Original Research Article

A study to refix the critical limit of copper in the major rice growing soils of Tamil Nadu, India

ABSTRACT

Aims: To refix the critical limit of Cu in the soils of the major rice-growing tracts of Tamil Nadu.

Study design: Completely Randomized Design and Randomized Block Design.

Place and Duration of Study: Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University between 2015 to 2018.

Methodology: The pot culture study was conducted in the laboratory followed by the field trials in the selected farmers'plot itself. The soil and plant samples are analyzed for soil copper and the data were statistically analyzed by following the standard procedures.

Results: The Cu deficient soils showed a significant response to the application of graded levels of Cu. For obtaining higher rice production in severely Cu-deficient soils (L_1 to L_9: 0.33 to 0.95 mg kg^{-1}), the Cu fertilizers may be applied @ 1.50 kg ha^{-1} i.e. 6.0 kg $CuSO_4$ ha^{-1} (+ NPK) while in moderately Cu deficient soils (L_{10} to L_{13}: 1.28 mg kg^{-1}), the Cu level @ 1.00 kg ha^{-1} i.e. 4.0 kg $CuSO_4$ ha^{-1} (+ NPK) increased significantly the grain and straw yields and in soils having high initial Cu status (L_{14}, L_{15}: 1.91, 2.12 mg kg^{-1}), the Cu level @ 0.50 kg ha^{-1} i.e. 2.0 kg $CuSO_4$ ha^{-1} (+ NPK) showed a significant increase in grain and straw yields.

Conclusion: The present investigation was carried out with the objective of re-fixing the critical limit in wetland soils and accordingly the critical limit for DTPA - Cu in wetland soils and rice crops at the panicle initiation stage was re-fixed as 0.93 and 4.82 mg kg^{-1}, respectively. Based on this, it is possible that a graded dose of micronutrient fertilizers (Cu) may be prescribed to rice crops for the major rice-growing soils.

Keywords: Cate and Nelson; Copper; Critical limit; Rice crop.

1. INTRODUCTION

"Micronutrients are essential for plant growth and in the midst of six important micronutrients, the requirement of Cu is high for cereal crops viz., rice, wheat, and maize which are highly susceptible to the Cu deficiencies. Among those cereal crops, rice is the important food crop which is consumed by more than half of the world's population. The micronutrient deficiency is common in the Indian agricultural soils and that impacted on yield loss of rice. The Indian soils showed 43 and 5.4 percent of Zn and Cu deficiencies respectively, while in Tamil Nadu soils the deficiency being 65.5 and 13.0 percent for Zn and Cu, respectively" (Shukla *et al.,* 2014).

The deficiency of any nutrient can be accessed through the critical limit i.e., the critical limit is the boundary line that separates the deficiency and toxicity of nutrients. The critical level of any nutrient can be determined by following Cate and Nelson's graphical and statistical methods. In different states of India, varied critical limits for micronutrients are being followed and in Tamil Nadu, 1.2 mg kg^{-1} is being adopted as the critical limit of Cu in soils. In comparison with the critical limits of other states, the critical limit for zinc and copper in Tamil Nadu seems to be high and quite different than other parts of the country resulting in higher estimates of Cu deficiency in

Tamil Nadu state. Hence, there was a need to relook into this issue and refix the critical limit for micronutrients especially copper in soil and plant. In consideration of the above-mentioned things the present study entitled 'A study to refix the critical limit of copper in the major rice growing soils of Tamil Nadu, India' was carried out.

2. MATERIAL AND METHODS

The pot and field experiments form the basis of the present investigation; the experiment details and methodology adopted are described as follows,

2.1. Soil survey

The basic soil survey was undertaken for identifying the major rice growing tracts and identified the areas viz., Erode, Coimbatore, Tirunelveli and Tiruvarur districts of Tamil Nadu. In total, 286 soil samples (0-15 cm) were collected randomly from the above-mentioned districts as representing the major rice-growing tracts of Tamil Nadu. The farm holdings selected for conducting the study include various villages (fifteen locations) of Erode (Bhavanisagar, Sathyamangalam and Gopichettipalayam blocks), Coimbatore (Anamalai block), Tirunelveli (Ambasamoodaram block) and Tiruvarur (Thiruthuraipoondi block) districts.

2.2. Initial soil Cu status

The soil collected samples were processed and analyzed for DTPA extractable Cu. The soils were categorized into six different levels viz., ≤ 0.6, 0.6 – 0.9, 0.9 – 1.2, 1.2 – 1.5, 1.5 – 1.8 and ≥ 1.8 mg kg^{-1} based on the soil available Cu status. The initial soil characteristics of Cu experimental fields also varied from each location. The soils recorded neutral pH with a range from 6.50 to 7.85. The EC of the soils were free from salinity. The soils of various locations belong to different textural classes' viz., sandy loam, sandy clay loam, clay loam and clay. The bulk density and the particle density of the soils ranged from 1.10 to 1.58 Mg m^{-3} and 2.00 to 2.88 Mgm^{-3}, respectively.

The organic carbon ranged from 2.6 to 6.0 mg kg^{-1} which is of medium category. The available NPK status of the soils falls under low-medium, medium and medium categories respectively. The other nutrients viz., S, Fe, Mn and B falls on high category in all the locations whereas the Zn recorded in moderate category. The soil Cu content recorded in the experimental soils was with a range of 0.33 to 2.12 mg kg^{-1}.

2.3. Pot culture experiment

Five kilograms of soil that was collected from the respective farmer's field were weighed and placed in the pots. The pots were replicated four times with aCompletely Randomized Design in glass house condition. Two – three rice seeds (ASD 16) were sown per pot and 10 days after germination, one seedling was maintained in the pot. Recommended levels of NPK (150:50:50 kg ha^{-1}) were given uniformly in solution form to all the pots. Nitrogen was applied in four equal splits viz., basal, tillering, panicle initiation and heading stages. A full dose of phosphorus was applied as basal and potassium was applied in two splits as basal and at the panicle initiation stage. Graded levels of Cu viz., 0, 0.5, 1.0, 1.5, 2.0 and 2.5 kg ha^{-1} (0, 2.0, 4.0, 6.0 and 8.0 kg ha^{-1} of $CuSO_4$) were applied in solution form. The crop was raised up to the harvest stage and the plant samples were analyzed for total Cu.

2.4. Field experiments

In total, 15 field experiments were conducted in the farmer's holdings of Erode, Coimbatore, Tirunelveli and Tiruvarur districts with rice (ASD 16) as a test crop. In order to establish the critical limit of Cu in soils and to fix the optimum level of Cu for rice crop, the field experiments were conducted with graded levels of Cu application in farmer's fields. The treatment details are, T_1 – NPK (Cu control), T_2 – NPK + 0.5 kg Cu ha^{-1}, T_3 – NPK + 1.00 kg Cu ha^{-1}, T_4 – NPK + 1.50 kg Cu ha^{-1}, T_5 – NPK + 2.00 kg Cu ha^{-1} and T_6 NPK + 2.5 kg Cu ha-[1]. Randomized Block Design was imposed in the fields with six treatments and four replications with a plot size of 5m × 4m. The inter cultural operations and fertilizer applications were carried out as per the standard recommendations.

2.5. Fixation of critical limit

The critical limit of Cu was refixed by following the Cate and Nelson graphical and statistical methods. Cate and Nelson (1971) reported an iterative statistical procedure in order to separate the percentage of yield data into two or more classes based upon the maximization of the class sum of squares of the differences between the percentage yield means for the various classes and mean values.

3. RESULTS AND DISCUSSION

3.1. Grain yield and straw yield plant^{-1} at the harvest stage

3.1.1. Pot culture experiment (Fig. 1 and Fig. 2)

In the pot culture experiment, the grain and straw yields of rice crops got significantly increased with the application of different Cu levels in different locations. From the locations L1 to L9, where the soil Cu content was low to optimum, the yield (grain and straw) was significantly increased by the application of 100% NPK + 1.50 kg Cu ha^{-1} (T4) followed by that in the locations L10 to L13 where the soil Cu content was slightly higher, the application of 100% NPK + 1.00 kg Cu ha^{-1} (T3) significantly recorded the highest yield. In locations L14 and L15, where the soil Cu content was very high, the application of 100% NPK + 0.50 kg Cu ha^{-1} (T2) registered significantly higher yields. It is discerned that by increasing soil Cu content status, the amount of Cu application as fertilizers can be gradually decreased.

In location L6, the application of 100% NPK + 1.50 kg Cu ha^{-1} (T4) reported significantly the highest grain yield as 46.2 g plant^{-1}. Among fifteen locations, the L6 recorded the significantly highest mean grain yield as 39.0 g plant^{-1} whereas the application of 100% NPK + 1.50 kg Cu ha^{-1} (T4) recorded significantly the highest grain yield mean as 41.3 g plant^{-1} which is of 32.7 per cent increase over control. Similar results were recorded in the straw yield in which the highest straw yield of 53.4 g plant^{-1} was reported by the application of 100% NPK + 1.50 kg Cu ha^{-1} (T4) at the location L6. Among fifteen locations, the L6 recorded the significantly highest mean straw yield as 46.9 g plant^{-1} whereas the application of 100% NPK + 1.50 kg Cu ha^{-1} (T4) recorded significantly highest straw yield mean as 49.1 g plant^{-1} which is of 27.7 percent increase over control.

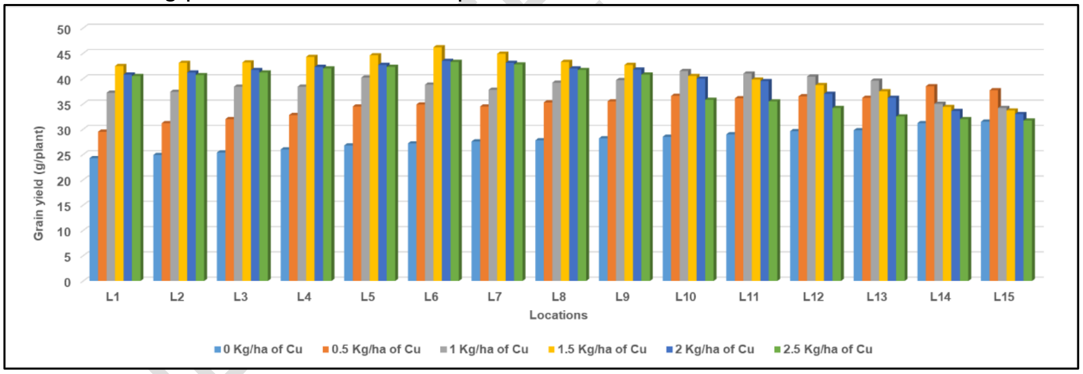

Fig 1. Effect of different doses of Cu (Kg/ha) on rice grain yield (g/plant) in pot culture experiment

The positive effect of Cu on the yield (grain and straw) of rice observed in the present study might be attributed to the enhancement of pollen viability, grain formation and grain filling by improving the enzymatic activities and the absorbed Cu increased the content of photosynthetic pigments in the plants resulting in the improvement of yield parameters of rice. The translocation of carbohydrates that have been produced in the leaves and stems into grains was a basic requirement for a higher grain filling rate and thus might have helped in increasing the grain yield. The increased straw yield was reported due to the effect of Cu on plant growth by enhancing crop root proliferation.

The increased root proliferation might have improved the nutrient uptake rate from soil and in turn, it enhanced the supply of nutrients to the aerial parts of the plants. The results were in line up with the findings of Khush and Peng (1996), Dobermann and Fairhust (2000), Xu *et al.* (2005), Alam *et al.* (2010), Liew *et al.* (2012) and Das (2014).

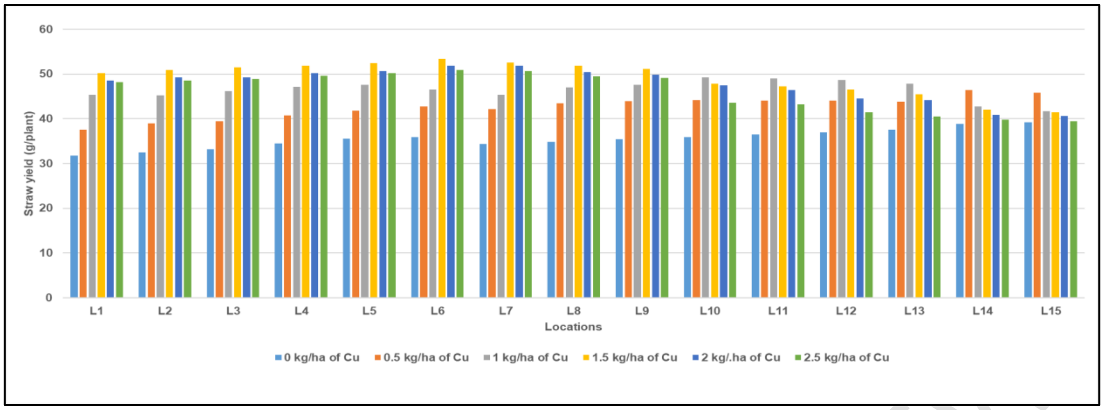

Fig 2. Effect of different doses of Cu (Kg/ha) on rice straw yield (g/plant) in pot culture experiment

3.1.2. Field experiments (Fig. 3 and Fig. 4)

In the field experiments, the application of different Cu levels in different locations significantly influenced the grain and straw yields of rice crop. From the locations L1 to L9, where the soil Cu content was low to optimum, the yield (grain and straw) was significantly increased by the application of 100% NPK + 1.50 kg Cu ha^{-1} (T4) followed by this in the locations L10 to L13 where the soil Cu content was slightly higher, the application of 100% NPK + 1.00 kg Cu ha^{-1} (T3) significantly recorded the highest yield. In the locations L14 and L15 where the soil Cu content was very high the application of 100% NPK + 0.50 kg Cu ha^{-1} (T2) registered a significantly higher yield. It is discerned that by increasing soil Cu content status, the amount of Cu application as fertilizers can be gradually decreased.

In location L6, the application of 100% NPK + 1.50 kg Cu ha^{-1} (T4) reported significantly the highest grain yield as 7.28 t ha^{-1}. Among fifteen locations, the L6 recorded the significantly the highest mean grain yield as 6.26 t ha^{-1} whereas the application of 100% NPK + 1.50 kg Cu ha^{-1} (T4) registered significantly the highest grain yield mean as 6.59 t ha^{-1} which is of 32.0 per cent increase over control. Similar results were found in the straw yield in which the highest straw yield of 8.48 t ha^{-1} was recorded by the application of 100% NPK + 1.50 kg Cu ha^{-1} (T4) at location L6. Among fifteen locations, the L6 reported the significantly highest mean straw yield as 7.47 t ha^{-1} whereas the application of 100% NPK + 1.50 kg Cu ha^{-1} (T4) recorded significantly highest straw yield mean as 7.84 t ha^{-1} which is 27.3 per cent increase over control.

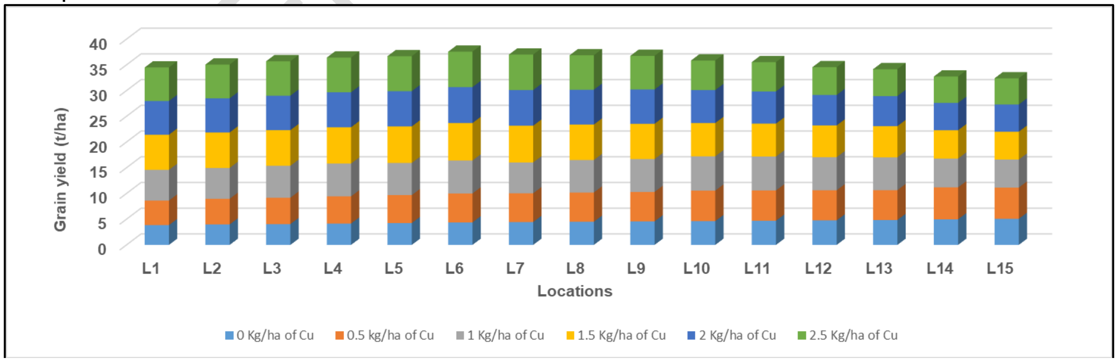

Fig 3. Effect of different doses of Cu (Kg/ha) on rice grain yield (t/ha) in field experiment

In the present study, the yield (grain and straw) of rice showed a positive effect by Cu application which might be attributed due to the enhancement of pollen viability, grain formation and grain filling by improving the enzymatic activities and the absorbed Cu increased the content of photosynthetic pigments in the plants resulting in the improvement of yield parameters of rice. The translocation of carbohydrates that have been produced in the leaves and stems into grains was a basic requirement for a higher grain filling rate thus helping to increase the grain yield. The increased straw yield found in our study may be due to the effect of Cu on plant growth by enhancing crop root proliferation. The increased root proliferation improved the nutrient uptake rate from the soil and in turn, it enhanced the supply of nutrients to the aerial parts of the plants. The results were in agreement with the findings of Khush and Peng (1996), Dobermann and Fairhust (2000), Xu *et al.* (2005), Alam *et al.* (2010), Liew *et al.* (2012) and Das (2014).

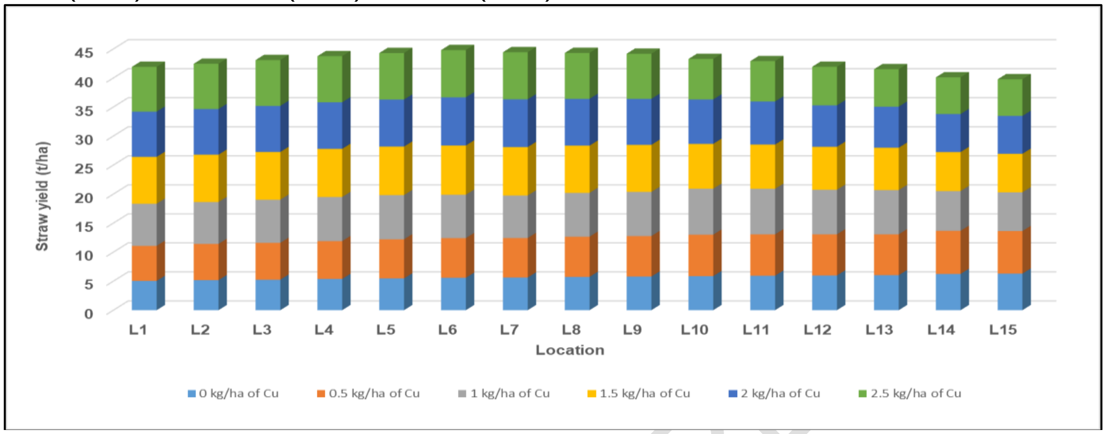

Fig 4. Effect of different doses of Cu (Kg/ha) on rice straw yield (t/ha) in field experiment

3.2. Soil Cu content at panicle initiation and harvest stages

3.2.1 Pot culture experiment

In the pot culture experiment, the available Cu content in soils at harvest stage was significantly influenced by the application of different levels of Cu in different locations. The higher Cu levels recorded the highest available Cu in the soils. The available Cu content in the soil was increased with the application of Cu treatments from T1 to T6 and the pooled mean shows that the treatment 100% NPK + 2.50 kg Cu ha^{-1} (T6) registered the highest Cu content in all the locations. From the locations L1 to L15 i.e., from lowest initial soil Cu content to highest soil Cu content, the soil Cu content at the harvest stage gradually increased based on its initial soil Cu content and quantity of Cu fertilizers applied.

At the harvest stage also the location L15 (soil with maximum initial soil Cu content) had the highest mean soil Cu content of 1.90 mg kg^{-1} and the application of 100% NPK + 2.50 kg Cu ha^{-1} (T6) recorded the highest mean soil Cu content as 1.16 mg kg^{-1} which is of 27.6 per cent increase over control. In our study, the application of Cu fertilizers to the soil, significantly increased the availability of DTPA-Cu in the soils and similar results were registered by Bowen (1969), Manchanda *et al.* (2006), Khush and Peng (1996), Dobermann and Fairhust (2000), Xu *et al.* (2005), Alam *et al.* (2010), Liew *et al.* (2012).

3.2.2. Field experiment

In field experiments, the available Cu content in soils at panicle initiation and harvest stage was significantly influenced by the application of different levels of Cu in different locations, as found in the pot experiment. The higher Cu levels recorded the highest available Cu in the soils. The available Cu content in the soil was increased with the application of Cu treatments from T1 to T6 and the pooled mean showed that the treatment 100% NPK + 2.50 kg Cu ha^{-1} (T6) registered the highest Cu content in all the locations. From the locations L1 to L15 i.e., from lowest initial soil Cu content to highest soil Cu content, the soil Cu content at the harvest stage gradually increased based on its initial soil Cu content and based on the quantity of Cu fertilizers applied.

At the harvest stage also the location L15 (soil with maximum initial soil Cu content) showed the highest mean soil Cu content of 2.02 mg kg^{-1} and the application of 100% NPK + 2.50 kg Cu ha^{-1} (T6) recorded the highest mean soil Cu content as 1.19 mg kg^{-1} which is of

22.7 per cent increase over control. The application of Cu fertilizers to the soil significantly increased the availability of DTPA-Cu in the soils in our study and similar results were registered by Bowen (1969), Manchanda *et al.* (2006), Khush and Peng (1996), Dobermann and Fairhust (2000), Xu *et al.* (2005), Alam *et al.* (2010), Liew *et al.* (2012).

3.3. Fixation of critical limit of Cu in soil and rice plant

An endeavor was made to refix the critical limit of Cu in soils and rice plant in both pot culture and field experiments.

3.3.1. Graphical method (Fig. 5)

"By adopting the Cate and Nelson graphical method, in the pot culture experiment, the critical limit Cu in soil and rice plants at PI was determined as 1.03 and 4.00 mg kg^{-1}, respectively. In the field experiments, the critical limit of Cu in soil and rice plant at PI was re-fixed as 1.04 and 4.88 mg kg^{-1}, respectively. It might be inferred that all the soils below these critical levels markedly responded to the Cu fertilizer application and a declining response was noted by the application of Cu fertilizers in the soils with higher Cu content (higher than the critical limit). In the earlier studies, the average Cu critical level was determined as 1.1 mg kg^{-1} for irrigated wheat in Iran and 0.87 mg kg^{-1} in Kurdistan province" (Sedri and Malakouti, 1998). Agarwal (1992) and Tandon (1995) reported that "the critical levels of Cu in wheat crops were recorded as 0.60 and 0.78 mg kg^{-1}, respectively in Indian soils". Sims and Johnson (1991) reported that "the critical level of crop plants ranged from 0.1 to 2.5 mg kg^{-1}. The major hostility against this method has been the human bias in drawing the lines, particularly the one parallel to the Y axis additionally, this approach appears subjective since it does not provide an adequate test of the goodness of fit of the data".

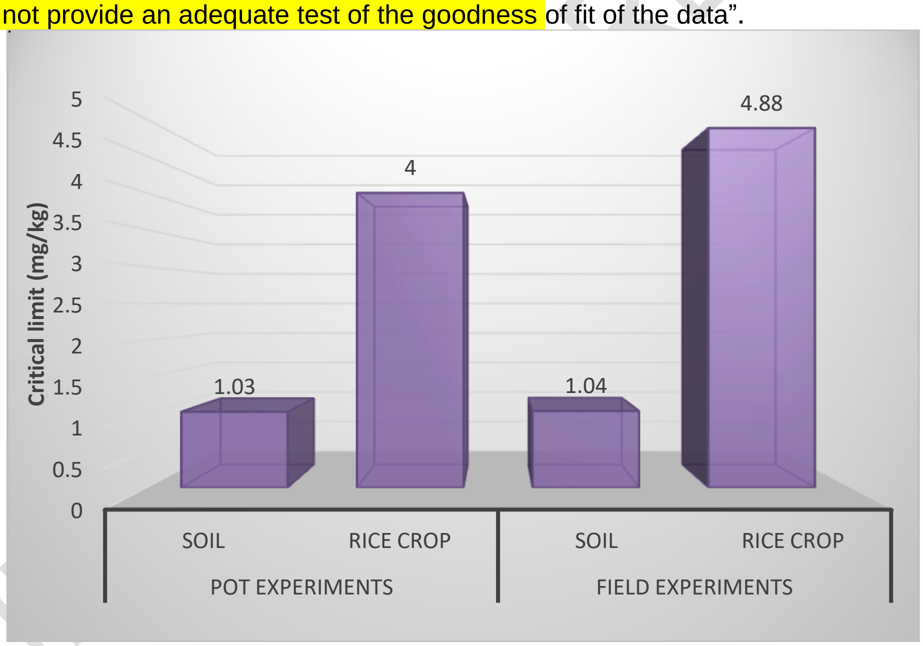

Fig 5. Critical limit of DTPA Cu in soil and total Cu in rice crop by Cate and Nelson graphical method

3.3.2. Statistical method – Analysis of variance method (Fig. 6) (Table 1 and 2)

The R^2 value of DTPA-Cu ranged in between 0.17 and 0.77 at pot culture experiments and 0.20 to 0.78 in field experiments. The postulated critical limit of DTPA-Cu corresponding to the highest R^2 may be fixed as the critical limit of Zn in the soil as 0.93 mg kg^{-1} in pot culture and field experiment. Similarly in the rice plant at PI, the R^2 value of total-Cu ranged from 0.14 to 0.86 at pot culture experiments and 0.16 to 0.85 in field experiments. The postulated critical limit of total-Cu corresponding to the highest R^2 may be fixed as the critical limit of Cu in rice at PI as 3.99 and 4.82 mg kg^{-1} in pot culture and field experiment respectively.

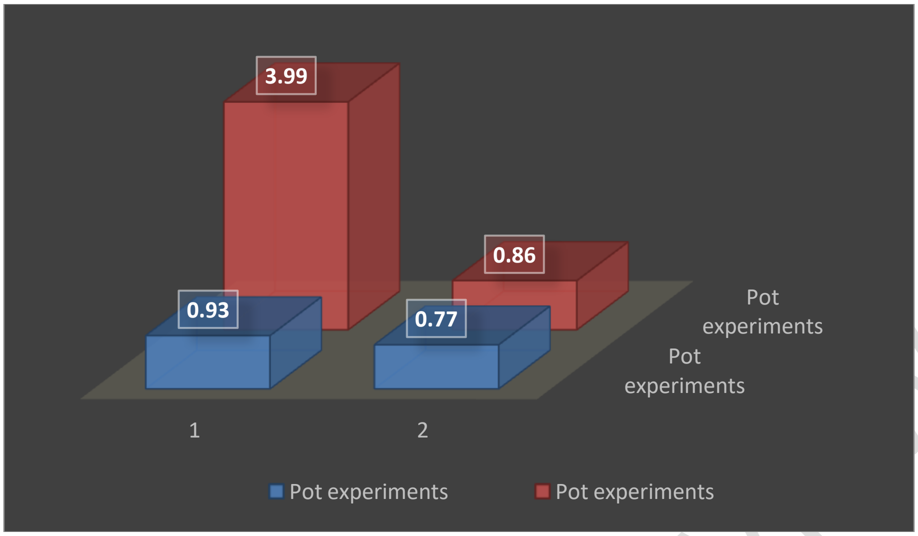

Fig 6. Critical limit of DTPA Cu in soil and total Cu in rice crop by Cate and Nelson statistical method (Pot culture experiment)

In previous research, various researchers used the Cate and Nelson method for fixing the critical limit. Accordingly, Sakal et al. (1982) recorded that the average Cu critical level was determined as 1.1 mg kg^{-1} for irrigated wheat in Iran and 0.87 mg kg^{-1} in Kurdistan province (Sedri and Malakout, 1998). Agarwal (1992) and Tandon (1995) reported that the critical levels of Cu in wheat crop were reported as 0.60 and 0.78 mg kg^{-1}, respectively in Indian soils. Sims and Johnson (1991) reported that the critical level of crop plants ranged from 0.1 to 2.5 mg kg^{-1}.

Table 1. Refixing the critical limit of DTPA Cu (mg/kg) in soil using Cate Nelson statistical method – Cu field experiments

Locations	Soil available Cu (mgkg^{-1})	*PCL	Bray's % yield	**CSS I	**CSS II	R^2
1	0.33	-	56.4	-	-	-
2	0.45	0.39	57.8	4.8	840.8	0.20
3	0.53	0.49	58.4	-0.6	732.9	0.31
4	0.63	0.58	59.0	1.9	623.7	0.41
5	0.74	0.69	59.9	11.8	519.2	0.50
6	0.84	0.79	60.2	10.6	396.9	0.61
7	0.90	0.87	62.3	25.5	286.8	0.70
8	0.92	0.91	65.4	54.9	220.8	0.74
9	0.95	**0.93**	66.7	91.5	141.0	**0.78**
10	1.28	1.12	69.3	160.2	90.2	0.76
11	1.33	1.31	71.2	246.9	62.4	0.71
12	1.57	1.45	74.1	367.4	26.4	0.63
13	1.61	1.59	75.9	519.2	8.7	0.50
14	1.91	-	80.2	-	-	-
15	2.12	-	83.5	-	-	-

*PCL – Postulated Critical Limit; **CSS – Class Sum of Square

Table 2. Refixing the critical limit of total Cu (mg/kg) in soil plant using Cate and Nelson statistical method – Cu field experiments

Locations	Plant Cu (mgkg^{-1})	*PCL	Bray's % yield	**CSS I	**CSS II	R^2

1	3.62	-	64.5	-	-	-
2	3.67	3.65	65.3	-4.9	552.6	0.16
3	3.73	3.70	65.9	-0.3	495.2	0.24
4	3.88	3.81	66.1	4.2	444.0	0.31
5	3.90	3.89	66.5	6.9	384.8	0.40
6	4.05	3.98	65.9	-3.6	301.2	0.54
7	4.65	4.35	67.2	10.9	226.2	0.63
8	4.78	4.72	68.4	6.0	150.0	0.76
9	4.85	**4.82**	69.7	16.7	77.9	**0.85**
10	5.29	5.07	73.8	72.5	51.1	0.81
11	5.35	5.32	75.5	130.6	29.7	0.75
12	5.40	5.38	77.8	218.1	15.5	0.64
13	5.45	5.43	79.1	308.8	8.3	0.51
14	5.52	5.49	82.4	-	-	-
15	5.58	-	84.6	-	-	-

*PCL – Postulated Critical Limit; **CSS – Class Sum of Square

4. CONCLUSION

The present study showed that, for rice under wetland conditions of Tamil Nadu the re-fixed critical limit of DTPA - Cu in the soil was 0.93 mg kg^{-1} and total–Cu in the plant at panicle initiation stage as 4.82 mg kg^{-1}. For the rice farmers, the findings of the present investigation underline the importance of complete soil testing for micronutrients along with macronutrients which will pave the way for the adoption of site-specific micronutrient management for rice. This research will help in augmenting rice productivity in Cu-deficient wetland soils of Tamil Nadu, India.

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