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Evolving appropriate zinc fertilization strategy for rice-rice (*Oryza sativa*) cropping system in Cauvery Delta Zone

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ABSTRACT

Six field experiments were conducted at Tamil Nadu Rice Research Institute, Aduthurai to evolve suitable zinc fertilization method for rice - rice (Oryza sativa L.) cropping system in Cauvery delta zone. The treatment includes: T_1: Control, T_2: 100 g zinc sulphate ($ZnSO_4$)/cent in nursery alone., T_3: root dipping alone in 2 % zinc oxide (ZnO) solution, T_4: 25 kg $ZnSO_4$ ha^{-1}, T_5: 37.5 kg $ZnSO_4$ ha^{-1}, T_6: 25 kg $ZnSO_4$ ha^{-1}+ Farm Yard Manure (FYM) 12.5 t ha^{-1}, T_7: 25 kg $ZnSO_4$ ha^{-1} + Green Leaf Manure (GLM) 6.5 t ha^{-1}, T_8: Tamil Nadu Agricultural University Micro Nutrient (TNAU MN) mixture 25 kg ha^{-1} as Enriched Farm Yard Manure (EFYM), T_9: TNAU MN mixture 37.5 kg ha^{-1} as EFYM, T_{10}: Foliar spray of 0.5% $ZnSO_4$ + 1 % urea at tillering and panicle initiation stage, T_{11} : 100g $ZnSO_4$/cent in nursery alone + Foliar spray of 0.5 % $ZnSO_4$ + 1 % urea at tillering and panicle initiation stage (T_2+ T_{10}), T_{12} : root dipping alone in 2 % ZnO solution + Foliar spray of 0.5 % $ZnSO_4$ + 1 % urea at tillering and panicle initiation stage (T_3 + T_{10}), T_{13}: 100 g $ZnSO_4$/cent in nursery alone + root dipping alone in 2 % ZnO solution + Foliar spray of 0.5 % $ZnSO_4$ + 1 % urea at tillering and panicle initiation stage (T_2 + T_3 + T_{10}). The treatments T_5, T_6, T_7 and T_9 were skipped in rabi season to know the residual effect of these treatments in the subsequent season. Among the treatment combinations, application of 25 kg $ZnSO_4$ ha^{-1} + FYM 12.5 t ha^{-1} recorded higher grain yield in both kharif (6232 kg ha^{-1}) and rabi (6236 kg ha^{-1}) seasons. The same treatment combination recorded higher Zn content and Zn uptake as well. Regarding soil nutrient content, the same treatment recorded higher N, P and K content. This treatment was followed by application of 25 kg $ZnSO_4$ ha^{-1} + green leaf manure 6.5 t ha^{-1}. The experimental findings suggested that combination of organic and inorganic sources not only increased the yield but also improves soil health in Cauvery delta zone.

Key words: *Cauvery Delta Zone, rice-rice system, soil health, yield, zinc*

INTRODUCTION

Micronutrients play an important role to enhance the agricultural productivity. Micronutrient deficiencies are becoming serious because of escalated nutrient demand from more intensive and exploitative agriculture, coupled with use of single-nutrient fertilizers and low amounts of organic manures. Zinc (Zn) is essential for normal plant growth and development since it is constituents of many enzymes and other proteins (Hafeez et al., 2013). Zinc deficient soils are common in various climatic regions world-wide and Zn deficiency is one of the most important nutritional problems after macronutrients deficiency in crop production (Asadi et al., 2012). Zinc deficiency is prevalent worldwide in temperate and tropical climates. Forty seven per cent of Indian soils and fifty percent of Tamil Nadu soils are deficient in zinc (Arunachalam et al., 2013). In Cauvery Delta Zone (CDZ), next to N, the deficiency of zinc is occurring widely. Heavy textured soils of old delta are more deficient in Zn (80.4%) than the new delta soils (47.4%) (Hafeez et al., 2013). Zinc availability in soil depends on soil properties such as pH and redox potential, contents of CO_3^{2-} and HCO_3^-, oxides of Fe and Al, and organic matter and inherent Zn status in the upper soil layer (Tuyogon et al., 2016). The problem of low Zn availability to plants is exacerbated when rice is grown in submerged soils (Meng et al., 2014). Rice grown in flooded conditions has higher requirement of Zn because the availability of other nutrients in submerged condition increases which decreases Zn availability to crop. Zinc deficiency is a well known nutritional and health problem in human populations where rice is the dominating staple food crop (Firdous et al., 2018).

Changes in crop production technology often present opportunities to develop fertilization strategies that may reduce production costs associated with product application or materials, improve nutrient delivery to plants, or provide flexibility in the timing of crop inputs. Due to high cost of Zn and its unavailability at proper time not only reduces the yield of rice but also there is a lot of contradiction in recommendation of the method and time of Zn application in rice. Foliar application of nutrients has also become an efficient way to increase yield and quality of crops. In semiarid regions, foliar application of nutrients is a more suitable option compared with soil fertilization as it gives quick compensation of nutrient deficiency. Therefore, present study was undertaken to find out an appropriate Zn fertilization strategy for enhancing productivity of irrigated rice in Cauvery Delta Zone.

MATERIALS AND METHODS

Field experiments were conducted during 2014-15 and ended up to 2017-18 at Tamil Nadu Rice Research Institute, Aduthurai in *kharif* and *rabi* seasons. The experiments were conducted in randomized block design with three replications and thirteen treatment combinations (Table 1). The treatment includes: T_1: Control, T_2: 100 g Zinc Sulphate ($ZnSO_4$)/cent in nursery alone, T_3 : Root dipping alone in 2 % Zinc oxide (ZnO) solution, T_4 : 25 kg $ZnSO_4$ ha^{-1}, T_5: 37.5 kg $ZnSO_4$ ha^{-1}, T_6 : 25 kg $ZnSO_4$ ha^{-1} + Farm Yard Manure (FYM) 12.5t ha^{-1}, T_7 : 25 kg $ZnSO_4$ ha^{-1} + Green Leaf Manure (GLM) 6.5t ha^{-1}, T_8 : Tamil Nadu Agricultural University Micro Nutrient (TNAU MN) mixture 25 kg ha^{-1} as Enriched Farm Yard Manure (EFYM), T_9 : TNAU MN mixture 37.5 kg ha_{-1} as EFYM, T_{10} : foliar spray of 0.5% $ZnSO_4$ + 1% urea at tillering and panicle initiation stage, T_{11} : 100g $ZnSO_4$/cent in nursery alone + foliar spray of 0.5% $ZnSO_4$ + 1% urea at tillering and Panicle initiation stage (T_2+T_{10}), T_{12} : Root dipping alone in 2% ZnO solution + foliar spray of 0.5% $ZnSO_4$ + 1% urea at tillering and panicle initiation stage (T_3 + T_{10}), T_{13}: 100g $ZnSO_4$/cent in nursery alone + root dipping alone

Table 1. Treatments

Treatment no.	Fertilizer source/dose	Season	
		kharif	*rabi*
T_1	Control	√	√
T_2	100g $ZnSO_4$/cent in nursery alone	√	√
T_3	Root dipping alone in 2% ZnO solution	√	√
T_4	25 kg $ZnSO_4$ ha^{-1}	√	√
T_5	37.5 kg $ZnSO_4$ ha^{-1}	√	-
T_6	25 kg $ZnSO_4$ ha^{-1} + FYM 12.5 t ha^{-1}	√	-
T_7	25 kg $ZnSO_4$ ha^{-1} + GLM 6.5 t ha^{-1}	√	-
T_8	TNAU MN mixture 25 kg/ha as EFYM	√	√
T_9	TNAU MN mixture 37.5 kg/ha as EFYM	√	-
T_{10}	Foliar spray of 0.5 % $ZnSO_4$ + 1 % urea at tillering and panicle initiation stage	√	√
T_{11}	100 g $ZnSO_4$/cent in nursery alone + foliar spray of 0.5% $ZnSO_4$ + 1% urea at tillering and panicle initiation stage (T_2 + T_{10})	√	√
T_{12}	Root dipping alone in 2% ZnO solution + foliar spray of 0.5% $ZnSO_4$ + 1 % urea at tillering and panicle initiation stage (T_3 + T_{10})	√	√
T_{13}	100g $ZnSO_4$/cent in nursery alone + root dipping alone in 2% ZnO solution + foliar spray of 0.5% $ZnSO_4$ + 1% urea at tillering and Panicle initiation stage (T_2+ T_3 + T_{10})	√	√

The common dose of NPK @ 150:50:50 50 kg ha^{-1} was applied for all the plots. $ZnSO_4$: zinc sulphate ; ZnO : zinc oxide ; FYM : farm yard manure ; GLM : green leaf manure ; TNAU MN mixture : Tamil Nadu Agricultural University micro nutrient mixture ; EFYM : enriched farm yard manure.

in 2 % ZnO solution + foliar spray of 0.5% $ZnSO_4$ + 1 % urea at tillering and Panicle initiation stage (T_2 + T_3 + T_{10}). The treatments T_5, T_6, T_7 and T_9 were skipped in *rabi* season to know the residual effect of these treatments in the subsequent season. All the plots received the uniform recommended dose of 150:50:50 NPK kg ha^{-1} in both the seasons. Most popular rice varieties of Cauvery delta region *viz*., ADT 43 and ADT 45 for short duration (*kharif*) and ADT 38 and ADT 39 for medium duration (*rabi*) were used in these experiments. Need based plant protection measures were taken up against pest and diseases.

The soil of experimental site was clayey (Typic Haplustert), having pH 7.6, organic carbon 0.12%, available N 125 kg ha^{-1}, P 56 kg ha^{-1} and K 320 kg ha^{-1} and Diethylene Triamine Penta Acetic acid-Tri Ethanol Amine (DTPA-TEA) extractable Zn was 0.51 mg kg^{-1} (low).

Chemical analysis of Zn in plant samples

The crop was harvested at maturity and grain and straw yield were recorded after sun drying of varieties. The concentration of Zn in grain and straw was estimated using Atomic Absorption Spectrometer (AAS) (Varian-Agilent) by following standard procedures. One gram (1 g) of powdered oven dried plant material (60-70 ^oC) was taken in 100 ml conical flask and 10 ml of di-acid mixture (10:4 of HNO_3-$HClO_4$) was added in the flask and mixed by swirling. The flask was placed on hot plate in a digestion chamber. After cooling, it was transferred to a 50 ml volumetric flask composed of ultra pure water and then filtered. The contents were further evaporated until the volume was reduced to 3 to 5 ml but not to dryness. The completion of digestion was confirmed when the liquid become colorless. After cooling the flask, 20 ml of glass double distilled water was added. The volume was made up to 50 ml with glass double distilled water and filtered the solution using What man no. 41 filter paper.

At the end of each year, representative post harvest soil samples (0-15 cm) were collected and analysed for pH and EC (1:2.5), organic carbon (Walkey and Black, 1943), available N (Jackson,1973), Bray P and 1 N NH_4OAC extractable K (Page et al., 1982). Likewise, the plant samples (grain and straw) were collected and analysed for N (Humphries, 1956) P and

Table 2. Effect of treatments on yield attributes.

S. No	Treatments	*Kharif*			*Rabi*		
		Plant height (cm)	No. of panicles/ m^2	1000 grain wt.(g)	Plant height (cm)	No. of panicles/ m^2	1000 grain wt.(g)
T_1	Control	78.3	272	19.5	78.9	271	21.2
T_2	100 g $ZnSO_4$/cent in nursery alone	79.4	279	20.5	79.6	282	21.9
T_3	Root dipping alone in 2 % ZnO solution	79.6	282	20.9	79.5	283	22.0
T_4	25 kg $ZnSO_4$ ha^{-1}	89.4	329	21.7	89.6	329	24.1
T_5	37.5 kg $ZnSO_4$ ha^{-1}	86.2	321	21.6	86.4	327	23.9
T_6	25 kg $ZnSO_4$ ha^{-1} + FYM 12.5 t ha^{-1}	92.4	337	23.2	92.9	349	25.1
T_7	25 kg $ZnSO_4$ ha^{-1}+ GLM 6.5 t ha^{-1}	91.8	332	22.4	90.8	344	24.7
T_8	TNAU MN mixture 25 kg ha^{-1}	89.5	330	21.6	89.3	328	24.2
T_9	TNAU MN mixture 37.5 kg ha^{-1}	85.2	322	21.4	85.0	324	24.0
T_{10}	Foliar spray of 0.5% $ZnSO_4$ + 1 % urea at tillering and Panicle initiation stage	88.3	312	20.9	88.7	317	22.9
T_{11}	T_2 + T_{10}	81.2	309	21.9	80.2	312	22.4
T_{12}	T_3 + T_{10}	82.3	315	20.5	82.5	319	22.6
T_{13}	T_2 + T_3+T_{10}	83.4	314	20.6	83.6	316	22.5
	SEm±	1.2	4.9	1.2	1.3	5.2	1.7
	CD @ 5 %	2.6	11.3	2.6	2.9	12.6	3.4

The common dose of NPK @ 150:50:50 50 kg ha^{-1} was applied for all the plots. $ZnSO_4$: zinc sulphate ; ZnO : zinc oxide ; FYM : farm yard manure ; GLM : green leaf manure ; TNAU MN mixture : Tamil Nadu Agricultural University micro nutrient mixture ; EFYM : enriched farm yard manure.

K (Jackson, 1973) and their uptake values were worked out. In order to compare the effect of various treatments on grain and straw yield, soil fertility and nutrient uptake the data were pooled and analysis of variance (ANOVA) was performed using standard statistical procedure for randomized block design.

RESULTS AND DISCUSSION

Yield attributes

The data pertaining to yield attributes as influenced by the treatments is presented in the Table 2. It was observed that higher yield attributes (plant height, number of panicles /m^2 and 100 grain weight) were recorded in T_6 *i.e*., application of recommended dose of NPK with 25 kg $ZnSO_4$ ha^{-1} + FYM 12.5 t ha^{-1} followed by application of recommended dose of NPK with 25 kg $ZnSO_4$ ha^{-1}+ GLM 6.5 t ha^{-1} in both the seasons. The combined application of fertilizers and manures influence on yield attributes compared to single application of any one. This could be attributed to adequate supply of Zn through organic manures which accelerates the activity of enzyme and auxin metabolism in plants. Yield attributes were significantly influenced by the application of organic manure and chemical fertilizers reported by (Babu et al. 2001). Similar results were also reported by (Rajani Rani et al., 2001). Application of chemical fertilizer and FYM recorded taller plants at harvest as compared to other treatment combinations (Mohanty et al., 2013). Application of chemical fertilizer along with organic manure increased the 1000 grain weight (Yang et al., 2004). Application of Zn with FYM significantly increased the tillering and this could be attributed to the improved enzymatic activity and auxin metabolism in plants (Hung et al., 1990). It is also due to the fact that Zn had a positive effect on formation of stamens and pollen which increased the fertility of flowers (Banks, 2004). The increase in seed weight upon zinc fertilization could be attributed to enhanced zinc uptake and translocation of sugars and higher carbohydrate accumulation in seed. Similar results have been reported by (Anand, 2007).

Grain and straw yield

The grain and straw yield of both the seasons are given in Table 3. The result showed that application of recommended dose of NPK with 25 kg $ZnSO_4$ ha^{-1} + FYM 12.5 t ha^{-1} recorded higher grain (6232 and 6236 kg ha^{-1} in *kharif* and *rabi*) yield in both the seasons. This was followed by application of recommended dose of NPK with 25 kg $ZnSO_4$ ha^{-1} + GLM 6.5 t ha^{-1} in both the seasons. It indicated that that application of organic manure along with chemical fertilizers increased growth and yield of rice as compared to application of chemical fertilizers alone. It may be due to slow release of nutrients for a longer period after decomposition of FYM, which favored better plant growth and improved the yield components of rice. And also it may be due to the fact that the integrated use of fertilizers with organic manures *viz*., FYM and BGA might have added huge quantity of organic matter in soil that increased grain and straw yield (Chaudhary and Thakur, 2007). Further, the addition of organic matter also maintains regular supply of macro and micronutrients in soil resulting in higher yields. These results are in conformity with the finding of (Gupta et al., 2006; Fageria et al., 2011). Higher yield due to zinc fertilization is attributed to its involvement in many metallic enzyme system, regulatory functions and auxin production (Sachdev et al., 1988), enhanced synthesis of carbohydrates and their transport to the site of grain production (Pedda Babu et al., 2007). Datta and Dhiman (2001), reported that the increase in grain and straw yield may be due to the fact that the zinc exerts a great influence on basic plant life processes such as nitrogen metabolism, uptake of N, and protein quality. This beneficial effect of organic matters may be attributed to the formation of organometallic complexes with Zn, which resulted in the increase of its efficiency. Abdoli et al. (2014) was of opinion that chlorophyll and IAA production causes prolonged period of photosynthesis which improves the production of carbohydrate and there transportation to seeds. The increase in yield of rice may be due to the beneficial effect of Zn and various organic manures on yield attribute like plant height, number of tillers, panicle length and number of grains per panicle which ultimately resulted in higher grain production (Yadav et al., 2015). The increase in grain yield because of the application of zinc along with FYM well corroborates with the enhanced zinc availability in the soil. The slow release of Zn by enriched manures would have helped in better uptake of zinc, which reflected in the increased grain yield.

Table 3. Effect of treatments on grain and straw yield.

S.No.	Treatments	*Kharif*		*Rabi*	
		Grain yield (kg/ha)	Straw yield (kg/ha)	Grain yield (kg/ha)	Straw yield (kg/ha)
T_1	Control	3205	4146	3426	4812
T_2	100 g $ZnSO_4$/cent in nursery alone	4832	5853	4123	5023
T_3	Root dipping alone in 2 % ZnO solution	5932	6535	4126	5123
T_4	25 kg $ZnSO_4$ ha^{-1}	5945	6825	5942	6958
T_5	37.5 kg $ZnSO_4$ ha^{-1}	6095	6942	6035	7135
T_6	25 kg $ZnSO_4$ ha^{-1} + FYM 12.5 t ha^{-1}	6232	7135	6236	7235
T_7	25 kg $ZnSO_4$ ha^{-1}+ GLM 6.5 t ha^{-1}	5916	6752	6212	7023
T_8	TNAU MN mixture 25 kg ha^{-1}	5846	6623	5946	6845
T_9	TNAU MN mixture 37.5 kg ha^{-1}	5876	6543	5843	6742
T_{10}	Foliar spray of 0.5% $ZnSO_4$ + 1 % urea at tillering and panicle initiation stage	5654	6232	5213	6012
T_{11}	T_2+T_{10}	5800	6652	4235	5236
T_{12}	T_3+T_{10}	5716	6819	4636	5239
T_{13}	T_2+T_3+T_{10}	5945	6942	4765	5156
	SEm±	161.46	221.8	152.36	212.9
	CD @ 5 %	352.44	585.56	329.5	462.8

The common dose of NPK @ 150:50:50 50 kg ha^{-1} was applied for all the plots. $ZnSO_4$: zinc sulphate ; ZnO : zinc oxide ; FYM : farm yard manure ; GLM : green leaf manure ; TNAU MN mixture : Tamil Nadu Agricultural University micro nutrient mixture ; EFYM : enriched farm yard manure.

Zn uptake

The Zn uptake in grain and straw for both the seasons are given in Table 4. The result showed that application of recommended dose of NPK with 25 kg $ZnSO_4$ ha^{-1} + FYM 12.5 t ha^{-1} recorded higher Zn uptake both in grain and straw (152 and 225 g ha^{-1} in *kharif* and 185 and 256 g ha^{-1} in *rabi*) in both the seasons. This was followed by application of recommended dose of NPK with 25 kg $ZnSO_4$ ha^{-1} + GLM 6.5 t ha^{-1} in both the seasons. It may be due to application of inorganic with organic fertilizers which enhanced the activity of beneficial microbes and colonization of mycorrhizal fungi, which play an important role in mobilization of micronutrients, there by leading to better uptake by plants. The increased micronutrient uptake under integrated nutrient management practices was due to the production of organic acids during decomposition of organic matter, which are capable of releasing the nutrients associated with clay minerals and better availability from both organic and inorganic sources. Moreover, the beneficial effect of inorganic with organics on micronutrient uptake might be attributed to their increased humic substances, faster release of nutrients during mineralization, thereby resulting in higher uptake by rice owing to higher grain yield. The increase in Zn uptake in grain and straw at harvest might be due to the presence of increased amount of Zn in soil solution by the application of Zn that might have facilitated the absorption of Zn through phloem. The higher concentration of Zn in straw as compared to grain was reported by (Naik and Das, 2007). The increase concentration of Zn due to foliar application might be due to Zn absorption by leaf epidermis and remobilization in to the rice grain through phloem and several membranes of Zn regulated transporters which might have regulated this process (Bashier et al., 2012). The increased supply of Zn favoured increased accumulation in the plant. Furthermore, the organic manures would have favourably influenced the rhizosphere environment for better Zn uptake (Sridevi et al., 2010).

Zn content in soil

The available Zn content in soil is given in Table 5. The data showed that application of recommended dose of NPK with 25 kg $ZnSO_4$ ha^{-1} + FYM 12.5 t ha^{-1} recorded higher Zn content in soil (1.24 ppm) followed by application of recommended dose of NPK with 25 kg $ZnSO_4$ ha^{-1} + GLM 6.5 t ha^{-1} (1.23ppm). The lowest available Zn content in soil was recorded in control (0.91 ppm). The results are in agreement with the findings of

Table 4. Effect of treatments on Zn uptake of grain and straw.

S.no.	Treatments	*Kharif*		*Rabi*	
		Grain ($g\ ha^{-1}$)	Straw ($g\ ha^{-1}$)	Grain ($g\ ha^{-1}$)	Straw ($g\ ha^{-1}$)
T_1	Control	104	162	105	146
T_2	100 g $ZnSO_4$/cent in nursery alone	110	186	145	223
T_3	Root dipping alone in 2% ZnO solution	119	192	149	212
T_4	25 kg $ZnSO_4$ ha^{-1}	136	219	165	210
T_5	37.5 kg $ZnSO_4$ ha^{-1}	140	225	170	225
T_6	25 kg $ZnSO_4$ ha^{-1} + FYM 12.5 t ha^{-1}	152	225	185	256
T_7	25 kg $ZnSO_4$ ha^{-1} + GLM 6.5 t ha^{-1}	150	212	180	240
T_8	TNAU MN mixture 25 kg ha^{-1}	149	206	159	212
T_9	TNAU MN mixture 37.5 kg ha^{-1}	140	198	146	205
T_{10}	Foliar spray of 0.5% $ZnSO_4$ + 1 % urea at tillering and panicle initiation stage	116	185	152	194
T_{11}	T_2 + T_{10}	120	189	146	196
T_{12}	T_3 + T_{10}	118	180	152	212
T_{13}	T_2 + T_3 + T_{10}	115	185	159	212
	SEm±	5.36	8.45	6.2	8.53
	CD @ 5 %	10.3	16.8	13.6	18.5

The common dose of NPK @ 150:50:50 50 kg ha^{-1} was applied for all the plots. $ZnSO_4$: zinc sulphate ; ZnO : zinc oxide ; FYM : farm yard manure ; GLM : green leaf manure ; TNAU MN mixture : Tamil Nadu Agricultural University micro nutrient mixture ; EFYM : enriched farm yard manure.

(Khan et al., 2002). This can be attributed to increased available Zn in soil solution. It could be observed here that soil Zn concentration increased with the application of Zn fertilizer and the concentration were also higher after harvesting of rice crop when compared to soil which is not fertilized with Zn. Similar results were also obtained by (Shaheen et al., 2007). Such build up of cationic micronutrients in soil might be partly owing to release of native soil micronutrients resulting from the dissolution action of organic manures and also partly due to release from applied organic manures. The results of the present study are similar to that of (Singh et al., 1999). The maximum availability of Zn in soils treated with inorganics coupled with organics might be due to their release through mineralization of manures and also due to production of chelating agents which have the ability to reduce their adsorption, fixation and precipitation resulting in their enhanced availability in soil (Kher, 1993). The INM treatments with organic manures either increased or retained the critical fertility status of micronutrients. Organic manures on decomposition produce a variety of biochemical substances (Organic acids, polyphenols, amino acids and poly saccharides) which stimulate the solubility, transport and availability of micronutrients.

Post harvest soil characteristics

pH and EC

The chemical properties of soil at post harvest stage are given in Table 6. The result showed the soil pH at harvest was not influenced by the imposed treatments. However, the pH values were slightly less in the plots which received the recommended dose of NPK with 25 kg $ZnSO_4$ ha^{-1} + FYM 12.5 t ha^{-1} as compared to other treatments. This could be due to the production of organic acids during the decomposition of organic residues. Kharche et al. (2013) attributed that buffering effect caused due to organic matter helped in maintaining the pH of Vertisols under sorghum-wheat cropping system. The total soluble salt content remained unaltered by the treatments. This might be due to the doses of fertilizers added in different treatments were quite small and salts added through fertilizers might have been leached down due to good number of irrigations and rains received by crop. Badole et al. (2011) reported

Table 5. Effect of treatments on Zn content in soil.

S. no.	Treatments	Zn content (ppm)
T_1	Control	0.91
T_2	100 g $ZnSO_4$/cent in nursery alone	1.02
T_3	Root dipping alone in 2% ZnO solution	1.09
T_4	25 kg $ZnSO_4$ ha^{-1}	1.10
T_5	37.5 kg ZnSO4 ha^{-1}	1.11
T_6	25 kg $ZnSO_4$ ha-1 + FYM 12.5 t ha^{-1}	1.24
T_7	25 kg $ZnSO_4$ ha-1+ GLM 6.5 t ha^{-1}	1.23
T_8	TNAU MN mixture 25 kg ha^{-1}	1.17
T_9	TNAU MN mixture 37.5 kg ha^{-1}	1.18
T_{10}	Foliar spray of 0.5% $ZnSO_4$ + 1 % urea at tillering and panicle initiation stage	1.15
T_{11}	T_2+T_{10}	1.14
T_{12}	T_3+T_{10}	1.14
T_{13}	T_2 + T_3 + T_{10}	1.11
	SEm±	0.12
	CD @ 5 %	0.24

The common dose of NPK @ 150:50:50 50 kg ha^{-1} was applied for all the plots. $ZnSO_4$: zinc sulphate ; ZnO : zinc oxide ; FYM : farm yard manure ; GLM : green leaf manure ; TNAU MN mixture : Tamil Nadu Agricultural University micro nutrient mixture ; EFYM : enriched farm yard manure.

that the EC of soil were slightly decreased with the increase in application of partially or fully decomposed FYM @ 5 to 10 t ha^{-1} along with recommended dose of fertilizers.

Organic carbon

The organic carbon content of soil was not influenced by the imposed treatments (Table 6) when compared to initial content (0.19%). Among the treatments higher organic carbon content was recorded in treatment which received organic matter either through FYM or GLM or TNAU mineral mixture with zinc sulphate. Highest organic carbon content was observed in T6, T_7, T_9 and T_{12} (0.23%) which received both inorganic and organic fertilizers and TNAU mineral mixture. Addition of organic nutrient source might have created environment conducive for formation of humic acid, stimulated the activity of soil microorganisms resulting in an increase in the organic carbon content of the soil (Bajpai et al., 2006).

The significant increase in organic content in all the treatments with integrated use of nutrient sources as compared to use of inorganic fertilizer alone might be due to the enhanced root growth, which leads to the accumulation of organic residues and also direct incorporation of organic matter through FYM and GLM in the soil. The increase in organic carbon content of the FYM or GLM treated plots might be due to direct incorporation of the organic matter in to the soil and also the subsequent decomposition of these materials might have resulted in the organic carbon content of the soil (Baskar, 2003; Singh and Pathak, 2003; Singh et al., 2008).

Available nitrogen

The available nitrogen content at post harvest stage in soil (Table 6) showed that there was an increase in available nitrogen content of soil at harvest of crop over the initial soil status (229 kg ha^{-1}). Application of recommended dose of NPK with 25 kg $ZnSO_4$ ha^{-1} + FYM 12.5 t ha^{-1} recorded higher N content (245 kg ha^{-1}) followed by application of 25 kg $ZnSO_4$ ha^{-1} + GLM 6.5 t ha^{-1} (244 kg ha^{-1}). It may be due to the fact that these INM treatments created favourable soil conditions which helped in the mineralization of the soil nitrogen and also enhanced the multiplication of microbes which catalyze the conversion of organically bound nitrogen to inorganic form leading to build up of higher available nitrogen in soil. Further, it was observed that there was no significant difference in available nitrogen content of soils among the treatments which received FYM and GLM with zinc sulphate and recommended dose of fertilizers. Incorporation of GLM to the soil complex, helps in breakdown of nitrogenous compounds slowly and make steady nitrogen supply throughout the growth period of the crop due to high C:N ratio as compared to FYM.

The increase in available nitrogen with INM could be due to the direct supply of nitrogen as well as enhanced microbial activity which improves the nitrogen transformations like ammonification and nitrification. These results are in agreement with the findings of Satyanaryanarao and Janawade (2009), Prasad et al. (2010b) and Katkar et al. (2002).

Lower amounts of available nitrogen in control plot which received RDF might be due to higher uptake of nutrients as well as considerable losses of inorganic nitrogen from soils. These results are in agreement with that of Siddaram et al. (2011).

Table 6. Effect of treatments on soil available nutrients.

S. no.	Treatments	pH	EC (dS/m)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	OC(%)
T_1	Control	7.9	0.12	229	52	258	0.19
T_2	100 g $ZnSO_4$/cent in nursery alone	8.2	0.15	232	53	259	0.21
T_3	Root dipping alone in 2% ZnO solution	8.3	0.13	226	54	223	0.21
T_4	25 kg $ZnSO_4$ ha^{-1}	8.4	0.16	224	52	236	0.19
T_5	37.5 kg $ZnSO_4$ ha^{-1}	8.1	0.15	225	51	242	0.21
T_6	25 kg $ZnSO_4$ ha^{-1} + FYM 12.5 t ha^{-1}	8.0	0.14	245	56	265	0.23
T_7	25 kg $ZnSO_4$ ha^{-1}+ GLM 6.5 t ha^{-1}	7.9	0.13	244	55	264	0.23
T_8	TNAU MN mixture 25 kg ha^{-1}	8.2	0.12	227	55	249	0.21
T_9	TNAU MN mixture 37.5 kg ha^{-1}	8.3	0.14	225	53	252	0.23
T_{10}	Foliar spray of 0.5% $ZnSO_4$ + 1 % urea at tillering and panicle initiation stage	8.1	0.13	226	54	224	0.21
T_{11}	T_2 + T_{10}	8.0	0.14	224	56	246	0.21
T_{12}	T_3 + T_{10}	7.9	0.15	225	57	235	0.23
T_{13}	T_2 + T_3 + T_{10}	8.1	0.13	221	51	252	0.20
	SEm±	0.06	0.02	8	4	15	0.01
	CD @ 5 %	0.12	NS	17	9	27	0.13

The common dose of NPK @ 150:50:50 50 kg ha^{-1} was applied for all the plots. $ZnSO_4$: zinc sulphate ; ZnO : zinc oxide ; FYM : farm yard manure ; GLM : green leaf manure ; TNAU MN mixture : Tamil Nadu Agricultural University micro nutrient mixture ; EFYM : enriched farm yard manure.

Available phosphorus

The data presented in table 6 revealed that there was an increase in available phosphorus content at harvest of crop over the control (52 kg ha^{-1}) by the treatments. Significantly higher amounts of available phosphorus content was recorded with the integrated application of Zinc sulphate with FYM, GLM over the control (RDF). The enhanced availability of soil P after harvest of rice might be due to production of organic acids during microbial decomposition of the incorporated organic manures in soil and decrease in soil pH. The increased availability of phosphorus with organics could be ascribed to their solubilizing effect on the native soil phosphorus and consequent contribution of the phosphorus as solubilized to labile pool. Incorporation of organics along with inorganic phosphorus increased the availability of phosphorus to crop and mineralization of inorganic phosphorus due to microbial action and enhanced mobility of phosphorus (Prasad et al., 2010b). Organic matter (humus) may also reduce the fixation of phosphate by providing protective cover on sesquioxides and thus reduce the phosphate fixing capacity and increase the available phosphorus in soil (Bharadwaj and Omanwar, 1994).

Available potassium

The status of available potassium at harvest of crop was significantly influenced by the imposed treatments (Table 6). Improvement in soil potassium status when compared to initial status of soil was observed. Application of recommended dose of NPK with 25 kg $ZnSO_4$ ha^{-1} + FYM 12.5 t ha^{-1} recorded higher K content (265 kg ha^{-1}) followed by application of 25 kg $ZnSO_4$ ha^{-1} + GLM 6.5 t ha^{-1} (264 kg ha^{-1}). The beneficial effect of INM on available potassium could be ascribed to the reduction of potassium fixation, solubilisation and release due to the interaction of organic matter with clay (Gopi, 2014). Similarly Prasad et al. (2010b) reported increase in available potassium due to incorporation of crop residues.

Correlation studies

Addition of Zn and yield

The correlation between yield of rice and Zn added through fertilizer is given in Fig. 1. There is a positive correlation occurs between yield and Zn added in both the seasons. There is a positive correlation occurred between rice yield and Zn added thorough fertilizers both in *kharif* (R^2 = 0.424) and *rabi* (R^2 = 0.750) seasons. The increase in grain yield with increased

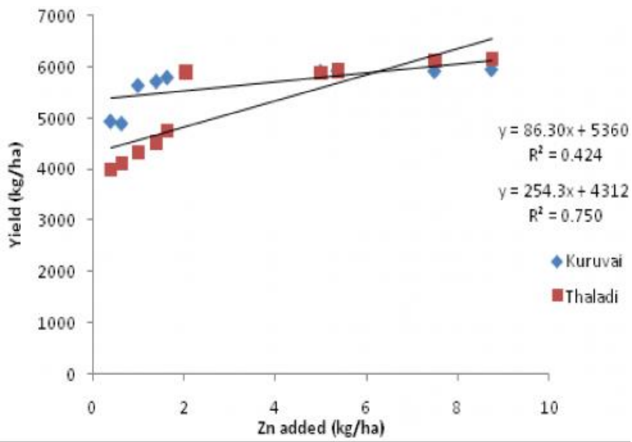

Fig. 1. Relationship between Zn added and yield in rice.

levels of zinc application could be possibly due to better supply of Zn, which plays a specific role in various metabolic activities and might also be attributed to enhanced synthesis of carbohydrates with higher levels of zinc application and their transport to the site of grain formation. Similar findings were reported by Zayed et al. (2011). Further, Stalin et al. (2011) also observed that the supply of micronutrient Zn resulted in better absorption of nutrients, thereby helping in photosynthetic activity and effective translocation to storage organs, thus, contributed to the increased yield. This was evidenced by significant relation between available zinc and grain yield of rice. The results are in complete agreement with the findings of Ravikiran and Reddy (2004).

CONCLUSION

Fertilizers cost is increasing day by day, and the cost benefit ratio of rice crop is declining due to higher input cost. Use of locally available plant nutrient sources, enhanced the crop yield at cheaper rate and improve soil health. Conjunctive application of organics along with inorganics sets a congenial soil environment with consistent supply of nutrients over the crop period by enhancing the crop growth which results in high yields. Application of recommended dose of NPK with 25 kg $ZnSO_4$ ha^{-1} + FYM 12.5 t ha^{-1} recorded higher yield. It may be a viable option for sustainable rice crop yield in rice belt of Tamil Nadu, India.

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