}. Accordingly, KMP-149, NLR, KMP-150, Lokanatha, Gangana, IR-64, Raksha, Ankush, Prakash, Sonalam, Sona, KHP-9, BKBM-23, Holesalu, Uddara, JGL, MTU-1001, Abhilashu, BR-2655, Hemavati, Thanu, KHP-2, Kirwana, GK-5003, Champaka, Annekal Batta, IR-20 and Doddige have been categorized under <50 mg Zn kg^{-1} straw (Table 4). Whereas KRH-2, Jyothi, CTH-1, Rajamudi, Billi Batta, Nagamani, Thunga, Siri-1253, Sana Batta, MTU-1010, KCP-1, Intaan, Siddhagiri-2, Kesari Batta, AVT-2, Thirthalli, Jaya, PUBM-8, IET-9926, Jeerge Sanna, Warangal, MO-4, KHP-5, CTH-3, Putta Batta, KHRS-28, Phalguna, Sharavati, Doddi (Red) and KHP-10 categorized under 50-80 mg Zn kg^{-1} straw. The rice genotypes Basmati, IET-7191, KMP-148, Rasi, BKV and Aryza-6444 were categorized under >80 mg Zn kg^{-1} straw.

Among 64 rice genotype collected from eight ACZ of Karnataka, the highest straw Zn content was observed in Aryza-6444 (102.3 mg kg^{-1}) while the lowest straw Zn content was observed in KMP-149 (16.2 mg kg^{-1}) as presented in Table 4.

3.4 Relationship of soil pH, OC and DTPA-Zn with Zn content in grain and straw:

The relationship of soil pH, OC and DTPA-Zn with Zn content in grain and straw of selected rice genotypes were established by determining the correlation coefficient values (Table 5). The correlation analysis revealed that soil pH had positive significant correlation with EC (r=0.690**) but negative significant correlation with OC (r= -0.496**), DTPA-Zn (r= -0.202**), grain Zn (r= -0.470**) and straw Zn (r= -0.451**). The correlation matrix revealed that EC had negative significant correlation with OC (r= -0.364**), DTPA-Zn (r= -0.163*), grain Zn (r= -0.315**) and straw Zn (r= -0.290**). The correlation data shows that OC had positive significant correlation with DTPA-Zn (r= 0.650**), grain Zn (r= 0.422**) and straw Zn (r= 0.342**). The correlation data also revealed that DTPA-Zn had positive significant correlation with grain Zn (r= 0.377**) and straw Zn (r= 0.281**). It was also noticed that grain Zn had positive significant correlation with straw Zn (r= 0.541**).

TABLE 5
CORRELATION MATRIX OF SOIL pH, EC, Zn CONTENT OF SOIL, GRAIN AND STRAW

Correlations Matrix						
Variables	**Soil pH**	**EC**	**OC**	**DTPA-Zn**	**Grain Zn**	**Straw Zn**
Soil pH	-	0.690**	-0.496**	- 0.202**	- 0.470**	- 0.451**
EC		-	-0.364**	- 0.163*	- 0.315**	- 0.290**
OC			-	0.650**	0.422**	0.342**
DTPA-Zn				-	0.377**	0.281**
Grain Zn					-	0.541**
Straw Zn						-

The R^2 values of the regression equation between soil pH and grain Zn content of fifteen rice genotypes ranged from 0.023 to 0.510 (Table 6) contributing about 2.3 per cent to 51.0 per cent towards grain Zn content whereas R^2 values ranged from 0.062 to 0.867 between soil pH and straw Zn content contributing about 6.2 per cent to 86.7 per cent towards straw Zn content through soil pH. The R^2 values of regression equation between OC and grain Zn content of rice genotypes ranged from 0.029 to 0.823 contributing about 2.9 to 82.3per cent towards grain Zn content while R^2 values between OC and straw Zn content of rice genotypes ranged from 0.114 to 0.605 contributing about 11.4 to 60.5 per cent towards straw Zn content through OC content of soil. The R^2 values of regression equation between DTPA-Zn and grain Zn content of rice genotypes ranged from 0.011 to 0.806 contributing about 1.1 to 80.6 per cent towards grain Zn content while R^2 values ranged from 0.086 to 0.772 between DTPA-Zn and straw Zn content of rice genotypes contributing about 8.6 to 77.2 per cent towards straw Zn content through DTPA-Zn of soil.

TABLE 6
RELATIONSHIP OF Zn CONTENT OF RICE GRAIN AND STRAW WITH SOIL pH AND DTPA-Zn IN SOIL

Sl. No.	Genotype	Regression equations (x = soil pH)	R^2 value	Regression equations (x = DTPA-Zn)	R^2 value	Regression equations (x = Organic carbon)	R^2 value
1	Sona	Grain Zn = -2.302x + 34.87	0.35	Grain Zn = 3.356x + 15.56	0.065	Grain Zn = 24.359x + 11.68	0.36
		Straw Zn = -4.914x + 76.02	0.242	Straw Zn = 13.02x + 30.40	0.15	Straw Zn = 48.801x + 27.35	0.219
2	MTU-1001	Grain Zn = -2.659x + 33.89	0.441	Grain Zn = 4.511x + 13.85	0.133	Grain Zn = 24.839x + 09.23	0.288
		Straw Zn = -6.222x + 83.82	0.237	Straw Zn = 13.61x + 34.56	0.119	Straw Zn = 49.830x + 28.80	0.114
3	MTU-1010	Grain Zn = -4.786x + 48.02	0.322	Grain Zn = 11.59x + 11.39	0.213	Grain Zn = 30.012x + 8.311	0.46
		Straw Zn = -8.819x + 108.3	0.18	Straw Zn = 31.60x + 32.90	0.261	Straw Zn = 45.341x + 39.21	0.173
4	JGL	Grain Zn = -2.414x + 33.96	0.134	Grain Zn = 3.621x + 14.71	0.369	Grain Zn = 34.737x + 5.558	0.406
		Straw Zn = -8.668x + 97.99	0.284	Straw Zn = 6.279x + 36.95	0.181	Straw Zn = 52.047x + 24.26	0.149
5	Jaya	Grain Zn = -2.507x + 37.17	0.11	Grain Zn = 0.736x + 21.83	0.011	Grain Zn = 15.9x + 16.058	0.121
		Straw Zn = -4.554x + 88.10	0.062	Straw Zn = 4.965x + 56.16	0.086	Straw Zn = 52.874x + 39.78	0.23
6	Jyothi	Grain Zn = -6.113x + 58.92	0.228	Grain Zn = 6.289x + 15.32	0.169	Grain Zn = 46.893x + 2.959	0.238
		Straw Zn = -21.38x + 180.3	0.504	Straw Zn = 14.40x + 36.42	0.16	Straw Zn = 91.744x + 14.59	0.164
7	Intaan	Grain Zn = -0.699x + 23.84	0.023	Grain Zn = 3.212x + 16.57	0.236	Grain Zn = 7.1324x + 16.70	0.029
		Straw Zn = -4.449x + 83.97	0.065	Straw Zn = 14.42x + 43.78	0.337	Straw Zn = 75.553x + 25.34	0.231
8	BR-2655	Grain Zn = -0.977x + 23.10	0.073	Grain Zn = 3.286x + 13.98	0.108	Grain Zn = 21.429x + 8.719	0.195
		Straw Zn = -10.68x + 114.1	0.346	Straw Zn = 33.41x + 16.73	0.445	Straw Zn = 182.57x - 23.53	0.56
9	Thanu	Grain Zn = -3.198x + 38.36	0.51	Grain Zn = 5.012x + 10.70	0.806	Grain Zn = 42.582x + 0.346	0.823
		Straw Zn = -10.65x + 120.6	0.867	Straw Zn = 7.354x + 38.48	0.266	Straw Zn = 67.859x + 21.305	0.32
10	Rajamudi	Grain Zn = -1.115x + 21.71	0.222	Grain Zn = 2.765x + 12.85	0.103	Grain Zn = 27.02x + 5.617	0.264
		Straw Zn = -8.270x + 106.3	0.439	Straw Zn = 19.18x + 41.46	0.179	Straw Zn = 133.16x + 9.421	0.23
11	Thunga	Grain Zn = -3.693x + 42.55	0.238	Grain Zn = 13.50x + 10.95	0.7	Grain Zn = 99.12x - 16.544	0.625
		Straw Zn = -4.741x + 83.26	0.178	Straw Zn = 21.05x + 39.57	0.772	Straw Zn = 153.75x - 3.186	0.605
12	IR-64	Grain Zn = -0.784x + 21.25	0.147	Grain Zn = 5.832x + 9.810	0.621	Grain Zn = 11.41x + 10.844	0.461
		Straw Zn = -4.826x + 64.08	0.764	Straw Zn = 14.34x + 14.15	0.515	Straw Zn = 31.125x + 15.487	0.472
13	MO-4	Grain Zn = -3.344x + 50.75	0.109	Grain Zn = 23.80x + 19.59	0.593	Grain Zn = 58.305x + 14.526	0.806
		Straw Zn = -8.651x + 115.8	0.077	Straw Zn = 82.52x + 23.28	0.75	Straw Zn = 121.33x + 31.557	0.367
14	Doddige	Grain Zn = -3.785x + 44.11	0.36	Grain Zn = 12.69x + 16.52	0.697	Grain Zn = 28.006x + 13.467	0.577
		Straw Zn = -25.26x + 196.5	0.817	Straw Zn = 56.99x + 24.62	0.715	Straw Zn = 108.65x + 16.181	0.442
15	Champaka	Grain Zn = -12.13x + 97.39	0.377	Grain Zn = 17.38x + 8.363	0.718	Grain Zn = 30.491x + 11.437	0.447
		Straw Zn = -23.56x + 192.0	0.7	Straw Zn = 19.22x + 31.82	0.432	Straw Zn = 35.16x + 34.657	0.292

IV. DISCUSSION

4.1 Zn content in soils:

The results as presented in Table 2 revealed that there was a wide variation in DTPA-Zn content of the collected soil samples across eight ACZ of Karnataka. The DTPA-Zn content of all the soil samples ranged from 0.2 to 4.5 mg kg^{-1} with a mean of 0.9 mg kg^{-1}. This variation could be attributed to the differences in physical and chemical properties of the collected soils. The soils, collected from different ACZ, were mainly characterized on the basis of types of soil, cropping system, amount of rainfall and management practices. The different types of soil have different nutrient availability due to difference in soil properties and mainly influenced by management practices and amount of rainfall since they have direct role in Zn availability in soils. This is in accordance with the result reported by Sidhu and Sharma (2010) who stated that wide variation in DTPA-Zn which was ranged from 0.04 to 8.60 mg kg^{-1} with a mean of 1.0 mg kg^{-1} across different ACZ of Indo-Gangetic Plain (IGP) of India was due to differences in soil characteristics and management practices. The large variation of DTPA Zn content in different major soil orders of India was also reported by Katyal and Sharma (1991) who stated that DTPA Zn was highest in Mollisols (1.86 ppm) followed by Oxisols (0.86 ppm) > Inceptisols (0.58 ppm) > Alfisols (0.55 ppm) > Entisols (0.46 ppm) > Vertisols (0.41 ppm) > Aridisols (0.38 ppm).

A wide variation in DTPA-Zn in four soil series of acid soil representing two eastern states (Orissa and Jharkhand), one northern state (Himachal Pradesh) and one southern state (Kerala) of India was reported by Behera et al. (2011). They observed that DTPA-Zn ranged from 0.04 to 10.8 mg kg^{-1} with a mean of 1.1 mg kg^{-1} across four soil series of India.

Among the eight ACZ of Karnataka, the highest DTPA Zn was observed in HZ (1.4 mg kg^{-1}) and lowest was observed in NEDZ (0.6 mg kg^{-1}) as mentioned in Table 2. The possible reason for highest DTPA-Zn in the soils of HZ might be due to its low soil pH and high OC content in soils. Whereas, the lowest DTPA-Zn in the soils of NEDZ may be attributed to its high soil pH and low OC content among the different ACZ inspite of receiving highest Zn application i.e. 67 per cent of the soil samples. From the results of the present investigation, it was observed that soil pH and OC were one of the most important soil properties controlling DTPA-Zn content in soil. In general, lower the pH of the soil, higher is the DTPA-Zn in soil or vice versa. This inverse relationship of soil pH and DTPA-Zn was also observed by Eyupoglu et al. (1994). Katyal and Sharma (1991) also reported that DTPA-Zn declined with a rise in soil pH. According to Sidhu and Sharma (2010) deficiency of Zn was more widespread in the Trans-Gangetic Plain where the soils were low in OC and high in pH followed by Upper, Middle, and Lower Plains where the soils were relatively low in pH and high in OC content. The distribution of available Zn in soils was mainly influenced by the physicochemical properties of soils like pH, $CaCO_3$ and organic matter content (Appavu and Sreeramulu 1981). Similarly, according to Rajkumar (1994), available Zn status in red (Alfisols) and black soils (Vertisols) of Karnataka was highly affected by soil pH. DTPA-Zn increased with an increase in OC content and decreased with increasing soil pH as reported by Sharma et al. (2004). Ye et al. (2015) reported that one-way ANOVA showed that soil organic matter and soil pH had a significant influence on available Zn content in soils of Yanqing County, Beijing, China. Soil Zn is usually more available in soils with greater organic matter content (Iratkar et al. 2014). This may be attributed to involvement of organic matter in supplying organic chemicals to the soil solution, which may be served as chelates and increase metal availability to plants (Vega et al. 2004; McCauley et al. 2009).

Among the soil chemical factors, soil pH plays the most important role in Zn solubility in soil solution (Anderson and Christensen 1988). In a pH range between 5.5 and 7.0, Zn concentration in soil solution is decreased by 30 to 45-fold for each unit increase in soil pH, thus increasing a risk for development of Zn deficiency in plants (Marschner 1993). Increasing soil pH stimulates adsorption of Zn to soil constituents (e.g., metal oxides, clay minerals) and reduces desorption of the adsorbed Zn (Cakmak 2008). Increasing soil pH, especially above 6.5, results in decreased extractability and plant availability of soil Zn as reported by Iratkar et al. (2014). Lindsay (1991) reported that the concentration of Zn^{2+} in soil solution is sufficiently high at pH 5.0, about $10^{-4}M$ (6.5 mg kg^{-1}). When soil pH increased from 5 to 8, concentration of soil solution Zn^{2+} is reduced 1,000 times and becomes nearly $10^{-10}\ M$ (approx. 0.007 mg kg^{-1}). Rupa and Tomar (1999) also observed a sharp increase in Zn sorption with an increase in pH from 4.25 to 6.75, beyond which almost the entire Zn is sorbed. Consequently, an increase in soil pH is associated with very sharp decrease in concentrations of Zn in plant tissues (Sarkar and Wynkjones 1982; Marschner 1995). This explains and corroborates the results of the present investigation in which soil pH plays a dominant role in plant available Zn content (DTPA-Zn) in soils.

Among the eight ACZ of Karnataka, the highest Zn deficiency in soil was observed in CZ (50 per cent deficiency) although 38 per cent of the soils received Zn application while lowest Zn deficiency was observed in SDZ (13.8 per cent deficiency) although 28 per cent of the soils received Zn application. According to Sakal (2001), about 48 per cent of Indian soils are deficient in Zn while Zn deficiency in soils of Karnataka is up to the extent of 78 per cent (Singh and Saha 1995). However, only 34 per cent of the collected soil samples from different ACZ of Karnataka were found to be deficient in Zn. This may be mainly attributed to 30 per cent of the collected soil samples received Zn application (Table 2).

4.2 Zn content in grain and straw of rice in different ACZ:

The results presented in Table 2, revealed that there was a wide variation in grain Zn content but the difference in mean value was narrow among the eight ACZ of Karnataka. The highest grain Zn content was recorded in CZ (27.9 mg kg^{-1}) followed by HZ (24.0 mg kg^{-1}) > NTZ (23.8 mg kg^{-1}) > STZ (22.4 mg kg^{-1}) > CDZ (18.1 mg kg^{-1}) > NDZ (16.8 mg kg^{-1}) > NEDZ (16.0 mg kg^{-1}) > SDZ (14.2 mg kg^{-1}).

It was expected that under low soil pH, DTPA-Zn might increase in soil and ultimately increasing in the grain and straw Zn content as many authors have pointed out. However, in the present investigation, this relationship was not observed in some of the ACZ of Karnataka. For instance, the mean grain Zn content was higher in CZ compared to that of HZ. But CZ recorded higher soil pH, lower DTPA-Zn and OC content compared to soil pH, DTPA-Zn content and OC of HZ (Table 2). Whereas, the lowest mean grain Zn content was recorded in SDZ although the soil pH of SDZ was lower than that of NEDZ and mean DTPA-Zn and OC was observed higher in SDZ compared to that of NEDZ. These changes in relationship between soil pH, DTPA-Zn, OC and grain Zn content may be attributed to genotypic variation in grain Zn accumulation. In CZ, most of the collected rice genotypes belong to the >40 mg kg^{-1} grain Zn category whereas most of the collected rice genotypes from HZ belong to the <20 mg kg^{-1} and 20-30 mg kg^{-1} grain Zn category. This may be the reason for higher mean grain Zn content in CZ compared to HZ. Similarly, grain Zn content in most of the collected rice genotypes in SDZ and Sona genotype in NEDZ belongs to the <20 mg kg^{-1} grain Zn category. But the range of grain Zn was higher in NEDZ (12.5-24.5 mg kg^{-1}) compared to SDZ (7.8-21.2 mg kg^{-1}). This indicates that Sona genotype can accumulate more Zn in grain although lower DTPA-Zn content in soils of NEDZ compared to other genotypes collected from SDZ.

Similarly, HZ recorded the highest (62.1 mg kg^{-1}) straw Zn content followed by CZ (60.6 mg kg^{-1}) > STZ (58.6 mg kg^{-1}) > NTZ (53.3 mg kg^{-1}) > NDZ (45.9 mg kg^{-1}) > SDZ (43.6 mg kg^{-1}) > CDZ (42.9 mg kg^{-1}) > NEDZ (34.4 mg kg^{-1}). The HZ recorded the lowest soil pH, highest DTPA-Zn and OC content whereas NEDZ recorded highest soil pH and lowest DTPA-Zn and OC. This may be the possible reason for observing highest straw Zn content in HZ and lowest in NEDZ. Moreover, most of the collected rice genotypes from HZ had straw Zn content in 50-80 mg kg^{-1} and >80 mg kg^{-1}straw Zn category. Whereas, the Sona rice genotype collected from NEDZ had straw Zn content of <50 mg kg^{-1} straw Zn category.

The above results is in accordance with Wissuwa et al. (2008) who observed that rice genotypes has a much larger effect than Zn fertilization and native soil Zn content for grain Zn concentration under slightly low Zn content whereas under severely low Zn in soil, native soil Zn was the dominant factor to determine Zn concentrations in both grain and straw of different rice genotypes. They also reported that there was a significant genotypic difference in straw Zn concentration under high-Zn upland soil (2.7 mg kg^{-1} DTPA-Zn) in which Jalmagna recorded highest (22.9 mg kg^{-1}) straw Zn concentration followed by RIL-507 (22.3 mg kg^{-1}) > RIL-597 (18.7 mg kg^{-1}) > IR-74 (17.7 mg kg^{-1}) > IR-68144 (16.9 mg kg^{-1}). Genotypic variation in grain Zn content was also reported by Yang et al. (1998) who reported that grain Zn content was ranged from 8.2 to 95.0 mg kg^{-1} with a mean value of 41.9 mg kg^{-1} among 286 rice genotypes.

4.3 Variation among the rice genotypes in Zn content of grain and straw:

Among the different rice genotypes, five most commonly grown genotypes were selected for studying the variation in Zn content of rice grain and straw. Sona genotype was collected in large number (n=50) representing six ACZ among the different rice genotypes followed by JGL (n=17) representing five ACZ, Jyothi (n=15) representing five ACZ, MTU-1001 (n=15) and MTU-1010 (n=11) representing three ACZ each, as shown in Table 3.

The results of the present investigation revealed that there was a wide variation in grain and straw Zn content in different rice genotypes collected from eight ACZ of Karnataka. The grain and straw Zn content for 64 rice genotypes ranged from 7.8 to 51.3 mg kg^{-1} and 16.6 to 284.0 mg kg^{-1} with a mean of 19.8 mg kg^{-1} and 50.8 mg kg^{-1}, respectively. This is in accordance with Lee et al. (2008) who reported that Zn content ranged from 10.0 to 33.0 mg kg^{-1} with a mean of 22.8 mg kg^{-1} from germplasm of 246 rice cultivars at International Rice Research Institute (IRRI), Philippines. They also observed that among the genotypes tested, there was approximately a two-fold difference in Zn concentrations, suggesting a genetic potential to increase Zn content in rice grain. Similar results was also reported by Graham et al. (1999) who stated that there were approximately four fold differences in grain Zn contents in 1138 brown rice samples and it ranged from 15.9 – 58.4 mg kg^{-1} suggesting ample variation for this trait that might be exploited through conventional breeding. Germplasm evaluations for Zn concentrations in rice grain have detected up to four fold genotypic differences (Gregoria 2002).

From the above variation in Zn content, a particular rice genotype can be able to accumulate wide range of Zn in their grain and straw from different soils with different soil properties (soil pH, OC, DTPA-Zn) apart from genotypic variation in grain and straw Zn accumulation among the genotypes. This may be due to the variation in soil pH (ranged from 4.5 to 8.8) and OC content (ranged from 0.11 to 0.74per cent) of collected soil samples from eight ACZ. Moreover, the DTPA-Zn content ranged from 0.2 to 4.5 mg kg^{-1}. Due to this variation in soil properties of the collected soil samples, a rice genotype may be able to accumulate wide range of Zn in their plant parts in the present investigation. This also showed the dominant role played by the soil pH, OC and DTPA-Zn in soil in determining their content in rice. This finding was in accordance with Wissuma et al. (2008) who stated that the native soil Zn status was the dominant factor to determine grain and straw Zn concentrations followed by genotype and fertilizer. Depending on the soil Zn status ranging from 0.79 to 2.7 mg kg^{-1}, grain Zn concentrations of a single genotype (RIL-597) could range from 8 mg kg^{-1} to 47.0 mg kg^{-1}. Straw Zn concentrations ranged from 12.4 to 22.9 mg kg^{-1} across five rice genotypes (Jalmagna, RIL-507, RIL-597, IR-74 and IR-68144) depending on the soil Zn status ranging from 0.97 to 2.7 mg kg^{-1}. In the present investigation, a single genotype (Jyothi) could accumulate Zn in grain and straw in a range of 10.5 to 51.3 mg kg^{-1} (upto five-fold) and 17.5 to 90.7 mg kg^{-1} (upto four-fold), respectively depending on the soil Zn status ranging from 0.5 to 3.0 mg kg^{-1}. Similarly, the Sona genotype can accumulate grain and straw Zn content upto three-fold (12.5 to 36.1 mg kg^{-1}) and to four-fold (22.3 to 90.3 mg kg^{-1}), respectively depending on the soil Zn status.

4.4 Categorization of rice growing soils for Zn content:

The DTPA-Zn content of soils of eight ACZ selected for the study were well below the general critical limit of 0.6 mg kg^{-1} soil as given by Katyal and Rattan (2003). The results revealed that 34 per cent of the 244 soil samples collected were below the general soil critical limit of Zn (0.6 mg kg^{-1} soil) as mentioned in Table 2. But the critical level of DTPA-Zn for predicting Zn deficiency in soils depends upon the kind of soil as well as crop to be grown. According to Doberman and Fairhust (2000), the critical value of Zn was 0.8 mg kg^{-1} soil for rice, while Katyal and Rattan (2003) reported a general value of 0.6 mg kg^{-1} as critical value for soils of India. Singh et al. (2003) suggested DTPA-Zn values of <0.5 mg kg^{-1} soil for vertisols of Gujarat, <0.7 mg kg^{-1} for vertisols of Madhya Pradesh and <1.2 mg kg^{-1} for red and vertisols of Tamil Nadu as low or critical value. Takkar et al. (1997) reported the critical limits of DTPA-Zn in different soils for rice crop as 0.84 - 1.34 mg kg^{-1} (Black soil), 0.45 - 2.0 mg kg^{-1} (Red and Black soil), 0.60 - 1.0 mg kg^{-1} (Red soil), 0.38 - 0.90 mg kg^{-1} (Alluvial soil) and 0.78 - 0.95 mg kg^{-1} (Tarai and river belt soil). They also reported a wide variation in the range of critical limit of Zn (for the same soil) for rice compared to other crops. This was mainly because of the variation in water management to which the rice crop was subjected and thereby changes in soil pH (Prasad and Power 1997) and the availability of Zn (Lindsay 1991).

Analysis of nearly 2,50,000 soil samples and 25,000 plant samples collected from different states in India showed that 48 per cent of the soil samples and 44 per cent of the plant samples contained inadequate levels of Zn (Takkar et al. 1990 and Singh 2007). According to Pirzadeh et al. (2010), the DTPA-Zn concentration in more than 50 per cent of paddy soils was less than its critical deficiency concentration of 2 mg kg^{-1} in 136 paddy soil samples collected from central and south-west Iran.

4.5 Categorization of rice genotypes for Zn content:

Among the 244 rice samples comprising 64 rice genotypes collected from eight ACZ of Karnataka, the highest grain Zn content was observed in Putta Batta (45.4 mg kg^{-1}) while the lowest was observed in Raksha (7.8 mg kg^{-1}) as shown in Table 4. The highest straw Zn content was observed in Aryza-6444 (102.3 mg kg^{-1}) while the lowest was observed in KMP-149 (16.2 mg kg^{-1}). The indigenous rice viz. Bhutmuri (34.8 ppm), Danarguri (31.4 ppm) and Daransail (30.1 ppm) showed high Zn content in brown rice among the seventeen genotypes tested as reported by Sardar et al. (2015). In the present investigation, it was observed that there was no single genotype which could accumulate Zn in both grain and straw at maximum level suggesting preferential storage of Zn in grain or straw. This was in accordance with Yang et al. (1998) who reported that some rice genotypes had high concentration of Zn in grain while some genotypes had high concentration of Zn in leaves. This may be due to the physiological differences in uptake capacity from soil and retranslocation efficiency from leaves into grain. Anuradha et al. (2012) also studied 126 accessions in Hyderabad, India including cultivated *indica* and *japonica* rice cultivars, germplasm accessions and wild rice genotypes for Zn concentration in brown rice. Zn concentration in grain ranged from 25.2 to 67.3 ppm in 126 rice accessions and was found highest in wild accessions of rice.

Based on Zn content of rice grain, sixty four rice genotypes were categorized as <20 mg Zn kg^{-1}, 20-30 mg Zn kg^{-1} and >30 mg Zn kg^{-1}. By considering the above categories, it was found that 48.4 per cent of the collected rice genotypes were categorized under <20 mg kg^{-1} Zn while 39.1 per cent and 12.5 per cent were categorized under 20-30 and >30 mg kg^{-1} Zn, respectively (Table 4).

Based on Zn content of rice straw, sixty four rice genotypes were categorized as <50 mg Zn kg^{-1}, 50-80 mg Zn kg^{-1} and >80 mg Zn kg^{-1}. By considering the above categories, it was found that 43.8 per cent of the collected rice genotypes were categorized under <50 mg kg^{-1} Zn while 46.9 per cent and 9.4 per cent were categorized under 50-80 and >80 mg kg^{-1} Zn, respectively (Table 4).

Similar type of categorization of rice grain and straw for its Zn content was attempted by Pirzadeh et al. (2010). According to them, rice grains were classified as definite Zn-deficient grains (less than 10 mg kg^{-1}), moderate Zn-deficient grains (very likely deficiency; between 10 and 15 mg kg^{-1}), moderate Zn sufficient grains (likely deficiency; between 15 and 20 mg kg^{-1}), and Zn-sufficient grains (more than 20 mg kg^{-1}). They observed that 40 per cent of the collected rice grain samples were considered to be Zn deficient and 15 per cent as definite Zn deficient. Generally, concentration of Zn in more than half of the rice grains was less than the suggested critical level of 20 mg kg^{-1}. A Zn level of 40 mg kg^{-1} was considered as critical level of deficiency for rice straw. Ninety percent of rice straw samples had Zn concentration less than its critical level.

In the present study, it was observed that half of the collected rice genotypes were categorized under low Zn category while very few genotypes come under high Zn category. The significance of this categorization is mainly to identify and selection of genotypes which have the capacity to accumulate more Zn in grain and straw. Cakmak (2008) pointed out that a breeding program aiming at development of new genotypes with high Zn concentration first requires existence of useful genetic variation for Zn accumulation in grain and also identification of a useful genetic variation and the most promising parents among the rice genotypes. Hence, there is a need for identification of rice genotypes which have high Zn accumulation capacity in rice grain.

4.6 Relationship of soil pH, OC and DTPA-Zn with Zn content in grain and straw of selected rice genotypes:

There was negative significant correlation between soil pH with OC (r= -0.496**), DTPA-Zn (r= -0.202**), grain Zn (r= -0.470**) and straw Zn (r= -0.451**) as shown in Table 5. This result is in accordance with the findings of Talukdar et al. (2009) who stated that DTPA-Zn recorded significant negative correlation with soil pH. Katyal and Sharma (1991) also reported that the DTPA-Zn declined with a rise in pH based on the linear coefficients of correlation. No significant correlation was observed between soil pH and DTPA Zn although negatively correlated (Sidhu and Sharma 2010). Contradictorily, Behera et al. (2011) observed significant positive correlation between soil pH and DTPA Zn. This may be due to the fact that the collected soil samples were acidic in soil reaction whereas in the present investigation soil pH ranged from 4.6 to 8.8 across different ACZ of Karnataka. The possible reason for negative correlation between soil pH and DTPA Zn, grain Zn, straw Zn may be due to enhanced Zn solubility under lower soil pH and thereby increasing grain and straw Zn content. This corroborates the findings of Katyal and Sharma (1991) who stated that under low soil pH, Zn availability was increased.

Organic carbon had positive significant correlation with DTPA-Zn (r= 0.650**), grain Zn (r=0.422**) and straw Zn (r=0.342**) as shown in Table 5. Dhaneshwar et al. (2016) reported available Zn maintained positive and significant correlation with soil OC but negative and significant correlation with soil pH indicating the availability of Zn decreases with increase pH. Similar results were reported by Sharma et al. (2003), Yadav (2008), Yadav and Meena (2009), Talukdar et al. (2009), Sidhu et al. (2010) and Rozas et al. (2015). The DTPA-Zn was significantly and negatively correlated with pH (r= -0.383**) while positively correlated with OC (r= 0.738**) as reported by Mathur et al. (2006). Mathur et al. (2006) also reported that DTPA-Zn had also positive significant correlation with grain Zn (r= 0.377**) and straw Zn (r= 0.281**). Likewise, grain Zn also noticed positive significant correlation with straw Zn (r= 0.541**). Kumar and Babel (2011) reported that the availability of Zn in wheat grains and straw positively correlated with silt, clay, OC and CEC and negatively correlated with sand, $CaCO_3$ and pH of soils. Grain content of Zn was positively and significantly correlated with DTPA-Zn in soils. A positive and significant correlation of DTPA-Zn with uptake of Zn showed that the availability of Zn to plant depended upon the amount of DTPA-Zn in soils (Chahal et al. 2005).

The R^2 values of the regression equation between soil pH and grain Zn content of selected fifteen rice genotypes (based on the number of samples collected) were ranged from 0.023 to 0.510 (Table 6) contributing about 2.3 per cent to 51.0 per cent towards grain Zn content through soil pH. Whereas R^2 values ranged from 0.062 to 0.867 contributing about 6.2 per cent to 86.7 per cent towards straw Zn content through soil pH. The R^2 values between OC and grain Zn content of rice genotypes were ranged from 0.121 to 0.823 contributing about 12.1 per cent to 82.3 per cent towards grain Zn content through OC. Whereas R^2 values ranged from 0.114 to 0.605 contributing about 11.4 per cent to 60.5 per cent towards straw Zn content through OC. The R^2 values between DTPA-Zn and grain Zn content of rice genotypes were ranged from 0.011 to 0.806 contributing about 1.1 per cent to 80.6 per cent towards grain Zn content through DTPA-Zn. Whereas R^2 values ranged from 0.086 to 0.772 contributing about 8.6 per cent to 77.2 per cent towards straw Zn content through DTPA-Zn. Generally, the contribution of soil pH and DTPA-Zn towards grain Zn content was lower compared to that of straw Zn content while OC content of soil contributed slightly higher in terms of grain Zn content. This indicates that there may be some other controlling factors in accumulation of Zn in grain.

The results of the present investigation indicated that higher the OC and DTPA-Zn content in soil, higher may be its accumulation in rice plants. This is in accordance with Wissuwa et al. (2008) which stated that compared to low Zn soil, high Zn soil increases the Zn content in rice grain and straw. Feng et al. (2012) reported that results of Classification and Regression Trees (CART) analysis showed that the spatial variation of the Zn content in crop grains was mainly affected by the soil organic matter and soil pH. Simple correlation and regression analysis revealed that soil pH was significantly and negatively correlated with Zn concentration in straw while no significant correlation was found between soil pH and Zn concentration in grain. Zinc concentration in straw were significantly and positively correlated with organic matter while significantly and negatively correlated between grain Zn concentration and organic matter content as reported by Zeng et al. (2011). Correlation and regression model analyzes suggest that pH and total organic carbon have distinct effect on the availability of Zn in paddy soils. The uptake of Zn in rice root is much higher than those in straw and rice grains as reported by Halim et al. (2015). Hamed et al. (2014) also reported that the exchangeable-Zn fraction of Zn in acid and alkaline soils of Iran was negative significantly correlated with soil pH while positive significantly correlated with soil organic matter. But contradictorily, Pirzadeh et al. (2010) observed that there was no significant correlation between soil and plant Zn concentrations which may be due to the fact that many other factors besides soil properties such as climate, farm management, and crop genotype are affecting plant uptake of micronutrients. Similarly, Raskin and Ensley (2000) and Brummer et al. (1988) also reported that metal concentration of the rice straw, hull, and grain were not related to soil metal concentration. Most of the large-scale studies have shown weak correlations between soil and plant concentrations of metals (Dudka et al.1995). It seems that only a small part of the taken-up (0.01–10 per cent) metal is allocated to the grain and thus affects the relationship between grain metal concentration and the soil metal content (Raskin and Ensley 2000).

V. CONCLUSION

The DTPA-Zn content of soils showed large variations (0.2 to 4.5 mg kg^{-1}) across eight ACZ of Karnataka, South India due to differences in soil chemical properties and management practices. The magnitude of Zn deficiency in soils varied widely not only among the ACZ but also within the same ACZ. About 34 per cent of the collected soil samples were below the general soil critical limit of Zn (0.6 mg kg^{-1} soil) inspite of receiving Zn application in 30 per cent of the soil samples. Wide variation of Zn content was observed in 244 rice samples comprising of 64 rice genotypes which ranged from 7.8 to 51.3 mg kg^{-1} in grain and 16.6 to 284.0 mg kg^{-1} in straw. A single genotype (Jyothi) could accumulate Zn in grain and straw in a range of 10.5 to 51.3 mg kg^{-1} and 17.5 to 90.7 mg kg^{-1}, respectively depending on the soil Zn status ranging from 0.5 to 3.0 mg kg^{-1} and soil chemical properties suggesting a genetic potential to increase Zn content in rice. The variation in Zn content is mainly influenced by soil pH, DTPA-Zn, OC apart from genotypic variation in grain and straw Zn accumulation among the rice genotypes.

Correlation analysis revealed negative relationship between soil pH and DTPA-Zn, OC, Zn content in grain and straw. However, positive relationship exists between DTPA-Zn, OC and Zn content in grain and straw. The present study provides a means to overcome the problem of low Zn content in rice through proper understanding of the relationship between the Zn content in rice plant and soil chemical properties such as soil pH, DTPA-Zn and OC and adoption of proper management practices accordingly. From the present investigation, it is possible to identify and select the genotypes which have the capacity to accumulate more Zn in grain and straw. The selection of genotypes can be exploited for further traditional breeding programme or selection of Zn fertilizer responsive genotypes to enhance Zn content in rice from the perspectives of nutrition of human and livestock.

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