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Response of Several Rice Cultivars to Zn[1]

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ABSTRACT

Differential response to Zn of several plant genotypes other than rice (*Oryza sativa* L) has been shown by others This study was conducted to compare the response to Zn of several foreign and domestic rice cultivars grown under varying fertility and water management conditions in greenhouse pot culture

Reduction in dry matter yields due to Zn deficiency in the several rice cultivars was in the order 'Bluebelle' > 'Bluebonnet 50' > 'Dawn' > 'Nato' > 'Calrose' The very early maturing variety Bluebelle was less tolerant to low levels of available Zn than the later maturing cultivars, especially Calrose Differences existed among cultivars with respect to Zn and P uptake, but could not be related to degree of Zn responsiveness Adaptation to upland soil conditions differed among cultivars although both growth and Zn uptake were always higher under flooded conditions The cultivar 'Sinaloa' from the Dominican Republic responded well to upland conditions whereas Calrose grew poorly 'Juma,' 'Bluebelle,' 'Star bonnet,' and 'Chontalpa' were intermediate

Additional index words Zn deficiency, Upland soil, Flooded soil, P availability

IN recent years the differential response of various genotypes of corn (*Zea mays* L) and navy beans (*Phaseolus vulgaris* L) to Zn has been demonstrated (3, 4, 9, 10) Although workers in Arkansas have observed since 1910 that certain cultivars of rice (*Oryza sativa* L) vary in tolerance to alkaline soils (8), only recently has this problem been associated at least in part to Zn deficiency Varietal differences in growth of rice under moderate Zn deficiency conditions have been reported in the Philippines (6)

Over 729,000 hectares (1 8 million acres) of rice was grown in the United States in 1972 (1, 2) Approximately 50% of this hectarage was planted to long grain cultivars, 40% to medium grain, and the remainder to short grain cultivars Because these broad classifications encompass a rather large number of cultivars, their individual tolerance to conditions of low Zn supply as well as their response to applied Zn is of interest This study was undertaken to determine the differential response to Zn of several foreign and domestic rice cultivars An attempt was made to relate certain varietal characteristics and growth parameters to degree of responsiveness

MATERIALS AND METHODS

Experiment 1 The objective of this experiment was to determine if P nutrition is related to differential response of rice cultivars to Zn Nolichucky scl was limed to pH 8 0 with a 2 1 $CaCO_3$ $MgCO_3$ mixture at a rate of 25 g/2.5 kg of soil in each pot This soil is a typic paleudult with a cation exchange capacity of 6 7 meq/100 g, 2 7% organic matter and 2 7 ppm of 0 1 *N* HCl extractable Zn Urea and K_2SO_4 were applied to supply 450 mg of N and 150 mg of K per pot Concentrated superphosphate (CSP) at rates of 60 and 600 mg of P per pot and finely ground ZnO at 0 5, and 50 mg of Zn per pot (0, 2, and 20 ppm) were mixed with the soil Six 21 day old seedlings each of Nato Dawn Bluebelle Bluebonnet 50 or Calrose per pot were transplanted to a series of treated pots The rice was subsequently flooded and harvested during the early heading stage after 95 days of growth Dry matter production and uptake of Zn and P were determined from triplicates of each treatment after harvest

Experiment 2 This experiment was conducted to determine the response to Zn of several cultivars differing in growth duration (days from seeding to maturity) Crowley sil a typic albaquult obtained from a rice field in Louisiana with a history of Zn deficiency was limed to pH 7 5 with $CaCO_3$ and $MgCO_3$ and fertilized with N and K as described in Experiment 1 Concentrated superphosphate at a rate of 500 mg of P and ZnO at rates of 0 2 5 and 10 mg (0 1 and 4 ppm) of Zn were mixed with 2 5 kg of soil in each pot Seeds of each cultivar (Table 2)

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were planted in moist soil prior to flooding when the seedlings were 2 to 3 cm tall Flooding was continuous until harvest at maturity Dry matter production and uptake of Zn and P were determined on triplicate treatments Germination tests were run on the seed harvested from each cultivar Twenty seeds composited from all three replicates were placed on moist filter paper in Petri dishes After 5 days the percentage germination was determined

Experiment 3 Several cultivars grown under flooded or upland soil conditions were compared for response to Zn Crowley sil was limed to pH 7.5 as in Experiment 2 Concentrated superphosphate at a rate of 500 mg of P and K_2SO_4 at 200 mg of K were mixed with 2.5 kg of soil in each pot Initially urea was added at a rate of 600 mg of N per pot An additional 200 mg/pot of N as urea solution was applied to the soil surface or the flood water at 8 and 10 weeks after planting ZnO was mixed with the soil at rates of 0 2.5 and 10 mg/pot of Zn (0 1 and 4 ppm) Several of the test cultivars from Mexico and the Dominican Republic are also under investigation in Puerto Rico for adaptation to upland culture Those cultivars showing promise in Puerto Rico are Juma Chontalpa Sinaloa and Starbonnet The latter is also grown extensively in the south central United States under paddy conditions In addition two domestic cultivars Bluebelle (Texas) and Calrose (California) were included for comparison Each cultivar (Table 5) was direct seeded and harvested approximately at panicle initiation During the growth period the soil was maintained at about 0 3 atm (moist) or flooded to a level of 3 cm above the soil surface Dry matter yields and uptake of Zn Mn and Fe were determined in triplicate treatments at harvest

RESULTS AND DISCUSSION

Experiment 1

Visual symptoms of Zn deficiency (bronzing) were evident among all 0 Zn treatments with the exception of Nato and Calrose This condition was most severe at the 600-mg P rate Reduction in dry matter yields due to Zn deficiency in the several rice cultivars was in the order Bluebelle > Bluebonnet 50 > Dawn > Nato > Calrose (Table 1) Except for Calrose, yield decreases were significantly greater with the high than the low rate of P without applied Zn Dry matter production was not increased significantly by Zn rates

Table 1 Response of several rice cultivars to applied P and Zn, Experiment 1

Cultivar	P applied	Zn applied	Dry matter yields	Concentration P	Concentration Zn
	mg/pot	mg/pot	g/pot	%	ppm
Bluebelle	60	0	33 b	20 b	20 ab
		5	43 c	16 a	22 ab
		50	46 cd	16 a	40 c
	600	0	18 a	27 c	18 a
		5	46 cd	21 b	24 b
		50	48 d	21 b	45 d
Bluebonnet 50	60	0	36 b	18 ab	18 ab
		5	42 c	16 a	22 bc
		50	42 c	16 a	34 d
	600	0	24 a	23 c	17 a
		5	41 c	19 b	23 c
		50	40 c	20 b	31 d
Dawn	60	0	46 b	16 a	17 a
		5	53 c	16 a	27 b
		50	51 c	15 a	42 d
	600	0	36 a	22 c	16 a
		5	52 c	19 b	23 b
		50	51 c	20 bc	6 c
Nato	60	0	48 b	16 a	17 a
		5	49 g	16 a	24 b
		50	47	16 a	35 d
	600	0	[illegible]	23 c	17 a
		5	b	20 b	22 b
		50	50 b	18 ab	30 c
Calrose	60	0	53 ab	15 ab	13 a
		5	55 b	15 ab	30 b
		51	56 b	13 a	32 c
	600	0	50 a	18 c	1 a
		5	55 b	1 c	20 b
		50	56 b	19	29

Values followed by the same letter are not different at the 5 level as determined by the Duncan Multiple Range Test Comparisons must be made within cultivars only

greater than 5 mg/pot even at the high P rate Apparently 60 mg/pot of P was adequate for maximum growth of rice on this soil under flooded conditions This may be attributed to greater solubility of native P under reduced soil conditions created by flooding (F N Ponnamperuma, 1955 The chemistry of submerged soils in relation to the growth and yield of rice Ph D Thesis Cornell University, Ithaca, New York)

Although the Zn concentration in Bluebelle (the most Zn responsive cultivar) was higher than that in Calrose (the least Zn responsive cultivar), total uptake was not appreciably different Dawn, Bluebonnet 50, and Nato had similar Zn concentrations where Zn was not applied, but Zn concentrations in Dawn were higher at the 50 mg Zn rate Maximum dry matter production resulted in tissue Zn concentrations between 20 and 25 ppm

The higher P application rate resulted in increased P uptake, but dry matter production was not increased In addition there was no consistent depressing effect on Zn uptake at the high P application rates with these cultivars Analyses of seed of all cultivars for P and Zn or P Zn ratios showed no relationship to Zn responsiveness (data not shown)

Uptake of Fe and Mn was similar among all cultivars and was not influenced by rates of applied Zn and P (data not shown) There was no indication that increased Zn concentration in the plants reduced the concentration of either Fe or Mn as reported by others (10)

Experiment 2

Bronzing occurred without applied Zn on all cultivars except Calrose and IR 8 All the cultivars responded to applied Zn but in varying degrees (Table 2) With certain cultivars grain yield increases in response to applied Zn were proportionately greater than straw yield increases (e g, Bluebelle), whereas the opposite occurred with other cultivars (e g, 'Arkrose' and Bluebonnet 50) The 2 5 mg Zn rate was usually sufficient for maximum grain yields, maximum straw yields were noted at either the 2 5 or 10 mg Zn rate with these cultivars

In general, uptake of Zn by straw increased with Zn rate, whereas Zn accumulation in grain increased with Zn rate only in the two most responsive cultivars —Bluebelle and 'Nova 66' The concentration of Zn in the harvested grain of all cultivars, even with the 0 Zn rate, was much higher than that in the corresponding seed from which the crop was grown No source of contamination was found, however, which could account for this difference

Concentration of P was much greater in grain than in straw In neither case did rate of applied Zn affect P uptake There was some variation in P uptake among the cultivars, but this was not related to Zn responsiveness Values for P Zn ratios were much lower in straw and grain, compared to those in the immature plants of Experiment 1 Thus, uptake of Zn increased greatly during the reproductive stage, where as P apparently translocated at that time from the vegetative portions of the plant to the grain The trend among most cultivars was for the P Zn ratio to decrease in straw and increase in grain with rate of

Table 2 Yield and concentration of Zn and P by straw and grain of several rice cultivars in response to applied Zn, Experiment 2

Cultivar	Zn applied	Dry matter		Concentration			
				Zn		P	
		straw	grain	straw	grain	straw	grain
	mg/pot	g/pot		ppm		%	
Belle Patna	0	39 a	26 a	23 a	125 b	07 a	30 a
	2 5	43 ab	29 a	28 b	91 a	07 a	27 a
	10 0	46 b	30 a	31 b	95 a	07 a	27 a
Saturn	0	40 a	29 a	16 a	76 a	05 a	31 a
	2 5	51 b	34 b	20 a	67 a	06 a	31 a
	10 0	53 b	34 b	26 b	66 a	05 a	30 a
Bluebelle	0	34 a	8 a	17 a	92 a	10 a	29 a
	2 5	37 ab	30 b	31 b	83 a	09 a	29 a
	10 0	42 b	33 b	38 c	99 b	08 a	28 a
Nova 66	0	41 a	29 a	19 a	67 a	07 a	29 b
	2.5	55 b	36 b	24 b	66 a	08 a	28 b
	10 0	56 b	35 b	33 c	100 b	06 a	23 a
Calrose	0	47 a	32 a	19 a	56 a	10 a	30 a
	2 5	47 a	32 a	30 b	66 a	13 a	31 a
	10 0	50 a	31 a	32 b	51 a	10 a	27 a
Caloro	0	37 a	22 a	17 a	60 a	05 a	26 a
	2.5	43 ab	29 b	20 ab	57 a	07 a	26 a
	10 0	49 b	28 b	24 b	46 a	08 a	27 a
Dawn	0	51 a	21 a	23 a	89 a	10 a	25 a
	2 5	52 a	24 ab	30 b	83 a	11 a	24 a
	10 0	53 a	26 b	35 c	77 a	10 a	27 a
Nato	0	41 a	15 a	21 a	69 a	08 a	37 a
	2.5	54 b	20 b	24 a	59 a	11 a	34 a
	10 0	50 b	20 b	32 b	54 a	11 a	38 a
Arkrose	0	37 a	25 a	23 a	65 a	06 a	26 a
	2 5	47 b	26 a	25 a	46 a	09 a	30 a
	10 0	47 b	28 a	33 b	44 a	08 a	27 a
Starbonnet	0	48 a	21 a	19 a	121 b	06 a	29 b
	2.5	55 b	23 a	25 b	85 a	04 a	22 a
	10 0	56 b	24 a	30 c	104 ab	06 a	28 b
Bluebonnet 50	0	49 a	18 a	20 a	86 a	09 a	35 a
	2 5	54 ab	20 a	25 b	87 a	11 a	38 a
	10 0	58 b	20 a	33 c	76 a	09 a	35 a
IR 8	0	48 a	34 a	26 a	83 a	10 a	25 a
	2 5	51 a	35 a	32 b	70 a	09 a	25 a
	10 0	53 a	36 a	38 c	68 a	09 a	29 a

Values followed by the same letter are not different at the 5 level as determined by the Duncan Multiple Range Test Comparisons must be made within cultivars only

applied Zn, P Zn ratios were generally slightly higher in grain than in straw

The growth duration varied widely among cultivars (Table 3) Zinc deficiency apparently resulted in delayed heading, up to 7 days with certain cultivars ('Belle Patna, Bluebelle, and Dawn), whereas applied Zn had no effect on the maturity date of others (Nova 66, Calrose, Arkrose, Starbonnet, Bluebonnet 50, and IR 8) Some of the earlier maturing cultivars appeared to be less tolerant to low Zn supply than later maturing cultivars, although this relationship did not prevail in all cases Workers at IRRI observed that early maturing cultivars were performing poorly in the field (7) This disorder was subsequently diagnosed as Zn deficiency This might have been due to an earlier demand for Zn before root development was sufficient to accumulate adequate amounts of native soil Zn Thus early maturing cultivars grown on marginally Zn deficient soil might exhibit Zn deficiency symptoms, whereas ratoon crops might be less affected due to their established root systems

Studies at IRRI indicated that varietal differences in susceptibility to Zn deficiency are related to recovery capability during the later growth stage rather than to rate of Zn absorption (6) Rate of recovery appeared to be controlled at least in part by tillering capacity Furthermore, critical Zn concentrations did not vary appreciably among the cultivars tested, including IR 8

Rate of applied Zn also had a marked effect on the germination of seed harvested from several of these cultivars (data not shown) Of the cultivars exhibiting a visual maturity response to applied Zn, percentage germination of only Bluebelle seed was reduced Although Bluebonnet 50 and IR 8 gave no indication of Zn response with regard to time of heading, maturity, or grain yield, the viability of the seed was reduced This suggests that rice grown especially for seed purposes should be routinely fertilized with Zn if a Zn deficiency is suspected

Table 3 Days to heading and maturity of several rice cultivars, as affected by applied Zn, Experiment 2

Cultivar	Heading date			Maturity date†	Field Maturity date‡
	Zn applied mg pot				
	0	2 5	10 0	10 0	
Belle Patna	73	70	68	101	104
Bluebelle	82	77	75	107	110
Saturn	9	79	3	107	120
Nova 66	79	79	79	107	120
Dawn	93	86	86	114	120
Nato	92	89	89	114	120
Starbonnet	100	100	100	121	130
Bluebonnet 50	110	110	110	135	140
Arkrose	99	99	99	121	150
Caloro	103	100	100	128	154
Calrose	98	98	98	128	154
IR 8	120	120	120	149	150+

Days from seeding to heading † Days from seeding to maturity (harvest based on maturity of plants receiving the 10-mg Zn rate) ‡ Days from seeding to maturity under field conditions

Table 4 Dry matter production and Zn concentration in several rice cultivars grown on moist or flooded soil, as affected by rate of applied Zn, Experiment 3

Cultivar	Zn applied	Flooded			Moist		
			Concentration			Concentration	
		Yield	P	Zn	Yield	P	Zn
	mg/pot	g pot		ppm	g pot		ppm
Juma 8	0	9 9 a	37 a	18 a	3 4 a	36 b	8 a
	2 5	16 6 b	39 a	20 ab	7 4 ab	31 ab	11 a
	10 0	20 0 b	36 a	26 b	7 8 b	26 a	16 b
Juma 13	0	7 1 a	36 a	13 a	0 9 a	31 b	12 a
	2 5	10 0 a	32 a	24 b	4 0 a	23 a	14 a
	10 0	10 5 a	36 a	2 b	3 9 a	6 ab	15 a
Juma 18	0	9 5 a	3 a	13 a	3 8 a	38 b	10 a
	2 5	15 3 ab	33 a	17 ab	0 ab	34 ab	13 a
	10 0	19 5 b	37 a	22 b	9 1 b	32 a	15 a
Chontalpa 16	0	15 6 a	33 a	9 a	1 9 a	36 b	7 a
	2 5	30 6 b	32 a	21 b	8 3 b	24 a	12 a
	10 0	27 0 b	32 a	28 b	8 3 b	19 a	12 a
Chontalpa 437	0	13 9 a	37 a	13 a	2 2 a	36 b	8 a
	2 5	29 7 b	35 a	23 b	6 0 ab	37 b	13 ab
	10 0	23 9 b	37 a	32 c	9 8 b	30 a	1 b
Sinaloa 1C	0	16 2 a	36 a	12 a	5 4 a	35 b	9 a
	2 5	19 8 ab	35 a	18 a	12 8 b	32 b	10 ab
	10 0	24 9 b	35 a	30 b	11 5 b	24 a	15 b
Sinaloa 8C	0	13 7 a	37 a	11 a	4 7 a	33 a	8 a
	2 5	25 3 b	35 a	22 b	13 7 b	30 a	10 ab
	10 0	23 6 b	37 a	34 c	13 4 b	28 a	14 b
Sinaloa 19C	0	16 8 a	38 a	12 a	6 0 a	36 b	10 a
	2 5	21 6 ab	37 a	18 a	12 5 b	35 b	10 a
	10 0	25 7 b	38 a	33 b	13 4 b	29 a	13 a
Bluebelle	0	6 3 a	35 a	10 a	1 6 a	36 b	6 a
	2 5	15 0 b	33 a	14 a	6 8 b	35 b	11 ab
	10 0	17 5 b	33 a	26 b	7 b	25 a	24 b
Calrose	0	12 8 a	32 a	11 a	3 7 a	33 b	10 a
	2 5	21 9 b	32 a	21 b	5 7 a	32 b	12 a
	10 0	21 4 b	32 a	43 c	5 9 a	18 a	5 b
Starbonnet	0	7 3 a	32 a	9 a	1 6 a	31 b	5 a
	2 5	14 9 b	31 a	14 a	6 5 b	27 ab	13 b
	10 0	21 3 c	31 a	24 b	8 0 b	24 a	25 c

Values followed by the same letter are not different at the 5% level as determined by the Duncan Multiple Range Test Comparisons must be made within cultivars only

Experiment 3

All of the cultivars responded to applied Zn under both moist and flooded conditions although Zn deficiency symptoms were most pronounced in the moist systems (Table 4) Yield increases beyond the 2 5 mg Zn rate were generally small The cultivars most responsive to Zn were the Chontalpas Bluebelle, and Starbonnet, whereas the least responsive cultivars were the Sinaloas and Calrose Maximum yields varied among cultivars under each moisture regime although

Table 5 Relative response of several rice cultivars grown on moist and flooded soil, Experiment 3

Cultivar	Relative response
Sinaloa 80	0 54
Sinaloa 190	0 52
Sinaloa 10	0 51
Juma 18	0 47
Blu belle	0 44
Juma 8	0 39
Starbonnet	0 37
Juma 13	0 36
Chontalpa 437	0 30
Chontalpa 16	0 27
Calrose	0 26

Relative response $\frac{\text{Maximum yield on moist soil}}{\text{Maximum yield on flooded soil}}$

the Sinaloa cultivars were superior under moist soil conditions When all of the cultivars were ranked according to their maximum yield under moist versus flooded soil conditions, the Sinaloas were highest and the Chantalpas and Calrose were lowest (Table 5) Although these results suggests that the Sinaloa cultivars are best adapted to upland culture, it is possible that cultivars adapted to various climatic and cultural environments would respond differently when grown in their natural habitat

Uptake of Zn (yield × concentration) increased through the 10 mg Zn application rate with all cultivars grown on flooded soil and in most cultivars grown on moist soil (Table 4) The Jumas, Starbonnet, and Bluebelle had the lowest uptake from flooded soil Whereas dry matter production was about twice as high on flooded as on moist soil, uptake of Zn ranged from three to ten fold higher under flooded soil conditions This indicates either increased availability of Zn or increased plant vigor resulting in more Zn uptake under flooded conditions

In general, concentration of Zn in the immature rice tissue increased with rate of applied Zn (Table 4) Except for Starbonnet and Bluebelle, Zn concentrations were considerably higher in plants of all cultivars grown on flooded than on moist soil A large percentage of the plants grown on moist soil in the absence of applied Zn had Zn concentrations below the critical value of 10 ppm (11) and the Zn concentrations of some others were below 15 ppm, even where Zn had been applied In contrast, values of 10 ppm or lower were noted in plants grown under flooded conditions only in Starbonnet and 'Chontalpa 16 where Zn was not applied This suggests that the difference in growth between plants from flooded and moist soil systems is partially related to Zn availability

Concentration of P, like Zn, was higher in plants grown on flooded than moist soil (Table 4) On flooded soil the P concentrations among all plants ranged from 0 32 to 0 39%, whereas on moist soil the range was 0 18 to 0 38% The availability of P may have been a limiting factor in moist soil, possibly accounting for the poor growth in nonflooded systems Although there was a wide range in dry matter production under flooded conditions, P concentration remained relatively constant In contrast, P concentrations in plants grown on moist soil varied inversely with dry matter production as a result of dilution

CONCLUSIONS

Results from this investigation indicate that rice cultivars differ in degree of response to low Zn supply Furthermore, certain cultivars are better adapted to upland conditions than others on soils where Zn is limiting There was no evidence, however, that P nutrition is related to varietal differences Although there was some variation in P Zn ratios in grain and straw among varieties this was not related to a differential response to Zn Because very early maturing cultivars may be more sensitive to low Zn supply, the rate at which certain cultivars accumulate Zn could be important Short term uptake studies are in progress to investigate this possibility

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