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International Journal of Current Research
Vol. 4, Issue, 10, pp.080-084, October, 2012

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

EVALUATION OF SEVERAL STRESS INDICES FOR IDENTIFICATION OF RICE GENOTYPES WITH HIGHER YIELD IN ZINC STARVED SOIL

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ARTICLE INFO

Article History:
Received 29th July, 2012
Received in revised form
27thAugust, 2012
Accepted 25th September, 2012
Published online 30th October, 2012

Key words:
Rice genotypes,
Grain yield,
Stress indices,
Zn efficiency

ABSTRACT

Micronutrient deficiencies have been widely noticed in rice, wheat and other crops which causes low yield and increases malnutrition. Zinc deficiency remained a major problem all over country. Zinc deficiency can be overcome by addition of Zn fertilizer. But alternative strategy is use of efficient plant genotype that can more effectively grow on soil with low available zinc. With this background, a pot experiment was conducted to evaluate stress indices for identification of rice genotypes with higher yield in zinc stress soil. The treatment consisted of ten rice genotypes with two levels of Zn (0, 5 mg/kg) applied through zinc sulfate. The experimental soil was deficient in zinc. The results revealed that stress tolerance index (TOL) and stress susceptible index (SSI) had poor correlation with grain yield under Zn stress and Zn adequate condition. Both were associated with poor yield under Zn adequate condition and therefore could not identify genotypes which perform well in both conditions. But mean productivity (MP), geometric mean productivity (GMP) along with stress tolerance index (STI) identified genotypes which could perform well under both Zn stress and Zn adequate condition. This was supported by very strong relationship that STI had with Y_S and Y_P. Thus ADT 43, CO 45, ADT 46 and ADT 36 was identified that perform well both in Zn stress and non stress environment.

INTRODUCTION

Increased incidence of micronutrient deficiencies in agricultural soils worldwide are attributed to loss of micronutrients through erosion, leaching, liming of acid soils, low use of organics, use of marginal lands for cultivation and intensive agriculture (Fageria *et al.,* 2002) It is estimated that about 50% of soils used for cereal production in the world have low level of plant available Zn (Graham and Welch, 1996) and In India, 49% of soils are deficient in Zn (Singh, 2009). Zn deficiencies in field crops have been reported worldwide (Frossaed *et al.,* 2000, Khoshgoftarmanesh et al., 2004, 2009). Several studies have reported significant reduction in growth and yield of different plant species grown under Zn deficient soils (Kalayci *et al.,* 1999, Fageria *et al.,* 2002). Mineral nutrients have played an important role in enhancing the crop production since the beginning of the green revolution. Borlaug and Douswell (1993) observed that nearly 50% of the increase in crop yields during the 20th century was due to chemical fertilizer application. As correcting Zn deficiency through application of Zn fertilizer is expensive one, an alternative approach to combat Zn deficiency is tailoring plants to suit soil condition. Scientists have identified crop genotypes that are able to grow and produce highest yield in Zn deficient soils (Rengel and Graham, 1995). Thus exploitation of the plant's genetic capacity for efficient nutrient uptake and utilization is a promising tool to cope up with nutrient deficiency stress (Irshad *et al*., 2004. Maqsood *et al*., 2009). Selection and breeding for increased Zn efficiency is a promising strategy of increasing crop productivity in low input and environmental friendly agricultural production system (Cakmak *et al.,* 2001).Genotypes that are more efficient in Zn acquisition from deficiency condition are generally considered better adaptable to Zn deficiency in soils. Sufficient genetic variability exists among several crop species and genotypes for Zn acquisition and utilization under low Zn environment (Cakmak *et al.,* 2001, Irshad *et al.,* 2004). There are several stress indices proposed by many workers as ways to identify genotype with better stress tolerance and high yield potential. Thus this paper examines various stress indices available to screen rice genotypes which will perform well and provide high yield under both Zn stress and Zn adequate environment.

MATERIALS AND METHODS

A pot experiment was conducted in glass house of experimental farm of Annamalai University to study the response of rice genotypes to zinc application. The experimental soil belongs to Kondal series (Typic Haplusterts). The physico-chemical characterization of the soil was clay loam , pH- 8.02, EC- 0.72 dSm^{-1}, organic carbon-6.74 g kg^{-1} ,$CaCO_3$ content-2.27%, $KMnO_4$-N -283 kg ha^{-1} , Olsen P – 26 kg ha^{-1}, NH$_4$OAc-K-320 kg ha^{-1} and DTPA Zn- 0.70 mg kg^{-1}.The experimental soil was deficient in Zn (critical limit of Zn- 0.84 mg kg^{-1} –Muthukumararaja and Sriramachandrasekharan, 2012). The treatments consisted of ten rice genotypes (ADT 36, ADT 37, ADT 45, ADT38, CO 45, ADT 43, ADT 46, ADT 39, CO 43, ADT 48) and two Zn levels(0 and 5 ppm) applied through zinc sulfate. Each pot was filled with 10 kg of processed soil sample. All the pots received uniform dose of 100:50:50 kg N, P$_2$O$_5$ and K$_2$O applied through urea, superphosphate and muriate of potash respectively. Grain yield was recorded at maturity. The yield data was used to calculate for each genotype the following

1. Zinc efficiency (SE) = (Yield P/Yield S) x 100, where P= grain yield produced under
2. Zn deficiency, S = grain yield produced with Zn fertilization
3. TOL - the yield difference between the stress (Ys) and non-stress conditions (Yp);
4. MP - the average yield of Ys and Yp;
5. GMP – calculated with formula *Ys*. *Yp;*
6. 5) SSI – stress susceptibility index expressed by following relationships: _ _
7. SSI = [1-Ys/Yp] / SI, where SI (stress intensity) and is estimated as [1 - Y_S/ Y_P]
8. STI = stress tolerance index = [Yp. Y_S / Y_P^2]

RESULTS AND DISCUSSION

The rice genotypes tested under zinc stress and non- stress environment differed significantly among them (Table 1.). The grain yield ranged from 27.97 g/pot (ADT 48) to 80.30 g/pot (ADT 43) under Zn stressed soil with an average of 52 g/pot. While in zinc adequate condition, grain yield ranged from 31.77 g/pot (ADT 48) to 83.5 g/pot (ADT 43) with an average of 54.99 g/pot. The per cent increase in grain yield ranged from 4.2 to 13.5 among genotypes. Four of the rice genotypes (40%) produced more than mean grain yield of 52 g/pot in Zn stressed soil as well as more than mean grain yield of 54.99 g/pot under Zn adequate condition. Higher grain yield by rice due to zinc application might be due to favorable effect of zinc on the proliferation of roots and thereby increasing the uptake of plant nutrients from the soil, supplying it to the aerial parts of the plant and ultimately enhancing the vegetative growth of plants and ultimately improving grain yield. Response of lowland rice to zinc addition has been reported by earlier workers (Mandal *et al.,* 2000, Fageria *et al.,* 2011). Differences in growth among cultivars have been related to the absorption, translocation, shoot demand, DMP potential per unit of nutrient absorbed (Baligar *et al.,* 1990). Large genotypic variation in response to Zn deficiency has been reported among rice (Hafeez *et al.,* 2010). Rice genotypes with small response to zinc fertilization are considered as the zinc efficient genotypes

Table 1. Effect of Zn application on rice grain yield and Zn efficiency

Rice genotypes	Grain yield (g/pot)		Mean	Zn Efficiency (%)
	- Zn	+Zn		
ADT 36	53.23	56.31	54.77	94.53
ADT 37	50.90	53.06	51.98	95.92
ADT 45	50.34	53.83	52.08	93.51
ADT 38	50.15	52.25	51.20	95.98
CO 45	54.78	57.06	55.92	96.0
ADT43	80.30	83.90	82.10	95.7
ADT 46	60.56	63.73	62.14	95.02
ADT 39	47.32	50.45	48.88	95.69
CO 43	44.49	47.61	46.05	93.44
ADT 48	27.97	31.77	29.88	88.03
Mean	52.0	54.99		
	Zn	G	Zn x G	
SE$_d$	0.28	0.62	0.88	
CD(p=0.05)	0.56	1.26	1.78	

Table 2. Stress tolerance attributes in rice genotypes estimated from yields Under zinc stress and zinc non stress

Genotypes	Y_S	Y_P	TOL	MP	GMP	SSI	STI
ADT 36	53.23	56.31	3.08	54.77	54.75	1.2	0.99
ADT 37	50.9	53.06	2.16	51.98	51.97	1.0	0.89
ADT 45	50.34	53.83	3.49	52.08	52.05	1.4	0.89
ADT38	50.15	52.25	2.10	51.20	51.19	1.0	0.86
CO 45	54.75	57.06	2.28	55.92	55.91	0.8	1.03
ADT 43	80.3	83.9	3.60	82.10	82.08	1.0	2.23
ADT 46	60.56	63.73	3.17	62.14	62.12	1.0	1.28
ADT 39	47.32	49.45	2.13	48.39	48.37	1.0	0.77
CO 43	44.49	47.61	3.12	46.05	46.02	1.4	0.70
ADT 48	27.97	31.77	3.80	29.87	29.80	2.4	0.29
Mean	52.0	54.9	2.89	53.45	53.43	1.22	0.99

Table 3. Correlation between several stress tolerance parameters

	YS	YP	TOL	MP	GMP	SSI	STI
YS	1						
YP	0.9987	1					
TOL	0.0291	0.0792	1				
MP	0.9997	0.9997	0.0539	1			
GMP	0.9997	0.9996	0.0529	0.9999	1		
SSI	-0.6984	0.6641	0.6450	0.6816	0.6824	1	
STI	0.9801	0.9861	0.1712	0.9834	0.9832	0.5560	1

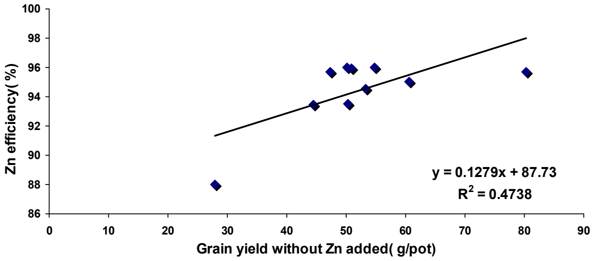

Fig 1a. Linear relationship between Zn efficiency with grain yield under Zn stress

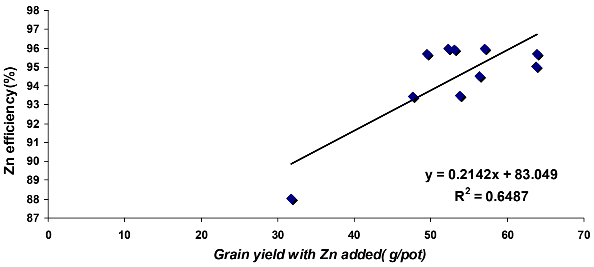

Fig1b.Linear relationship between Zn efficiency with grain yield under Zn adequate

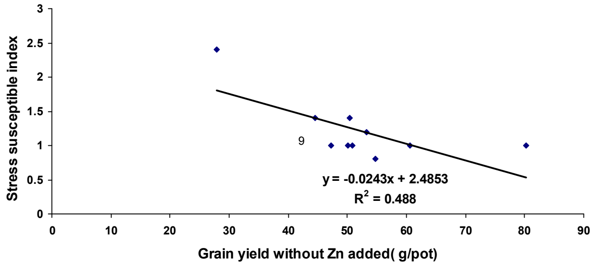

Fig 2a. Linear relationship between SSI with grain yield under Zn stress

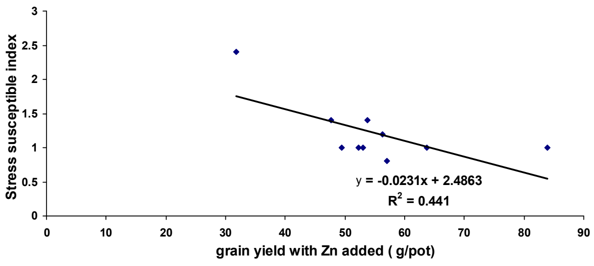

Fig 2b. Linear relationship between SSI with grain yield under Zn adequate

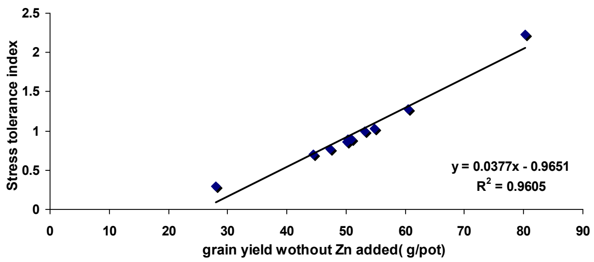

Fig. 3a. Linear relationship between STI with grain yield under Zn stress

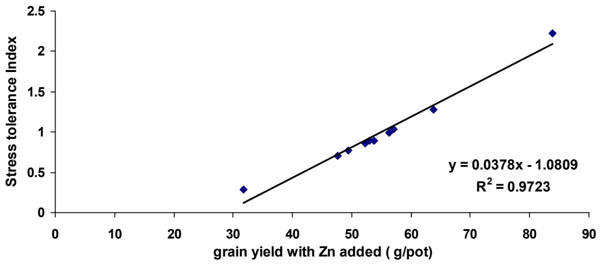

Fig 3b.Linear relationship between STI with grain yield under Zn adequate

whereas the Zn inefficient genotypes have larger yield response to zinc fertilization (Marschner, 1995). Accordingly, in the present study genotypes ADT 48, CO 43, ADT 39, ADT 45, ADT 36 and ADT 46 were considered Zn inefficient, while genotypes ADT 37, ADT 38, CO 45 and ADT 43 were considered Zn efficient. Zn efficiency as per Peng et al., (2007) was worked and it ranged from 88 to 96% among rice genotypes (Table 1). There are several mechanism that could be involved in nutrient efficiency include root process that increase the bio availability of soil nutrients to root uptake, enhanced root uptake and translocation of nutrients from root to shoot (Baligar *et al.,* 2001, Fageria and Baligar , 2003) and may also be due to different crop demand to Zn (Marschner , 1995). There was limitation in using Zn efficiency as parameter to identify a Zn efficient genotype with high yield potential. This is because a genotype which is considered as Zn efficient produce yield which is lower than Zn inefficient for eg., genotypes ADT 46, ADT 36 which is considered as Zn inefficient recorded higher grain yield than Zn efficient genotype like ADT 37,ADT 38, CO 43. This was supported by weak relationship between Zn-efficiency and grain yield without Zn added (Y = 0.129x + 87.73 R^2 = 0.4738., Fig 1a) and slightly better relationship between Zn- efficiency and grain yield with Zn added(Y= 0.2142x + 83.049 R^2 = 0.6483.,Fig1b.).Sadrarhami *et al.,*(2010) also reported similar relationship in selecting high grain yield iron deficiency tolerant wheat genotypes in calcareous soil Various stress tolerance indicators were studied to identify high yielding rice genotypes which perform both under Zn stress and Zn adequate environment (Table 2). Roselle and Hamblin (1981) define stress tolerance (TOL) as the difference in yield between Zn stress (Y_S) and Zn non stress (Y_P) and mean productivity (MP) as the average yield of Y_S and Y_P. Accordingly in the present study, lowest value of TOL was recorded by ADT 38, ADT 39 and ADT 37. This index only pointed out the above genotypes that performed poorly under non-Zn stress condition. TOL had poor correlation with yield both under Zn stress and non-stress condition. Fact that a small value of TOL is desirable, selection for this parameter would tend favor low yielding genotypes. The highest average yield (MP) and geometric mean yield (GMP) was recorded in genotypes ADT 43 (MP = 82.10 g/pot, GMP = 82.08 g/pot), ADT 46 (MP = 62.14 g/pot, GMP = 62.12 g/pot) and CO 45 (MP = 55.92 g/pot, GMP = 55.91 g/pot). On average rice genotypes recorded a MP value of 53.45 g/pot and GMP 53.43g/pot. In the present study, as expected mean productivity and geometric mean productivity were strongly correlated with both Y_P and Y_S. MP and GMP were strongly correlated between each other(r= 0.99). While both were very poorly correlated with TOL. The stress susceptible index (SSI) is another indicator used for screening genotypes.

A larger value of the tolerance index represents relatively more sensitive to stress and thus a smaller value of tolerance is favored. Accordingly, genotypes ADT 37, ADT 38, CO 45, ADT 43, ADT 46 and ADT 39 had lower SSI indicating that they perform well under Zn stress while recording low yield under non- Zn stress condition. In the present study, SSI was strongly negatively correlated with yield under Zn stress and had positive correlation with yield under Zn adequate condition. Selection for this parameter would also tend to favor low yield genotypes was confirmed by the poor linear relationship between SSI and yield under Zn stress $Y= -0.023x + 2.4863$, $R^2= 0.441$ and with yield under Zn adequate $Y= -0.0243x + 2.4853$, $R^2=0.488$ Fig 2a, 2b). All the above stress indices fail to indicate the rice genotypes which would yield higher both under Zn stress and non- Zn stress with higher tolerance potential. Fernandez (1991) claimed that the selection based on stress tolerance index (STI) would result in genotypes with higher stress tolerance and good yield potential. Larger the value of STI for a genotype in a stress environment, the higher was its tolerance and yield potential. This was supported by significant high positive correlation between STI and rice yield without Zn, $Y= 0.0377x- 0.9651$, $R^2= 0.9605$ and with yield under Zn adequate, $Y= 0.0378 -1.809$, $R^2=0.9723$ Fig 3a, 3b). Further STI had very strong correlation with Y_S, Y_P, MP and GMP while poor relationship with TOL and negative correlation with SSI (Table 3). In the present study the STI values ranged from 0.29 to 2.23. Based on STI, mean yield under non stress (Y_P) and mean yield under stress (Y_S), ten rice genotypes are classified into four groups

1. **Group A-** Uniform superiority under stress and non-stress - ADT 43, CO 45, ADT 46 and ADT 36 had high STI> 1.0
2. **Group B-** Perform favorably only under non-stress condition-,ADT 37, ADT 45 and ADT 38 had moderate to high STI – 0.70- 1.00
3. **Group C-** Genotype yield relatively higher only in stress environment- No genotype
4. **Group** D- Genotype perform poorly in both stress and non- stress environmen**t-** ADT 39, CO 43 and ADT 48 had low STI- <0.70

Khoshgoftarmanesh *et al*., (2009) showed that STI could be better selection criterion compared with other indices to identify high yielding wheat genotypes in zinc stress condition. Similarly Sadrarhami *et al*., (2010) also concluded that STI could be used to select high grain yield Fe deficiency tolerant wheat genotypes in calcareous soil.

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