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RESPONSE OF FLOODED RICE GROWN ON A VERTISOL FROM NORTHERN NIGERIA TO ZINC SOURCES AND METHODS OF APPLICATION

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SUMMARY

Greenhouse and laboratory studies were conducted to study the effect of zinc sources and methods of application on correcting zinc deficiency in flooded rice grown on Vertisol from Ngala, northern Nigeria, using the variety IR-20.

Plant dry matter yield was similar for $ZnSO_4$, ZnEDTA, metallic Zn and fritted Zn with mixed soil application. Zinc uptake was affected in the following order; $ZnSO_4$ > ZnEDTA > metallic Zn > fritted Zn. Comparable dry matter yield and zinc uptake were obtained with mixing, surface broadcasting and banding of ZnEDTA. Mixing the fritted Zn gave higher dry matter yield and zinc uptake than broadcasting or banding.

Seed soaking with a suspension of fritted Zn resulted in higher dry matter yield and zinc uptake than with ZnEDTA solution. Seed soaking for 24 hours with fritted Zn suspension at a concentration of about 0.5 per cent Zn appeared to be a suitable method for applying zinc with direct seeded rice.

INTRODUCTION

Field deficiency of zinc in flooded rice has been reported in several rice growing areas in Asia [6]. More recently responses to zinc have also been observed in the principal rice growing areas in the United States [3 5 7]. The zinc deficiency problems are associated with alkaline or calcareous soils, the use of improved varieties and high fertilizer rates [3 5 6 8]. In Northern Nigeria zinc deficiency in flooded rice grown on a Vertisol was observed by the senior author in 1972 in the South Chad Irrigation Pilot Project Area at Ngala.

For correcting zinc deficiency in flooded rice, several zinc sources and methods of applications have been tested [2 5 7 9]. Sedberry *et al.*[5] obtained higher rice yields with ZnO than with $ZnCl_2$, $ZnSO_4$

or ZnEDTA, although the yield differences among the sources were not significant. A greenhouse study by Giordano and Morvedt[2] showed no differences between ZnO, $ZnSO_4$ and ZnEDTA in terms of dry matter production of the rice plant. The zinc uptake was, however, affected by the sources in the following order; ZnO > $ZnSO_4$ > ZnEDTA. According to Yoshida *et al.*[9], $ZnSO_4$ applied to the soil or as foliar application was as effective as dipping the seedlings in a ZnO suspension for correcting zinc deficiency, although, dipping the seedlings was considered as the most practical method. Giordano and Morvedt[1] observed in potted rice plants that dry matter production and zinc uptake were comparable for mixed or surface applied $ZnSO_4$, while placement at 8 cm below the surface was less effective.

This study was to test the effects of various zinc sources and methods of zinc application for correcting zinc deficiency in flooded rice grown on a Vertisol from northern Nigeria.

MATERIALS AND METHODS

The soil used in all the experiments is a Vertisol collected from zinc deficient rice plots at the South Chad Irrigation Pilot Project area, Ngala, North-eastern State, Nigeria. The soil has the following characteristics: clay texture; predominant clay mineral montmorillonite, pH in 1: 1 soil/water ratio, 6.7; organic C, 0.86%; CEC, 34.84 me/100 g; N, 0.06%; available P (Bray I) 4.0 ppm; 0.1*N* HCl extractable Zn, 1.40 ppm. Soil was used at 750 g per pot and fertilized with 100 ppm N (ammonium orthophosphate + urea), 100 ppm P (ammonium orthophosphate), 50 ppm K(KH_2SO_4) and 5 ppm Fe($FeSO_4$) in experiments 1, 2 and 3.

Experiment 1. Study on zinc sources

The experiment was a randomized complete-block design with three replications. Four zinc sources, $ZnSO_4$, Na_2ZnEDTA (14.6% Zn) metallic Zn (powder) and fritted Zn (40% Zn) were tested each at 2, 4, 6 and 8 ppm Zn levels. A no-Zinc treatment was added. The zinc sources and other nutrients were mixed with the soil before planting. Six five-day-old seedlings of IR-20 were planted per pot. Four weeks after transplanting the plants were harvested, dried at 65°C and analyzed for zinc contents after wet digestion with HNO_3—$HClO_4$. Zinc was measured using a Perkin Elmer atomic absorption spectrometer model 403.

Experiment 2. Study on placement method

The experiment was carried out in a randomized complete block design

with three replications. Zinc was applied at a rate of 2 ppm Zn in the form of ZnEDTA and fritted Zn. The sources were applied as follows:
(1) mixed with entire soil,
(2) broadcast at soil surface, and
(3) applied in a band at soil surface.

Twelve seeds of IR-20 were planted per pot. The number of plants were reduced to six plants per pot at two weeks after planting. Four weeks after planting the remaining plants were harvested. Plants harvested at two and four weeks were dried at 65°C, weighed and analyzed for zinc content after wet digestion with HNO_3-HClO_4.

Experiment 3. Study on seed soaking

The experiment was set up in a randomized complete block design with three replications. Seeds of IR-20 were soaked for 24 hours with the following concentrations of ZnEDTA and fritted Zn; 0, 0.1, 0.5, 1.0, 5.0 and 10.0% Zn. After soaking, 10 seeds were planted per pot, the number of plants was reduced to six plants per pot at one week after planting. Height measurements were taken at 6, 8 and 21 days after planting. Plants were harvested at four weeks after planting, dried at 65°C, weighed and analyzed for zinc content after wet digestion with HNO_3-HClO_4. The amounts of zinc retained by the seeds and absorbed by the husked rice grain were determined. Lots of 20 of the soaked seeds were extracted with 10 ml of 0.1 N HCl, shaken for 30 minutes and the amount of zinc in the extract determined. This is designated as the amount of zinc adhering to the seeds. After extraction, the seeds were washed several times with distilled water, dried and husked and the zinc content in the rice grain determined after wet digestion with HNO_3-HClO_4.

Experiment 4. Study on zinc mobility

This experiment measured the mobility of zinc from ZnEDTA and fritted Zn in the Vertisol under flooded conditions. Sieved soil ($<$ 2 mm size) was evenly packed in thin mylar plastic tubes with a diameter of 5.5 cm and a length of 12 cm. Each treatment was run in duplicate. The soil was flooded for one week before adding the zinc sources. Zinc was applied at the soil surface at a rate of 30 mg zinc per tube and carefully mixed with the first few mm of the soil surface. The tubes were then incubated for 15 days under flooded condition. After incubation the tubes were allowed to dry for three days, and cut into 1-cm sections. The zinc content of the various soil sections was determined in the soil extract obtained by shaking 10 g soil, in 50 ml of 1N HCl for 30 minutes.

RESULTS

Experiment 1

With no zinc application, the plants were slightly chlorotic, stunted and showed brown streaks on the lower leaves, typical symp-

TABLE 1

Effect of zinc rates and zinc sources on dry matter yield and zinc uptake by rice variety IR-20

Zn source	Zn rate ppm	Dry matter yield g/pot	Zn content ppm	Zn uptake ug/pot
Control	0	0.79	13.0	10.5
$ZnSO_4$	2	2.49	37.8	94.1
	4	2.18	39.4	85.8
	6	2.07	49.4	102.1
	8	2.09	61.8	129.4
	Mean	2.21		102.9
ZnEDTA	2	2.00	38.4	76.8
	4	2.15	41.3	88.9
	6	2.03	48.4	89.1
	8	2.44	51.1	124.7
	Mean	2.18		97.1
Fritted Zn	2	1.89	23.1	43.7
	4	2.25	26.0	58.6
	6	2.45	30.6	68.3
	8	2.14	39.7	84.9
	Mean	2.13		63.9
Metallic Zn	2	2.06	26.1	53.8
	4	2.24	35.4	79.3
	6	2.24	46.2	113.2
	8	1.96	45.9	90.1
	Mean	2.18		84.1
CV (%)		12.23	9.49	13.05
LSD 0.01		0.24	3.45	10.16

toms of zinc deficiency. As seen in Table 1 there was a highly significant increase in dry matter production of the rice plants with zinc application, although the response was limited to a rate of 2 ppm Zn. The dry matter yield showed no significant differences between the various zinc sources, indicating that the zinc sources were equally effective. The zinc content and zinc uptake increased with increased rate of zinc application. Comparing the four zinc sources, the amount of zinc uptake is in the following order: $ZnSO_4 > ZnEDTA < \text{metallic Zn} < \text{fritted Zn}$. These results indicate that the zinc from the water soluble sources, $ZnSO_4$ and ZnEDTA, is more available for the plant than from the two non-soluble sources.

TABLE 2

Effect of zinc sources and placement method on dry matter yield and zinc uptake by 2 and 4 weeks old seedlings of rice variety IR-20

Zn source	Placement method	Dry matter yield		Zn content		Zn uptake	
		2 wks	4 wks	2 wks	4 wks	2 wks	4 wks
		g/pot		ppm		µg/pot	
Control	–	0.32	0.96	13.1	12.8	4.2	12.2
ZnEDTA	Banded	0.34	2.21	35.0	46.1	13.4	101.9
	Broadcast	0.32	2.15	33.6	44.4	10.7	95.7
	Mixed	0.34	2.13	39.8	54.5	13.5	116.2
Fritted Zn	Banded	0.32	1.41	12.6	24.7	4.1	34.7
	Broadcast	0.30	1.96	18.7	29.0	5.6	56.8
	Mixed	0.33	2.18	23.8	39.5	8.1	85.8
CV (%)		10.51	10.73	10.97	4.38	12.58	9.57
LSD 0.01		0.08	0.51	7.0	3.9	2.7	17.5

Experiment 2

Although at two weeks after planting the effect of zinc application on dry matter yield was not noticeable, the dry matter yield showed a highly significant increase at four weeks after planting (Table 2). With ZnEDTA there were no differences in dry matter yield among the three placement methods. However, with fritted Zn mixing the fertilizer was better than broadcasting or banding. The results also indicated that fritted Zn was equally effective as ZnEDTA when mixed with the soil.

Despite the insignificant effect of zinc application on dry matter yield at two weeks after planting, the zinc content and uptake on the contrary showed significant increases with zinc application. Placement method did not show any significant effect on zinc content and zinc uptake with ZnEDTA, although, at four weeks after planting mixing apparently resulted in higher zinc uptake by the plants. With fritted Zn the zinc content and uptake showed significant differences resulting from the placement method in the following order: mixed > broadcasted > banded. Banding was the least effective. At two weeks after planting there was hardly any zinc uptake from band applied fritted Zn. Comparing the two zinc sources, similar to the results of the first experiment, the zinc uptake from ZnEDTA was much higher than from fritted Zn with all the three placement methods.

TABLE 3

Amount of Zinc attached to rice seeds and Zinc content of husked rice grains after 24 hours soaking with various concentrations of ZnEDTA and fritted Zn

Solution or suspension concentration % Zn	Amount Zn attached to seeds*		Zn content of grain, ppm	
	ZnEDTA	Fritted Zn	ZnEDTA	Fritted Zn
0 (control)	0.00	0.00	12.6	12.6
0.1	0.05	0.12	54.6	29.2
0.5	0.19	1.00	76.8	41.6
1.0	0.35	1.15	197.3	45.5
5.0	0.88	29.42	203.4	44.8
10.0	1.86	44.75	191.5	56.1

* mg Zn/10 seeds

Experiment 3

With seed soaking a substantial amount of zinc was found to be attached to the seeds (Table 3). The amount of zinc attached to the seeds increased with increased concentration of the soaking solution or suspension. Since, fritted Zn is insoluble and in suspension it adhered better to the seeds than the soluble ZnEDTA. Because of its high solubility, more of the zinc from ZnEDTA diffused through the husk during the soaking exercise and was absorbed by the rice grains as demonstrated by the higher zinc content of the rice grains after soaking with the various concentrations of ZnEDTA. The amount of zinc absorbed by the rice grains also increased with increasing concentration of the soaking solution. The amount of zinc absorbed by the rice grains from fritted Zn was less than from ZnEDTA and only showed a small increase with increasing zinc concentration in the suspension.

Soaking the seeds with ZnEDTA at concentrations above 0.1 per cent Zn delayed germination and depressed the early growth of the rice plants as is seen from the height measurements (Figure 1). Soaking with fritted Zn did not affect germination at lower concentrations. At concentrations of 1.0% Zn and above it caused a slight retardation in the early plant growth. There was an improvement in growth with the 0.1 per cent and 0.5 per cent Zn concentrations.

The plants were able to overcome the early harmful effects of seed soaking with high zinc concentrations as seen by the significant improvement in plant growth at 21 days after planting with both the

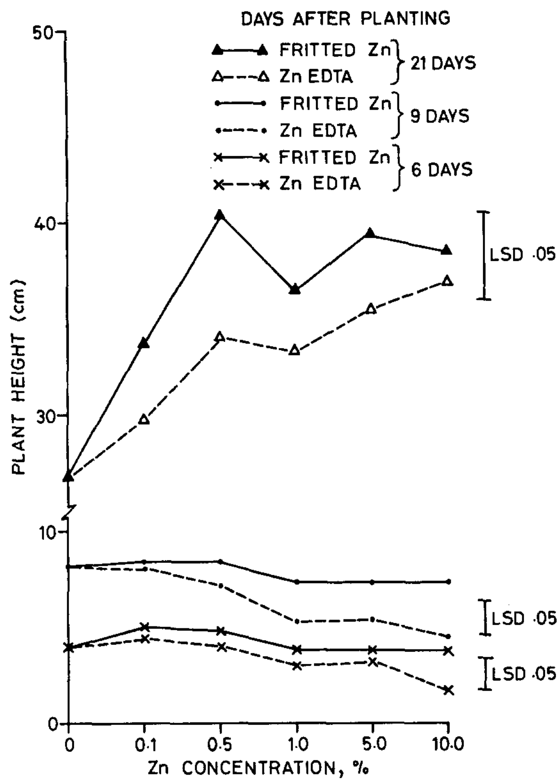

Fig. 1. Effect of seed soaking with various zinc concentrations on plant height.

zinc sources (Figure 1). The growth of the rice plants was better with fritted Zn than with ZnEDTA at the various soaking concentrations. There was no significant improvement in plant height with fritted Zn at concentrations above 0.5 per cent Zn in the suspension. However, with ZnEDTA the plant height increased with increased concentration of the zinc in the soaking solution up to 10 per cent Zn.

Soaking the seeds with the various zinc concentrations also increased the plant dry matter yield over the no Zn treatment (Table 4). With fritted Zn, soaking with 0.5 per cent Zn suspension gave the highest dry matter yield, and the yield appeared to decline at higher zinc concentrations. With ZnEDTA the highest dry matter yield was obtained with 1.0 per cent Zn solution, and a higher zinc con-

TABLE 4

Effect of 24 hours soaking of rice seeds with various concentrations of ZnEDTA and fritted Zn on dry matter yield and zinc uptake of rice variety IR-20

Zn source	Solution or suspension concentration % Zn	Dry matter yield g/pot	Zn content ppm	Zn uptake μg/pot
Control	0	0.88	11.3	9.9
ZnEDTA	0.1	1.32	17.3	22.9
	0.5	1.69	13.3	23.0
	1.0	2.03	21.3	43.2
	5.0	1.66	20.7	36.5
	10.0	1.74	27.3	47.7
Fritted Zn	0.1	1.60	14.0	22.1
	0.5	2.38	18.0	42.7
	1.0	1.88	21.3	40.3
	5.0	2.22	24.7	54.8
	10.0	1.89	33.3	63.4
CV (%)		10.8	12.1	18.9
LSD 0.01		0.32	5.7	16.3

centration appeared to decrease the dry matter weight. Seed soaking with fritted Zn also resulted in higher dry matter yield than with ZnEDTA. The zinc content of the plants and zinc uptake also increased with increased zinc concentration in the soaking solution or suspension with both sources although the uptake was more with fritted Zn.

Experiment 4

The data on the zinc movement during incubation under flooded conditions as shown in Table 5, indicated a greater amount of movement of the zinc from ZnEDTA than from fritted Zn. Despite the relatively slow downward movement of the zinc in this Vertisol, the data also indicated that within the 15-day incubation period some of the zinc from the ZnEDTA had moved to a depth of 10 cm. During the same period with fritted Zn, all of the applied zinc was still confined in the 0–1 cm layer. The slightly higher zinc content in the 0–1 cm layer of the control treatment, might be due to contamination.

TABLE 5

Effect of surface broadcast application of ZnEDTA and fritted Zn on the 1*N* HCl extractable zinc content (ppm) at various soil depths of a vertisol from Ngala after 15 days incubation under flooded conditions

Sampling depth mm	Control	ZnEDTA	Fritted Zn
0–10	3.8	336.8	570.5
10–20	2.7	108.9	2.9
20–30	3.1	67.3	2.9
30–40	2.9	63.5	2.9
40–50	3.2	36.3	2.9
50–60	2.8	16.8	2.8
60–70	3.1	7.8	2.3
70–80	2.9	3.5	2.9
80–90	3.1	3.4	2.9
90–100	2.9	3.2	2.4

DISCUSSION

The plant dry weight response, clearly indicates that the Vertisol from Ngala is deficient in zinc for flooded rice. This was also substantiated by the low zinc level in the control plants, which ranges from 11.3 to 13.1 ppm Zn. These levels are comparable to the critical values reported by Yoshida and Tanaka [6] for zinc deficient rice plants.

For correcting the zinc deficiency on this soil $ZnSO_4$, ZnEDTA, fritted Zn and metallic Zn were equally effective if mixed with the soil (Table 1). Depending on the solubility of the zinc source, the effectiveness was affected by the placement method (Table 2). Despite the relatively low mobility of the zinc in this soil, data from the incubation experiment (Table 5) shows a substantial downward movement of the Zn only from the highly soluble ZnEDTA, while there is hardly any movement of the Zn from the fritted Zn during a two-week incubation period. Giordano and Morvedt [1] working with a Nolichuky silt loam under flooded conditions also observed a greater movement of the zinc from ZnEDTA as compared to ZnO of $ZnSO_4$. The much greater movement of the zinc from ZnEDTA, also increases the possibility of the Zn being intercepted by the plant roots. This resulted in the insignificant effect of placement on the effectiveness of this source. On the contrary with fritted Zn, which showed little movement of the zinc, the effectiveness is largely decreased by banding or broadcasting at the soil surface and mixing is necessary inorder to increase the possibility of contact between the plant roots and fertilizer.

Although Yoshida *et al.*[9] considered dipping the rice seedlings in ZnO suspension as the most practical method for correcting Zn deficiency, this method is only limited for transplanted rice. However, for most of West Africa where availability of labor is a problem, rice is mostly planted by direct seeding. Under this condition applying the Zn source with the seed at planting will be most practical. Murphy and Walsh [4] reviewed the literature on the effectiveness of seed treatment with zinc solution or zinc powders for correcting zinc deficiency and concluded that this method of zinc application was not successful in preventing zinc deficiency in various upland crops. Giordano and Mortvedt [2] observed no adverse effect of coating the rice seeds with low rates of $ZnSO_4$ and reported that this method of Zn application was equally effective as mixing the $ZnSO_4$ with the soil or applying to the water at planting time for flooded rice. The results of the seed-soaking trial (Figure 1) also showed no adverse effect of soaking with low Zn concentrations on the seed germination. The adverse effect of high zinc concentrations, particularly with ZnEDTA in the early growth of the rice plants as shown in Figure 1, might be due to the high amount of zinc that was absorbed by the rice grain from the soaking solutions (Table 3). In the case of fritted Zn, where the zinc absorption by the rice grain was less, the adverse effect of soaking with high concentrations of the suspension was hardly noticeable. Soaking with fritted Zn has the additional advantage that a substantial quantity of the material adhered to the outside of the seeds (Table 3). Because the amount of zinc absorbed by the rice grain only will be inadequate to supply the zinc need of the plants, the amount adhering to the seeds will be important and can be subsequently utilized by the plants during later growth. For direct seeded rice, where pre-soaking of the seeds in water is practiced, soaking with fritted Zn suspension can be recommended in areas with zinc problems. The results, shown in Table 4, indicate that a 24-hour soaking with a suspension of 0.5% Zn as fritted Zn appears adequate to supply the early need of the plants.

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