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Screening Upland Rice Genotypes for Manganese-use Efficiency

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Abstract: Manganese (Mn) deficiency in upland rice grown after common bean or soybean, which received adequate rate of liming on highly weathered Oxisols, is observed. A greenhouse experiment was conducted to evaluate Mn-use efficiency of 10 promising upland rice genotypes. The genotypes were grown on an Oxisol at 0 mg Mn kg^{-1} (natural soil Mn level) and 20 mg Mn kg^{-1} of soil applied as manganese sulfate. Grain yield, panicle number, and grain harvest index (GHI) were significantly ($P < 0.01$) influenced by genotype. However, shoot dry weight was significantly affected by Mn as well as genotype treatments. Manganese uptake in the shoot as well as in the grain was also affected by genotype treatment. On the basis of Mn-use efficiency (mg grain weight/mg Mn accumulated in shoot and grain), genotypes were classified as efficient and responsive (ER), efficient and nonresponsive (ENR), nonefficient and responsive (NER), and nonefficient and nonresponsive (NENR). Genotypes Carisma, CNA8540, and IR42 were classified as ER, and genotypes CNA8557 and Maravilha were classified as ENR. Genotype Caipo was in the group NER, and in the NENR group were genotypes Bonança, Canastra, Caraja, and Guarani. From a practical point of view, genotypes that produce high grain yield at a low level of Mn and respond well to Mn additions are the most desirable because they are able to express their high yield potential in a wide range of Mn availability.

Keywords: Grain yield, Mn uptake, Oxisol, shoot dry weight

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INTRODUCTION

Brazil is the largest producer of upland rice in the world. This crop in Brazil is mainly grown in the central part, which is locally known as the Cerrado region. Most of the soils of the Cerrado region are Oxisols and Ultisols having low fertility (Goedert 1983; Fageria 1994, 2000a; Barbosa Filho and Silva 2000; Fageria and Costa 2000). Responses of upland rice, common bean, corn, and soybean to manganese (Mn) application have been reported in Oxisols of central Brazil when soil pH is around 6 and Mn concentration lower than 8 mg kg^{-1} in the soil (Fageria 2001a). The main reason for Mn deficiency in Cerrado soils is liming (Fageria 2000b). Liming is an essential practice to reduce acidity and improve crop yield on these soils, especially legume crops (Barbosa Filho and Silva 2000; Fageria, Stone, and Santos 1999). Lindsay (1979) reported that there was a linear decrease in Mn concentration in the soil solution when soil pH was raised from 3 to 8.5. Similarly, Fageria (2000b) also reported a significant quadratic decrease in the Mn uptake in the tops of upland rice genotypes grown on an Oxisol of central Brazil when pH was raised from 4.6 to 6.8.

Annual crops require micronutrients in low quantity compared to macronutrients. Therefore, the Mn requirement can be easily met if a genotype or cultivar efficient in uptake and utilization of Mn is used. Variation in crop genotypes in use of Mn have been reported in the literature (Marschner 1995). However, data are limited on the variation of upland rice genotypes' Mn-use efficiency. The objective of this study was to evaluate promising upland rice genotypes grown on an Oxisol of central Brazil for Mn-use efficiency.

MATERIALS AND METHODS

A greenhouse experiment was conducted at the EMBRAPA Rice and Bean Research Center, Santo Antônio de Goías, to evaluate Mn-use efficiency of 10 promising upland rice genotypes supplied by the Center's breeders. The soil used in the experiment was an Oxisol (clayey, kaolinitic, isothermic Typic Haplustox). It had the following chemical and textural properties before the application of Mn treatments: pH 4.1 (1:2.5 soil–water ratio), extractable phosphorus (P) 0.6 mg kg^{-1}, extractable potassium (K) 45 mg kg^{-1}, extractable calcium (Ca) 0.27 $cmol_c\,kg^{-1}$, extractable magnesium (Mg) 0.15 $cmol_c\,kg^{-1}$, extractable aluminum (Al) 1.0 $cmol_c\,kg^{-1}$, extractable copper (Cu) 1.3 mg kg^{-1}, extractable zinc (Zn) 0.6 mg kg^{-1}, extractable iron (Fe) 59 mg kg^{-1}, extractable Mn 10 mg kg^{-1}, and organic matter 22 g kg^{-1} of soil. Textural analysis values were 515 g kg^{-1} clay, 150 g kg^{-1} silt, and 335 g kg^{-1} sand.

Phosphorus and K were extracted by the Mehlich 1 extracting solution [0.05 M hydrochloric acid (HCl) + 0.0125 M sulfuric acid (H_2SO_4)]. Phosphorus was determined colorimetrically, and K by flame photometry. Calcium, Mg, and Al were extracted with 1 M potassium chloride (KCl). Aluminum was determined by titration with sodium hydroxide (NaOH), and Ca and Mg by titration with ethylenediaminetetraacetic acid (EDTA). Micronutrients were determined on a portion of the extract of P by atomic absorption spectrophotometry. Organic matter was determined by the Walkley–Black method and textural analysis by pipette method. Soil analysis methods used in this study are described in a soil analysis manual published by EMBRAPA (1997).

The treatment consisted of two Mn levels, low (0 mg Mn kg^{-1}, without Mn addition) and high (20 mg Mn kg^{-1}), applied as Mn sulfate to 10 upland rice (*Oryza sativa L.*) genotypes. Genotypes used were Bonança, Caiapó, Canastra, Carajas, Carisma, CNA8540, CNA8557, Guarani, Maravilha, and IR42. A completely randomized design was used in a factorial arrangement, and treatments were replicated three times. The study was conducted in plastic pots, with 5 kg of soil in each. Each pot received 10 g dolomitic lime and was subjected to wetting and drying cycles for 3 weeks before sowing. The liming material had 27.4% calcium oxide (CaO), 15.2% magnesium oxide (MgO), and neutralizing power of 73%. At the time of sowing, in addition to Mn treatments, each pot received a basal application of 900 mg nitrogen (N) as ammonium sulfate [$(NH_4)_2SO_4$], 786 mg P kg^{-1} as triple superphosphate, and 996 mg K as potassium chloride. Each pot also received 900 mg N as topdressing through ammonium sulfate at active tillering (50 days after sowing). These basal fertilizer rates and N topdressing were based on the recommendations of Fageria and Baligar (1997). Each pot contained four plants, which were frequently watered to maintain moisture at approximate field capacity. Plants were harvested at maturity.

At harvest, grain yield, shoot dry weight, and panicle numbers were determined. Plant material (shoot and grain) was dried in a forced-draft oven at about 70 °C until constant weight was achieved and then milled. Ground material (shoot and grain) was digested with a 2:1 mixture of nitric (HNO_3) and perchloric acid ($HClO_4$) for chemical analysis. Micronutrients Zn, Cu, Fe, and Mn in the shoot and grain were analyzed by atomic absorption spectrophotometry. Grain harvest index (GHI) and Mn-use efficiency (MnUE) were calculated with the help of following equations (Fageria 1998):

GHI = (Grain yield / grain + straw yield)

MnUE = (Grain weight in mg at higher Mn level – grain weight in mg at lower Mn level) / (Mn uptake in mg in shoot and grain at higher K level – Mn uptake in mg in shoot and grain at lower Mn level)

Data were analyzed by analysis of variance, and F-test was used to evaluate treatment significance. Turkey's test was used to compare treatment means at the 5% probability level.

RESULTS AND DISCUSSION

Results of shoot dry weight, grain yield, number of panicles, and GHI are presented in Table 1. Grain yield, number of panicles, and GHI did not have significant Mn and genotype (Mn $\times$ G) interactions. Therefore, results related to these parameters across two Mn levels are presented. However, shoot dry weight showed Mn $\times$ G interaction was highly significant, and data of this parameter at two Mn levels are presented. Nonsignificant Mn $\times$ G interaction means that these plant parameters can be evaluated at one Mn level. When selecting one nutrient level for genotype screening purposes, care should be taken to select an appropriate level. This level should be neither too high nor too low (Fageria and Baligar 1993).

Shoot dry weight varied from 46.37 g pot^{-1} to 91.23 g pot^{-1} at a lower Mn level depending on the genotype with an average value of 62.42 g pot^{-1}. The variation was 97% between lowest shoot dry weight, genotype Carajas, and highest shoot weight, genotype IR42. At the higher Mn level, shoot dry weight varied from 51.73 to 76.27 g pot^{-1} with an average value of 63.42 g pot^{-1}. The highest dry weight of shoot producing genotype IR42 at low Mn level also produced nearly highest

Table 1. Shoot dry weight, grain yield, number of panicles, and grain harvest index (GHI) of 10 upland rice genotypes

Genotype	Shoot dry wt. (g pot^{-1})		Grain yield (g pot^{-1})	Number of panicles (pot^{-1})	GHI
	Mn_0	Mn_{20}			
Bonança	51.43cde	60.47abc	45.38b	20.50bc	0.45abc
Caipó	68.03bc	76.27a	48.83ab	19.67c	0.40c
Canastra	65.20bcd	65.87abc	48.98ab	21.00bc	0.43bc
Carajas	46.37e	57.93bc	43.32b	22.67bc	0.45abc
Carisma	61.00bcde	54.33c	52.30ab	23.00bc	0.47ab
CNA8540	55.70bcde	55.47c	57.28ab	24.83bc	0.51a
CNA8557	64.57bcd	68.20abc	65.05a	26.50b	0.49a
Guarani	48.83de	51.73c	41.97b	19.33c	0.46abc
Maravilha	71.80b	68.23abc	51.05ab	22.67bc	0.42bc
IR42	91.23a	75.70ab	55.90ab	35.83a	0.40c
Average	62.42	63.42	51.01	23.60	0.45

Note. Means in the same column followed by the same letter are statistically not different at the 5% probability level by Tukey's test.

shoot dry weight at the higher Mn level. Shoot dry weight had positive significant correlation (r = 0.44^{**}) with grain yield. Generally, shoot dry matter has positive correlation with grain yield in annual crops (Snyder and Carlson 1984); however, the relationship is quadratic (Fageria and Baligar 2001). This means it is not necessary that highest-grain-yield-producing genotypes should produce highest dry-matter yield of shoot. However, they should produce reasonably good dry-matter yield. Highest grain-yield-producing genotypes CNA8557, CNA8540, and IR42 produced maximum or nearly maximum shoot dry matter.

Grain yield varied from 41.97 g pot^{-1} to 65.05 g pot^{-1} depending on genotype. The variation in grain yield was 55% between lowest grain-yield-producing genotype Guarani and highest grain-yielding-producing genotype CNA8557. Number of panicles varied from 19.33 to 35.83 pot^{-1} depending on genotype. The variation was 87% between highest panicle-producing genotype IR42 and lowest panicle-producing genotype Guarani. Panicle number had positive significant correlation (r = 0.51^{**}) with grain yield. Similarly, GHI also had positive significant correlation (r = 0.60^{**}) with grain yield. The relationship between rice grain yield and yield components has been studied extensively at the phenotypic level (Gravois and Helms 1992; Fageria and Baligar 1999). Fageria (2000a) reported that panicle and GHI had highest correlation in upland rice genotypes as compared to other yield components. Fageria and Baligar (1999) also reported that panicle per pot was the most important component of yield, accounting for 87% of the variation in rice yield.

The GHI varied from 0.40 to 0.51 with an average value of 0.45. Efficiency of grain production in crop plants is frequently expressed as harvest index. Sinclair (1998) and Hay (1995) reported that GHI is an important trait associated with dramatic increase in crop yields that have occurred in the twentieth century. Grain harvest index reflects the partitioning of photosynthate between the grain and the vegetative part of the plant, and improvements in harvest index emphasize the importance of carbon allocation in grain production (Yoshida 1981). Upland rice is totally dependent on rainfall and planted in lower density as compared to lowland or flooded rice in Brazil (Fageria 2001b) to reduce plant competition for water, which generally gives taller plants and lower harvest index. However, in recent years, breeding has contributed to reducing plant height and to upland rice varieties in Brazil having harvest index equal to flooded or lowland rice. Grain harvest indices of promising Brazilian upland rice genotypes used in our study are within the range of 0.40 to 0.49 reported by Yoshida (1981) for lowland rice. The highest harvest index exhibited by California lowland rice cultivars under direct seeding was 0.59 (Roberts et al. 1993). Values of GHIs of some genotypes reported in Table 1 are approaching this

Table 2. Concentration and uptake of Mn in the shoot and grain of 10 upland rice genotypes

Genotype	Concentration ($mg\,kg^{-1}$)		Uptake ($mg\,pot^{-1}$)	
	Shoot	Grain	Shoot	Grain
Bonança	465b	27b	27	1.26b
Caipó	340b	32ab	25	1.84ab
Canastra	448b	45ab	30	2.11ab
Carajas	570ab	28ab	32	1.34ab
Carisma	350b	47a	19	2.72a
CNA8540	482ab	40ab	27	1.95ab
CNA8557	457b	33ab	31	2.30ab
Guarani	730a	32ab	37	1.31b
Maravilha	427b	35ab	30	1.77ab
IR42	317b	27b	26	1.35ab
Average	459	35	28	1.79

Note. Means in the same column followed by the same letter are statistically not different at the 5% probability level by Tukey's test.

value. This means that there has been significant progress in improving GHI of Brazilian upland rice cultivars.

Manganese concentration (Mn content per unit of dry weight) and uptake (concentration × dry weight of shoot or grain) in the shoot and grain of 10 rice genotypes across two Mn levels are presented in Table 2. Manganese concentration was significantly affected by genotype in the shoot as well as in the grain. However, uptake was significantly affected only in the grain by genotype. Manganese concentration as well as uptake was higher in the shoot. Across 10 genotypes, Mn concentration in the shoot was about 13 times higher compared to grain. This means a small fraction of Mn is exported to grain at the adequate Mn level in the soil. Fageria (1999) also reported that Mn translocation in upland rice grain is about 18% of the total uptake.

Results related to influence of Mn on the concentration and uptake of Zn, Cu, Fe, and Mn in shoot as well as grain is presented in Table 3. Concentrations as well as uptakes of Zn, Cu, and Fe in the shoot and grain decreased with the addition of 20 mg Mn kg^{-1} of soil as compared to control treatment except Fe concentration and uptake in shoot. However, difference was statistically not significant except the Cu concentration in the grain (Table 3). Normally, there is an antagonistic effect or interaction between cations of similar charge but this depends on the level of each nutrient present in the soil (Wilkinson, Grunes, and Sumner 2000). Interactions occur when the supply of one nutrient affects the absorption, distribution, or function of another nutrient (Robson and Pitman 1983). The result may be induced deficiencies, toxicities, modified

Table 3. Influence of Mn on the concentration and uptake of Mn, Zn, Cu, and Fe in the shoot and grain across 10 upland rice genotypes

Micronutrient	Shoot		Grain	
	Mn_0	Mn_{20}	Mn_0	Mn_{20}
Concentration ($mg\,kg^{-1}$)				
Zn	15.47a	14.20a	28.70a	25.93a
Cu	3.80a	3.37a	14.13a	10.57b
Fe	114a	136a	35a	32a
Mn	231b	686a	23b	46a
Uptake ($mg\,pot^{-1}$)				
Zn	1.18a	0.92a	1.45a	1.31a
Cu	0.23a	0.21a	0.70a	0.55a
Fe	5.26a	8.48a	1.78a	1.60a
Mn	14.28b	42.58a	1.23b	2.36a

Note. Values followed by the same letter in the same line under the same heading (shoot or grain) are statistically not different by Tukey's test.

growth responses, and/or modified nutrient composition (Wilkinson, Grunes, and Sumner 2000). Concentration as well as uptake of Mn was higher at higher concentration as compared to lower Mn concentration as expected. Among four micronutrients analyzed in the plant, Cu concentration and uptake were lowest and Mn concentration and uptake was highest in the shoot as well as grain. Fageria, Baligar, and Jones (1997) and Fageria (1999) also reported similar patterns in the uptake of these micronutrients in upland rice grown on an Oxisol of central Brazil.

Based on Mn-use efficiency and grain yield at low Mn level, genotypes were classified into four groups (Figure 1). Fageria and Baligar (1993) suggested this type of classification for the nutrient-use efficiency of crop genotypes. The first group was the efficient and responsive (ER) genotype. The genotypes that produced above average yield at low Mn level and higher than average Mn-use efficiency were classified in this group. Genotypes Carisma, CNA8540, and IR42 fall into this group. The second classification was efficient and nonresponsive (ENR) genotypes. These genotypes produced more than average yield of 10 genotypes at low Mn level, but response to Mn application was lower than the average. The genotypes CNA8557 and Maravilha fall into this group. The third type of genotypes are known as nonefficient and responsive (NER). The genotypes that produced less than average grain yield of 10 genotypes at low Mn level but responded to Mn application above the average are classified in this group. The only genotype that falls into this group is Caipó. The fourth group of genotypes is those that produce less than average yield at low Mn level and less than average response to applied Mn. This type of genotype is classified as nonefficient and

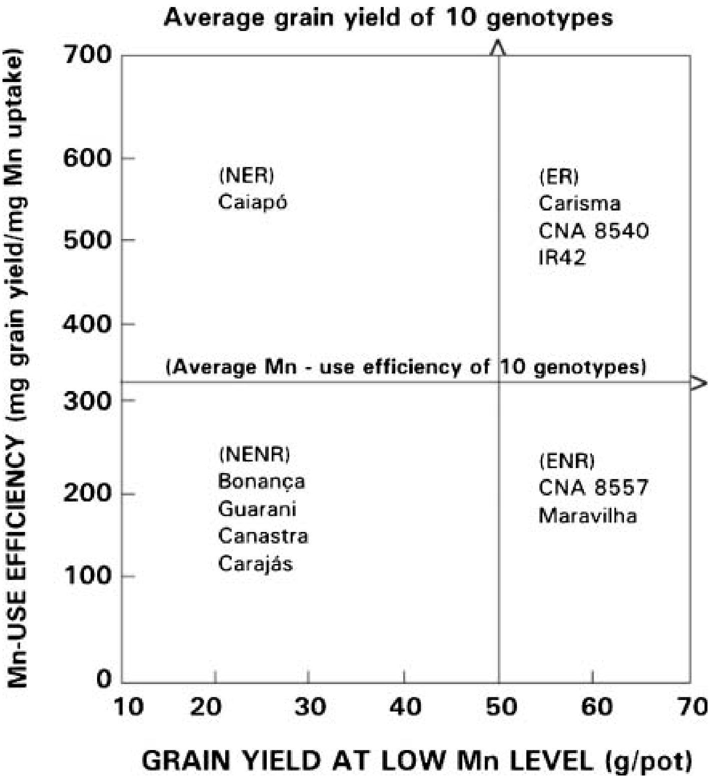

Figure 1. Classification of upland rice genotypes for Mn-use efficiency.

nonresponsive (NENR). The genotypes that fall into this group are Bonança, Canastra, Carajas, and Guarani. From a practical point of view, the genotypes that fall into the efficient and responsive group are the most desirable because these genotypes can produce more at a low Mn level and also respond well to applied Mn. This means this type of genotype can be utilized under low as well as high technology with reasonably good yield (Fageria and Baligar 1993). The second most desirable group is efficient and nonresponsive genotypes. Genotypes of this type can be planted under low Mn level and produce more than average yield. The nonefficient and responsive genotypes sometimes can be used in a breeding program for their Mn-responsive characteristics. The most undesirable genotypes are the nonefficient and nonresponsive type. These results indicate that upland rice genotypes differ in Mn-use efficiency. Both inter- and intraspecific variation in Mn nutrition have been recognized among cereal species and genotypes (Fageria 1998; Fageria and Baligar 1993; Fageria, Baligar, and Jones 1997) and suggest that it may be possible to develop cultivars that are efficient at low nutrient levels or are capable of using Mn more efficiently when applied as fertilizer.

CONCLUSIONS

Upland rice genotypes differed significantly in relation to grain yield, yield components, and GHI. Grain harvest index had highest correlation with grain yield, followed by number of panicles and shoot dry weight. These indices can be used in a breeding program for improving upland rice yield. Manganese concentration in the shoot as well as grain varied with genotypes. However, it was higher in the shoot than in grain. Concentration and uptake of micronutrients were in the order of Mn > Fe > Zn > Cu in the shoot as well as in the grain. Among 10 genotypes tested, Carisma, CNA8540, and IR42 were most desirable because of higher response to applied Mn as well as higher yield at lower Mn level. These results suggested that variability in upland rice genotypes in Mn-use efficiency can be an important trait in breeding Mn-efficient upland rice genotypes.

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