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CORRELATION AND PATH COEFFICIENT ANALYSIS OF SHOOT, ROOT MORPHOLOGICAL TRAITS AND MICRONUTRIENT (FE AND ZN) CONTENT ON GRAIN YIELD IN RICE (*ORYZA SATIVA* L.) UNDER CONTRASTING MOISTURE REGIMES

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ABSTRACT
The relevance of several shoot and root morphological traits in improving grain yield of rice under flooded and aerobic condition were studied. Grain yield was significantly correlated with maximum root length (0.280), root volume (0.323), root dry weight (0.283) and root number (0.319) under aerobic condition. Above ground traits like plant height (0.218), panicle length (0.408), number of productive tillers (0.586) and straw yield per plant (0.433) were showed significant positive correlation with grain yield per plant. Path analysis indicated that root traits like maximum root length (0.897), root dry weight (0.686) and root number (0.639) positive direct effect on grain yield. Above ground traits like plant height (0.648), panicle length (0.993), number of productive tillers (0.895), test weight (0.708) and straw yield per plant (0.236) had direct positive effects on grain yield. These results indicate the role of root traits for improving yield under aerobic situations possibly through improved water and nutrient uptake and also well developed root system will help the plant in maintaining high plant water status which ultimately leads to increase in yield potential under aerobic condition with sufficient amount of Fe and Zn content.

INTRODUCTION

Rice (*Oryza sativa* L.), a semi-aquatic cereal is adapted to a variety of climates ranged from flooded to aerobic condition. Increased productivity in irrigated rice has out-paced because 40 per cent irrigation water will get reduced by 2020. A large number of land races which are drought resistant but non-responsive to improved management practices are being cultivated in marginal lands and receive comparatively lower inputs under subsistence agriculture (IRRI, 1995). A number of shoot and root morphological traits have been proposed to improve performance of rice under drought condition. Among the root characters maximum root length, root volume, root number and root dry weight are found to be associated with the yield (Arya *et al.,* 2013) under water scarcity in aerobic condition (Sandhu *et al.,* 2013).

Globally, rice is a most consumed cereal grain, constituting the dietary staple food for most of the people across the world (Dhanwani *et al.,* 2013). About 50 per cent of world's populations depends on rice as their main source of nutrition (White, 1994). However, rice is a poor source of micronutrients (Bouis and Welch, 2010). Micronutrients deficiency is a global problem, contributing to world's widespread malnutrition and high rate of children and women's mortality (WHO, 1996). It is estimated that more than 2 billion people in the world are deficient in Vitamin A, Iodine and Iron and more than 2.5 billion people in the developing world are Zinc deficient (Panopio, 2010).

Iron deficiency is probably the most widespread micronutrient deficiency in humans. To achieve iron balance, adult men need to take about 6-8 mg/day and adult menstruating women about 8-18 mg/day, although this is highly variable. Towards the end of pregnancy, the absorption of 23-27 mg/day is necessary (http://www.nrv. gov.au/nutrients/iron). Iron deficiency in rice can induce chlorosis and decreases photosynthetic activity, leading to lower plant productivity. It participates in electron transfer through reversible redox reactions, cycling between Fe^{2+} and Fe^{3+}. Insufficient Fe uptake leads to Fe-deficiency symptoms such as interveinal chlorosis in leaves and reduction of crop yields.

According to WHO (2002), zinc deficiency ranks fifth among the most important health risk factors in developing countries and eleventh worldwide. Zinc deficiency is more extensive in developing countries where more than 60 per cent of the population is at risk. Zinc is required as a cofactor in over 300 enzymes and plays critical structural roles in many protein and transcriptional factors and DNA synthesis (Rosa *et al.,* 2010). Its requirement is increased during pregnancy as well as throughout childhood and adolescence. Zinc deficiency is characterized by diarrhea, pneumonia, weight loss, growth retardation and delayed puberty in adolescents, poor appetite, delayed wound healing etc and it is fatal if untreated (WHO 1996). The daily recommended dietary allowance (Camak, 2007) for Zn is around 15mg $day.^{-1}$

Increasing world rice production under water scarcity condition with enhanced micronutrient content like iron and zinc in grains of rice could make a major contribution to meet the dietary demands of a growing global population. Hence present study was undertaken with the objective to study the correlation between the shoot, root morphological traits, direct and indirect effects of grain yield on different traits and relationship between grain yield with micronutrient (Fe and Zn) content under contrasting moisture regimes.

MATERIALS AND METHODS

Plant material

A doubled-haploid (DH) population were used in this study. The material for the present study was procured by from Barwale foundation, Hyderabad, India which was developed at International Rice Research Institute (IRRI). The material consists of a Ninthly-eight doubled-haploid (DH) lines developed from a cross between IR 64 (an *indica* type with a lowland and high yielding variety) and Azucena (an upland *japonica* type possessing a deep and thick root system) at IRRI were evaluated for plant growth and micronutrients content (Fe and Zn).

Root and Shoot morphological traits

Grain yield and related traits were evaluated in two seasons, one during Summer-2013 and other during *Kharif*-2013 at the field of Aerobic Rice Research Laboratory at the Department of Plant Biotechnology, University of Agricultural Sciences, G.K.V.K Campus, Bangalore representing the Eastern dry zone which is located at the latitude of 12º58′ North; longitude 77º35′ East and altitude of 930 meters above Mean Sea Level (MSL). The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Genotypes were raised by direct seeding in the polyvinyl chloride (PVC) pipes measuring about 1 meter in length and 18 cm diameter. The pipes were filled with fine, filtered, homogenized soil. Recommended cultural operations and plant protection measures were taken up to ensure uniform and healthy crop stand as per package of practices. Only one plant was allowed to grow in single pipe (Hemamalini *et al.,* 2000).

Two moisture regimes *viz.,* flooded and aerobic condition were maintained for Summer and *Kharif*-2013. In flooded condition, all the entries were watered daily and allow the water to stagnate throughout the cropping period. The plants were irrigated to field capacity; irrigation to field capacity was resumed and continued up to harvest. This constituted the aerobic environment (Venuprasad *et al.,* 2002). The sampling in both the condition was done at maturity stage.

In both the experiments, for shoot morphological traits observations on each plant were recorded on plant height (PHT) in centimeter, panicle length (PL) in centimeter, number of tillers (NOT), number of productive tillers (NPT), grain yield plant^{-1} (GY) in grams, shoot yield plant^{-1} (SY) in grams and test weight (TW) in grams. For root morphological traits, PVP pipes after harvest of plant with soil were thoroughly soaked in water over-night and sampled the next day. Sampling was done with care to retain roots, root hairs, and branches. Observations in all the three replication and condition were carried out. Samplings consisted of maximum root length (MRL) in centimeters, number of roots (RN), number of roots at 15 cm from the base of the stem (RN 15), root dry weight (RDW) in grams and root volume in cubic centimeters (RV).

Estimation of Iron and Zinc Content

Iron and Zinc content was estimated in the grain samples collected from the genotypes grown in the pipes. Grains of individual lines were harvested manually and hand threshed to avoid any contamination. The grains were then manually dehusked. Unbroken, uniform grains was then washed in dilute hydrochloric acid followed by washing with doublse distilled water to remove any surface contaminants and dried in hot air oven at 70 °C for 72 hours. The iron and Zinc content in these grains of brown rice was estimated from X-ray fluorescence (XRF) at M. S. Swaminathan Research foundation (MSSRF), Chennai, Tamil Nadu. The instrument was switched on 3-5 hours before the time when observations were to be recorded. Initially, five grams of grains from selected genotypes was subject to XRF as a standard to check the calibration of the equipment (Gande *et al.,* 2014). Grains from 98 DHs were subjected to XRF and the concentration was recorded in ppm. Three replications were maintained and their average was considered.

Statistical analysis

The correlation and path-coefficient analysis were computed with "WSTAT" statistical software package.

RESULTS AND DISCUSSION

Phenotypic correlation studies

Grain yield being a complex polygenic character, direct selection based on these traits would not yield fruitful results without giving due importance to their genetic background. The association of yield and its component traits reflects the nature and degree of relationship between them. The correlation analysis helps in examining the possibility of improving yield through indirect selection of its component traits which are highly correlated. In present investigation, correlation analysis was carried out in 98 DHs genotypes of IR64 x Azucena were grown in flooded and aerobic condition during Summer and *Kharif*-2013. The results of the correlation analysis for flooded and aerobic condition, Summer-2013 season were presented in Tables 1a and 1b. The results of the correlation analysis for flooded and aerobic condition, *Kharif*-2013 season were presented in Tables 2a and 2b.

Association between grain yield and its component characters

In Summer-2013 under flooded condition, four out of 13 characters studied *viz.*, plant height (0.200), panicle length (0.237), number of tillers (0.314) and number of productive tillers (0.248) exhibited significant positive correlation with grain yield per plant (Table 1a and 1b). However, plant height has significant positive correlation for panicle length (0.500), straw yield per plant (0.233) and test weight (0.246). Panicle length showed positive correlation for test weight (0.244). A significant positive correlation between number of tillers and number of productive tillers (0.989). Under aerobic condition, three out of 13 characters studied *viz.*, panicle length (0.327),

Table 1a: Phenotypic correlation coefficients for different traits in doubled-haploid lines under flooded condition -Summer 2013

	PH	PL	NOT	NPT	Sy/pl	TW	RW	RL	RV	RN	RN 15	FeG	ZnG
PL	0.500**												
NOT	-0.055	-0.116											
NPT	-0.085	-0.124	0.989**										
Sy/pl	0.233*	0.159	0.183	0.166									
TW	0.246*	0.244*	-0.179	-0.190	0.162								
RW	0.135	0.078	0.052	0.124	0.075	0.007							
RL	0.128	-0.037	-0.095	-0.135	0.385**	0.036	0.094						
RV	0.289**	0.052	0.085	0.090	0.213*	0.261**	0.076	0.440**					
RN	0.312**	0.183	0.041	0.086	0.145	-0.098	0.276**	0.457**	0.248*				
RN 15	0.391**	0.169	0.015	0.039	0.234*	-0.077	0.228*	0.503**	0.298**	0.936**			
FeG	-0.049	-0.139	0.146	0.080	0.078	-0.162	-0.053	0.082	0.055	0.055	0.001		
ZnG	-0.039	-0.104	0.021	0.022	-0.060	0.139	-0.258**	0.118	0.093	0.138	0.143	0.131	
GY/pl	0.200*	0.237*	0.314**	0.248*	0.171	0.003	-0.113	-0.091	-0.050	0.007	0.010	0.162	-0.129

Note: Fe and Zn content were analyzed in brown rice; *Significant @ P=0.05 ** Significant @ P=0.01

Table 1b: Phenotypic correlation coefficients for different traits in doubled-haploid under aerobic condition -Summer 2013

	PH	PL	NOT	NPT	Sy/pl	TW	RW	RL	RV	RN	RN 15	FeG	ZnG
PL	0.657**												
NOT	-0.082	-0.116											
NPT	0.013	0.014	0.957**										
Sy/pl	0.454**	0.198	0.124	0.210									
TW	0.046	0.338**	-0.122	0.116	0.018								
RW	0.229*	-0.030	0.235*	0.149	0.291**	-0.156							
RL	0.234*	-0.013	-0.119	-0.097	0.315**	-0.021	0.483**						
RV	0.306**	-0.095	0.206*	0.192	0.378**	0.032	0.623**	0.568**					
RN	0.355**	0.072	0.018	-0.013	0.204*	0.020	0.700**	0.515**	0.581**				
RN 15	0.390**	0.076	-0.028	-0.079	0.177	0.060	0.703**	0.524**	0.516**	0.969**			
FeG	-0.059	-0.116	-0.076	-0.053	-0.151	-0.210*	-0.009	-0.056	-0.020	-0.010	-0.025		
ZnG	-0.016	0.066	-0.311	-0.279**	-0.007	0.123	-0.139	-0.110	0.003	-0.026	-0.009	0.131	
GY/pl	0.184	0.327**	0.067	0.229*	0.244*	-0.232*	-0.165	0.089	-0.179	-0.203*	-0.180	0.152	-0.167

Note: Fe and Zn content were analyzed in brown rice; *Significant @ P=0.05 ** Significant @ P=0.01

number of productive tillers (0.229) and straw yield per plant (0.244) exhibited significant positive correlation with grain yield per plant. However, plant height has significant positive correlation for panicle length (0.657) and straw yield per plant (0.454). Panicle length showed positive correlation for test weight (0.338). A significant positive correlation between number of tillers and number of productive tillers (0.957).

In *Kharif*-2013 under flooded condition, five out of 13 characters studied *viz.*, plant height (0.218), panicle length (0.408), number of tillers (0.518), number of productive tillers (0.586) and straw yield per plant (0.433) exhibited significant positive correlation with grain yield per plant (Table 2a) However, plant height has significant positive correlation for panicle length (0.661), straw yield per plant (0.526) and test weight (0.310). Panicle length showed positive correlation for straw yield per plant (0.336) and test weight (0.261). Number of productive tillers (0.981) and straw yield per plant (0.493) showed significant positive correlation number of tillers. A significant positive correlation between number of productive tillers and straw yield per plant (0.435). Under aerobic condition, five out of 13 characters studied *viz.*, plant height (0.377), panicle length (0.237), number of tillers (0.384), number of productive tillers (0.422) and straw yield per plant (0.527) exhibited significant positive correlation with grain yield per plant (Table 2b). However, plant height has significant positive correlation for panicle length (0.575), number of tillers (0.334), number of productive tillers (0.305), straw yield per plant (0.599) and test weight (0.388). Panicle length showed positive correlation for number of tillers (0.281), number of productive tillers (0.295), straw yield per plant (0.378) and test weight (0.345). Number of productive tillers (0.938) and straw yield per plant (0.695) showed significant positive correlation number of tillers. A significant positive correlation between straw yield per plant and test weight (0.482). While grain Zn content showed significant negative association with grain yield per plant (-0.386).

Plant height, panicle length, number of tillers and number of productive tillers exhibited significant positive correlation with grain yield per plant. This results accordance with the Akinwale *et al.* (2011) for number of productive tillers. Rasheed *et al.* (2004); Khan *et al.* (2009) and Bekele *et al.* (2013a) reported similar results of significant and positive correlation between plant height and grain yield per plant. However, plant height has significant positive correlation for panicle length, straw yield per plant and test weight. Similar results were reported by Sandhu *et al.* (2013) and Raiz *et al.* (2013) between panicle length and plant height. Panicle length showed positive correlation for test weight. A significant positive correlation between number of tillers and number of productive tillers. Similar results were reported by Laxuman *et al.* (2011); Bekele *et al.* (2013a and b) and Gande *et al.* (2014).

Association among shoot and root related traits

In Summer-2013 under flooded condition (Table 1a), plant

Table 2a: Phenotypic correlation coefficients for different traits in doubled-haploid lines under flooded condition - *Kharif* 2013

	PH	PL	NOT	NPT	Sy/pl	TW	RW	RL	RV	RN	RN 15	FeG	ZnG
PL	0.661**												
NOT	0.139	0.124											
NPT	0.069	0.123	0.981**										
Sy/pl	0.526**	0.336**	0.493**	0.435**									
TW	0.310**	0.261**	-0.157	-0.211	0.082								
RW	0.290**	0.296**	0.146	0.148	0.530**	0.149							
RL	0.249*	0.198	-0.351	-0.227*	0.310**	0.153	0.512**						
RV	0.307**	0.219*	0.164	0.190	0.444**	0.067	0.811**	0.491**					
RN	0.425**	0.172	0.269**	0.258**	0.539**	-0.046	0.779**	0.526**	0.690**				
RN 15	0.420**	0.220**	0.109	0.185	0.385**	-0.044	0.685**	0.630**	0.573**	0.815**			
FeG	-0.318	-0.072	-0.138	-0.251*	-0.296	0.142	0.075	0.075	0.033	-0.237*	-0.190		
ZnG	-0.074	-0.003	-0.198	-0.162	-0.021	0.098	0.273**	0.322**	0.121	0.171	0.185	0.046	
GY/pl	0.218*	0.408**	0.518**	0.586**	0.433**	0.151	0.173	0.062	0.139	0.150	0.063	-0.175	-0.159

Note: Fe and Zn content were analyzed in brown rice; *Significant @ P=0.05 ** Significant @ P=0.01

Table 2b: Phenotypic correlation coefficients for different traits in doubled-haploid lines under aerobic condition- *Kharif* 2013

	PH	PL	NOT	NPT	Sy/pl	TW	RW	RL	RV	RN	RN 15	FeG	ZnG
PL	0.575**												
NOT	0.334**	0.281**											
NPT	0.305**	0.295**	0.938**										
Sy/pl	0.599**	0.378**	0.695**	0.637**									
TW	0.388**	0.345**	0.043	0.054	0.482**								
RW	0.202*	0.166	0.373**	0.340**	0.369**	0.238*							
RL	0.249*	0.114	0.042	0.068	0.408**	0.298**	0.764**						
RV	0.146	0.193	0.320**	0.249*	0.337*8	0.424**	0.964**	0.806**					
RN	0.276**	0.234*	0.174	0.152	0.366**	0.330**	0.783**	0.837**	0.806**				
RN 15	0.234*	0.272**	0.191	0.212	0.317	0.131	0.710	0.809**	0.789**	0.917**			
FeG	-0.053	0.184	0.010	-0.011	-0.088	0.162	0.002	-0.021	-0.058	-0.056	-0.012		
ZnG	0.012	0.126	0.107	0.053	0.109	0.142	0.345**	0.376**	0.332**	0.378**	0.257*	0.121	
GY/pl	0.377**	0.237*	0.384**	0.422**	0.527**	-0.003	0.283**	0.180	0.323**	0.310**	0.019	0.055	-0.386**

Note: Fe and Zn content were analyzed in brown rice; *Significant @ P=0.05 ** Significant @ P=0.01

height showed a positive correlation for root volume (0.289), root number (0.312) and root number at 15 cm from the base (0.391). Similarly, Straw yield per plant showed positive correlation for root length (0.385), root volume (0.213) and root number at 15 cm from the base (0.234). Under aerobic condition (Table 1b), plant height showed a positive correlation for all the root traits studied *viz.,* root dry weight (0.229), root length (0.234), root volume (0.306), root number (0.306) and root number at 15 cm from the base (0.390). Similarly, number of tillers has significant positive correlation for root volume (0.206). Straw yield per plant showed positive correlation for root dry weight (0.291), root length (0.315), root volume (0.378) and root number (0.204).

During *Kharif*-2013 under flooded condition (Table 2a), plant height showed a positive correlation for all the root traits studied *viz.* root dry weight (0.290), root length (0.249), root volume (0.307) root number (0.425) and root number at 15 cm from the base (0.420). Similarly, root number showed significant positive correlation for number of tillers (0.269) and number of productive tillers (0.258). Panicle length has significant positive correlation for root dry weight (0.296), root volume (0.219) and root number at 15 cm from the base (0.220). Straw yield per plant showed positive correlation for root dry weight (0.530), root length (0.310), root volume (0.444), root number (0.539) and root number at 15 cm from the base (0.385). Under aerobic condition (Table 2b), plant height showed a positive correlation for all the root traits studied *viz.* root dry weight (0.202), root length (0.249), root number (0.276) and root number at 15 cm from the base (0.234). Similarly, number of tillers and number of productive tillers has significant positive correlation for root dry weight (0.373 and 0.340) and root volume (0.320 and 0.249). Panicle length has significant positive correlation for root number (0.234) and root number at 15 cm from the base (0.272). Straw yield per plant showed positive correlation for root dry weight (0.369), root length (0.408), root volume (0.337) root number (0.366) and root number at 15 cm from the base (0.317).

Plant height showed a positive correlation for root dry weight, root volume, root length, root number and root number at 15 cm from the base. Sandhu *et al.* (2013) also reported that plant height showed significant positive correlation for root dry weight, root length, root volume and root number; Venuprasad *et al.* (2002) reported that there is a significant positive correlation between plant height and root length. Similarly, Straw yield per plant showed positive correlation for root length, root volume and root number at 15 cm from the base. Similar results were reported by Raiz *et al.* (2013) between root length and straw yield. Number of tillers has significant positive correlation for root volume. This is accordance with the Sandhu *et al.* (2013). Similarly, panicle length has significant positive correlation for root dry weight, root volume and root number at 15 cm from the base. This is accordance with the

Table 3a: Path-coefficient analysis for different traits of doubled-haploid lines under flooded condition – Summer 2013

	PH	PL	NOT	NPT	Sy/pl	TW	RW	RL	RV	RN	RN 15	FeG	ZnG	Partial R^2
PH	0.107	0.054	-0.006	-0.009	0.025	0.026	0.014	0.014	0.031	0.033	0.042	-0.004	-0.004	0.021
PL	0.211	0.423	-0.149	-0.053	0.067	0.103	0.033	-0.016	0.022	0.078	0.071	-0.059	-0.044	0.100
NOT	0.331	0.704	-0.064	-0.995	-0.110	1.086	-0.318	0.573	-0.514	-0.246	-0.090	-0.882	-0.128	-1.904
NPT	-0.566	-0.829	0.806	0.682	0.108	-1.269	0.827	-0.902	0.601	0.572	0.259	0.532	0.150	1.655
Sy/pl	-0.050	-0.034	-0.039	-0.035	-0.213	-0.035	-0.016	-0.082	-0.046	-0.031	-0.050	-0.017	0.013	-0.036
TW	0.040	0.040	-0.029	-0.031	0.027	0.164	0.001	0.006	0.043	-0.016	-0.013	-0.027	0.023	0.001
RW	-0.081	-0.046	-0.031	-0.074	-0.045	-0.004	-0.198	-0.057	-0.045	-0.165	-0.136	0.032	0.155	0.067
RL	0.115	-0.034	-0.085	-0.121	0.345	0.032	0.085	0.897	0.395	0.410	0.451	0.073	0.106	-0.082
RV	-0.156	-0.028	-0.046	-0.049	-0.115	-0.141	-0.041	-0.237	-0.539	-0.134	-0.161	-0.030	-0.050	0.027
RN	-0.479	-0.282	-0.062	-0.132	-0.222	0.150	-0.425	-0.704	-0.382	0.639	-1.441	-0.085	-0.212	-0.011
RN 15	0.381	0.165	0.015	0.038	0.228	-0.075	0.222	0.490	0.291	0.013	0.975	0.001	0.139	0.010
FeG	-0.029	-0.082	0.086	0.047	0.046	-0.096	-0.032	0.048	0.032	0.033	0.000	0.591	0.078	0.096
ZnG	0.009	0.025	-0.005	-0.005	0.014	-0.033	0.061	-0.028	-0.022	-0.033	-0.034	-0.031	-0.238	0.031

Residual effect: 0.47; Note: Fe and Zn content were analyzed in brown rice

Table 3b: Path-coefficient analysis for different traits of doubled-haploid lines under aerobic condition– Summer 2013

	PH	PL	NOT	NPT	Sy/pl	TW	RW	RL	RV	RN	RN 15	FeG	ZnG	Partial R^2
PH	0.011	0.664	-0.082	0.013	0.459	0.046	0.232	0.236	0.309	0.359	0.395	-0.059	-0.017	0.186
PL	-0.652	0.993	0.115	-0.014	-0.196	-0.336	0.029	0.013	0.095	-0.071	-0.076	0.115	-0.066	-0.325
NOT	0.083	0.117	-0.014	-0.970	-0.126	0.123	-0.238	0.121	-0.208	-0.019	0.029	0.077	0.315	-0.068
NPT	0.012	0.012	0.856	0.895	0.188	0.104	0.134	-0.087	0.172	-0.012	-0.071	-0.047	-0.250	0.205
Sy/pl	-0.128	-0.055	-0.035	-0.059	-0.281	-0.005	-0.082	-0.088	-0.106	-0.057	-0.050	0.042	0.002	-0.068
TW	0.274	0.244	0.030	0.038	0.341	0.708	0.168	0.211	0.300	0.233	0.093	0.115	0.100	0.000
RW	0.157	-0.020	0.161	0.102	0.200	-0.107	0.686	0.331	0.427	0.480	0.482	-0.006	-0.095	-0.113
RL	0.153	-0.008	-0.078	-0.064	0.206	-0.014	0.317	0.656	0.372	0.338	0.344	-0.037	-0.072	0.058
RV	-0.338	0.105	-0.227	-0.212	-0.417	-0.036	-0.688	-0.627	-1.104	-0.642	-0.570	0.022	-0.004	0.197
RN	1.076	0.217	0.055	-0.039	0.619	0.060	2.124	1.562	1.763	-0.682	0.837	-0.032	-0.080	-0.616
RN 15	-1.404	-0.274	0.102	0.286	-0.638	-0.216	-2.530	-1.886	-1.856	-3.484	-0.957	0.091	0.031	0.778
FeG	0.008	0.016	0.010	0.007	0.021	0.029	0.001	0.008	0.003	0.001	0.003	-0.136	-0.018	-0.021
ZnG	-0.003	0.013	-0.061	-0.054	-0.001	0.024	-0.027	-0.022	0.000	-0.005	-0.002	0.025	0.195	-0.033

Residual effect: 0.422: Note: Fe and Zn content were analyzed in brown rice

Venuprasad *et al.* (2002) for panicle length. Root number showed significant positive correlation for number of tillers and number of productive tillers. Similarly, number of tillers and number of productive tillers has significant positive correlation for root dry weight and root volume. Similar results were reported by Sandhu *et al.* (2013) between root number, root volume, number of tillers and number of productive tillers.

Association among grain yield and root related traits

Correlation analysis was carried out to identify how root morphological characters influence the grain yield and yield morphological traits. In *Kharif*-2013 under aerobic condition, a significant positive correlation between test weight and root weight (0.238). Similarly, root dry weight (0.283), root volume (0.323) and root number (0.310) exhibited significant positive correlation for grain yield per plant (Table 2b). Similarly, root dry weight, root volume and root number exhibited significant correlation for grain yield per plant. Our study identified a significant and positive correlation between some of the root traits (root number, root volume and root dry weight) and grain yield under aerobic condition, indicating the role of root traits for improving yield under aerobic situations possibly through improved water and nutrient uptake. This shows that a well developed root system will help the plant in maintaining high plant water status which ultimately leads to increase in yield potential under aerobic condition. This is accordance with the Venuprasad *et al.* (2002) and Sandhu *et al.* (2013).

Association among root related traits with grain Zinc

In Summer-2013 under flooded condition, root weight (0.273) and root length (0.322) exhibited significant positive correlation for grain Zn (Table 1a). During *Kharif*-2013 under aerobic condition, root traits like root dry weight (0.345), root volume (0.332), root length (0.376), root number (0.378) and root number at 15 cm from the base (0.257) showed significant positive correlation for grain Zn content (Table 2b).

Association among root related traits

Root traits like root dry weight, root length, root volume, root number and root number at 15 cm from the base showed significant positive correlation among themselves irrespective of treatments (flooded and aerobic condition) and seasons (Summer and *Kharif*-2013). This is inaccordance with the Toorchi *et al.* (2002), Mohankumar *et al.* (2011) and Sandhu *et al.* (2013).

Relationship between grain yield and grain nutrient contents

Assessment of the relationship between grain Fe and Zn content and grain yield per plant in DH grown in Summer and *Kharif*-2013 showed that there was presence of negative correlation in these traits as shown on Figures 1, 2 and 3, 4 respectively. Thus, selection for enhancement of these traits could be executed separately but simultaneously. Similar reports on negative correlation between grain Zn concentration and grain yield per plant were revealed by Shi *et al.* (2008); Nagarathna

Table 4a: Path-coefficient analysis for different traits of doubled-haploid lines under flooded condition – *Kharif* 2013

	PH	PL	NOT	NPT	Sy/plt	TW	RW	RL	RV	RN	RN 15	FeG	ZnG	Partial R^2
PH	-0.588	-0.389	-0.082	-0.040	-0.310	-0.182	-0.171	-0.146	-0.180	-0.250	-0.247	0.187	0.044	-0.128
PL	0.230	0.348	0.043	0.043	0.117	0.091	0.103	0.069	0.076	0.060	0.077	-0.025	-0.001	0.142
NOT	0.036	0.032	0.261	0.255	0.128	-0.041	0.038	-0.092	0.043	0.070	0.028	-0.036	-0.052	0.135
NPT	0.002	0.004	0.035	0.835	0.015	-0.008	0.005	-0.012	0.007	0.009	0.007	-0.009	-0.006	0.021
Sy/plt	0.124	0.079	0.116	0.103	0.236	0.019	0.125	0.073	0.105	0.127	0.091	-0.070	-0.005	0.102
TW	0.126	0.106	-0.064	-0.086	0.033	0.407	0.061	0.062	0.027	-0.019	-0.018	0.058	0.040	0.061
RW	-0.159	-0.162	-0.080	-0.081	-0.291	-0.082	-0.548	-0.281	-0.445	-0.427	-0.376	-0.041	-0.150	-0.155
RL	-0.018	-0.014	0.026	0.024	-0.023	-0.011	-0.037	-0.073	-0.036	-0.038	-0.046	-0.006	-0.024	-0.005
RV	0.103	0.074	0.055	0.064	0.149	0.023	0.273	0.165	0.336	0.232	0.193	0.011	0.041	0.109
RN	0.463	0.188	0.293	0.282	0.588	-0.050	0.849	0.574	0.753	-1.091	0.839	-0.258	0.187	0.338
RN 15	-0.259	-0.136	-0.067	-0.114	-0.237	0.027	-0.423	-0.389	-0.354	-0.503	-0.618	0.118	-0.114	-0.039
FeG	0.070	0.016	0.031	0.056	0.066	-0.031	-0.017	-0.017	-0.007	0.052	0.042	-0.222	-0.010	0.070
ZnG	0.004	0.000	0.012	0.009	0.001	-0.006	-0.016	-0.019	-0.007	-0.010	-0.011	-0.003	-0.058	0.009

Residual effect: 0.39; Note: Fe and Zn content were analyzed in brown rice

Table 4b: Path-coefficient analysis for different traits of doubled-haploid lines under aerobic condition– *Kharif* 2013

	PH	PL	NOT	NPT	Sy/pl	TW	RW	RL	RV	RN	RN 15	FeG	ZnG	Partial R^2
PH	0.648	0.372	0.216	0.197	0.388	0.251	0.131	0.161	0.095	0.179	0.152	-0.034	0.008	0.244
PL	-0.736	1.282	-0.360	-0.378	-0.484	-0.443	-0.213	-0.146	-0.247	-0.300	-0.349	-0.235	-0.162	-0.304
NOT	-0.859	-0.723	-1.571	-0.412	-1.787	-0.110	-0.958	-0.109	-0.824	-0.448	-0.492	-0.027	-0.274	-0.986
NPT	0.860	0.833	1.648	1.822	1.799	0.151	0.959	0.193	0.704	0.428	0.598	-0.032	0.150	1.190
Sy/pl	-0.043	-0.027	-0.050	-0.046	-0.072	-0.035	-0.027	-0.029	-0.024	-0.026	-0.023	0.006	-0.008	-0.038
TW	0.274	0.244	0.030	0.038	0.341	0.708	0.168	0.211	0.300	0.233	0.093	0.115	0.100	-0.002
RW	-0.063	-0.052	-0.116	-0.106	-0.115	-0.074	-0.312	-0.238	-0.301	-0.244	-0.222	-0.001	-0.108	-0.029
RL	-0.598	-0.275	-0.102	-0.164	-0.980	-0.717	-1.836	-1.404	-1.939	-2.113	-1.946	0.051	-0.905	-0.433
RV	0.083	0.109	0.180	0.140	0.190	0.239	0.543	0.454	0.563	0.454	0.444	-0.033	0.187	0.025
RN	-0.700	-0.594	-0.443	-0.386	-0.929	-0.838	-1.990	-1.127	-1.047	-1.541	-2.029	0.142	-0.962	-0.229
RN 15	0.931	1.082	0.761	0.843	1.260	0.522	2.823	1.219	1.136	2.645	0.977	-0.046	1.023	0.075
FeG	-0.006	0.021	0.001	-0.001	-0.010	0.018	0.000	-0.002	-0.007	-0.006	-0.001	0.113	0.014	0.006
ZnG	0.009	0.099	0.084	0.042	0.086	0.111	0.272	0.296	0.261	0.298	0.202	0.095	0.387	-0.304

Residual effect: 0.51; *Note*: Fe and Zn content were analyzed in brown rice

PH	: Plant height (cm)	PL	: Panicle length (cm)
NOT	: Number of tillers	NPT	: Number of productive tillers
Gy/pl	: Grain yield/plant (g)	Sy/pl	: Straw yield/plant (g)
TW	: Test weight (g)	RW	: Root dry weight (g)
RL	: Root length (cm)	RV	: Root volume (cc)
RN	: Root number	RN 15	: Root number @ 15 cm from the base
FeG	: Grain Iron (ppm)	ZnG	: Grain Zinc (ppm)

et al. (2010); Nagesh *et al.* (2012) and Bekele *et al.* (2013a).

Path-coefficient analysis

The relationship between grain yield and yield components may be negative or positive but it is the net result of direct effect of that particular trait and indirect effects *via* other traits. Hence, it is necessary to determine the path coefficients which partition the observed correlation in to direct and indirect effects and also reveals the cause and effect relationship between grain yield and their related traits and the results of the same are presented in Tables 3a and 3b for Summer and Tables 4a and 4b for *Kharif*-2013 flooded and aerobic conditions respectively.

Path analysis in DHs population of cross IR64 x Azucena

In DH grown in Summer-2013 under flooded condition, number of roots at 15 cm from the base had the highest positive direct effect (0.975), followed by root length (0.897), number of productive tillers (0.682), root number (0.639), grain Fe content (0.591), panicle length (0.423) and plant height (0.107) towards grain yield per plant. Among the characters studied, straw yield per plant (-0.213) had the highest negative direct effect towards grain yield per plant. Whereas, number of tillers (-0.064) had lowest negative direct effect towards grain yield per plant. Root weight (0.827) had highest positive indirect effect via number of productive tillers on grain yield. Plant height (0.009) *via* grain zinc content had lowest positive indirect effect on grain yield per plant. Test weight (-1.269) *via* number of productive tillers had highest negative indirect effect on grain yield. Grain zinc content (-0.005) via number of tillers and number of productive tillers had lowest negative indirect effect on grain yield (Table 3a).

In DH grown in *Kharif*-2013 under flooded condition, number of productive tillers (0.835) had the highest positive direct effect, followed by test weight (0.407), panicle length (0.348), root volume (0.336) and straw yield per plant (0.236) towards grain yield per plant. Among the characters studied, root number at 15 cm from the base (-1.091) had the highest negative direct effect towards grain yield per plant. Whereas, grain Zn content (-0.058) had lowest negative direct effect towards grain yield per plant. Root weight (0.849) had highest positive indirect effect *via* root number at 15 cm from the base on grain yield. Plant length (0.000) *via* grain zinc content had

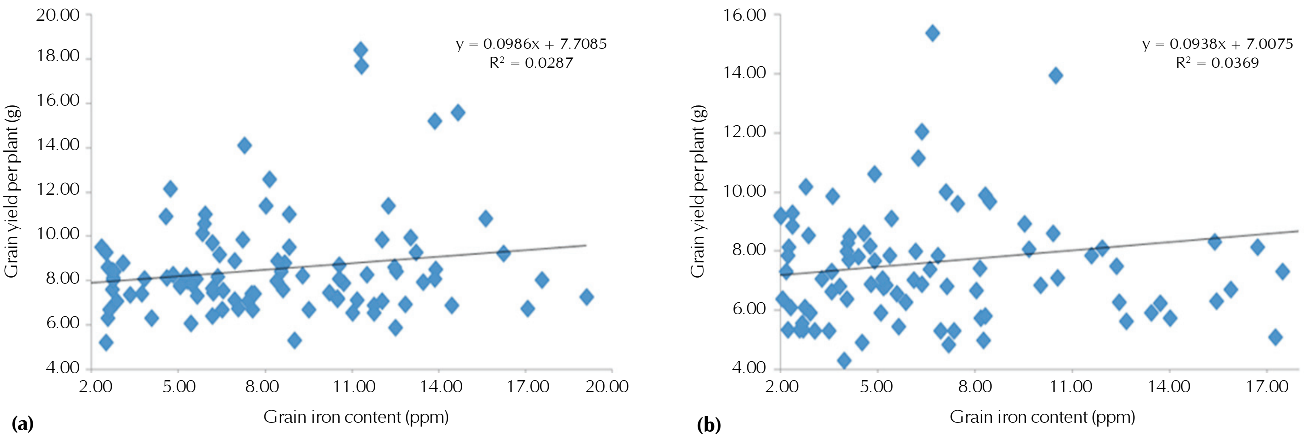

Figure 1: Relationship between grain Iron content and grain yield per plant in doubled-haploid lines grown under (a) Flooded condition (b) Aerobic condition, during Summer-2013

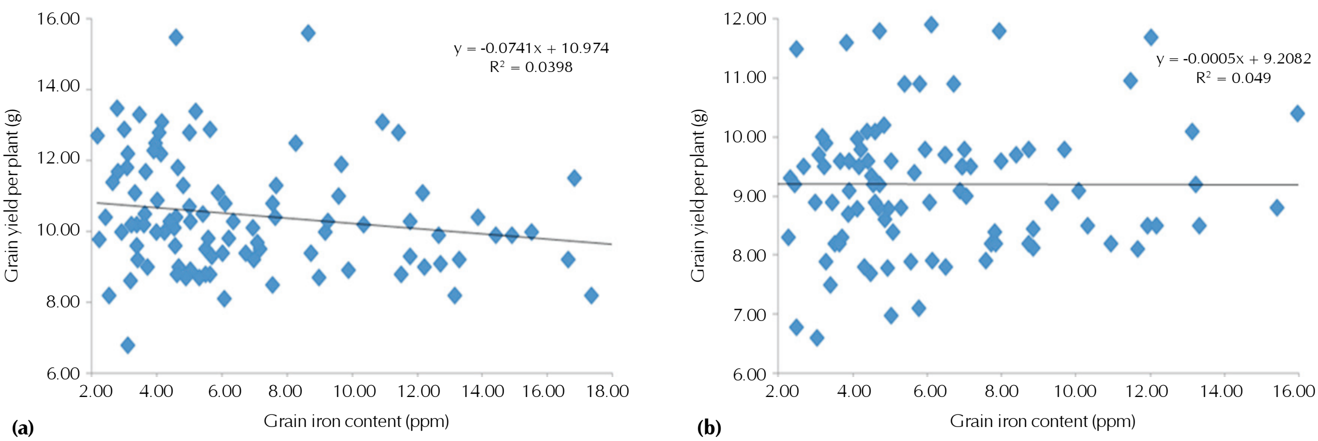

Figure 2: Relationship between grain Iron content and grain yield per plant in doubled-haploid lines grown under (a) Flooded condition (b) Aerobic condition, during *Kharif*-2013

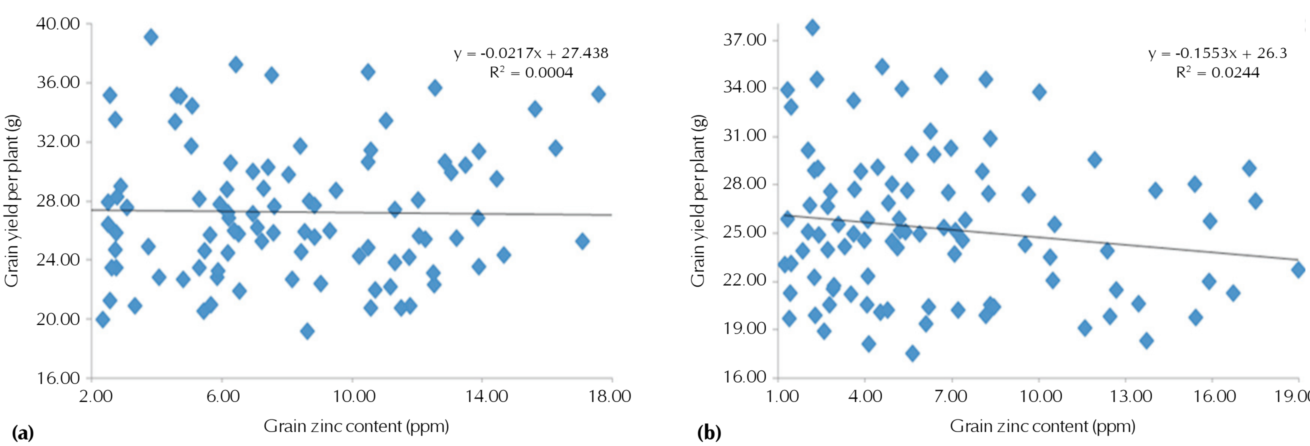

Figure 3: Relationship between grain Zinc content and grain yield per plant in doubled-haploid lines grown under (a) Flooded condition (b) Aerobic condition, during Summer-2013

lowest positive indirect effect on grain yield per plant. Root volume (-0.445) *via* root weight had highest negative indirect effect on grain yield. Grain Zn content (-0.001) *via* panicle length had lowest negative indirect effect on grain yield (Table 4a).

Under flooded condition, the phenotypic path-coefficient analysis indicated high positive direct effect of number of roots at 15 cm from the base, root length, number of productive tillers, root number, root volume, grain Fe content, panicle length and plant height on grain yield per plant. Under aerobic

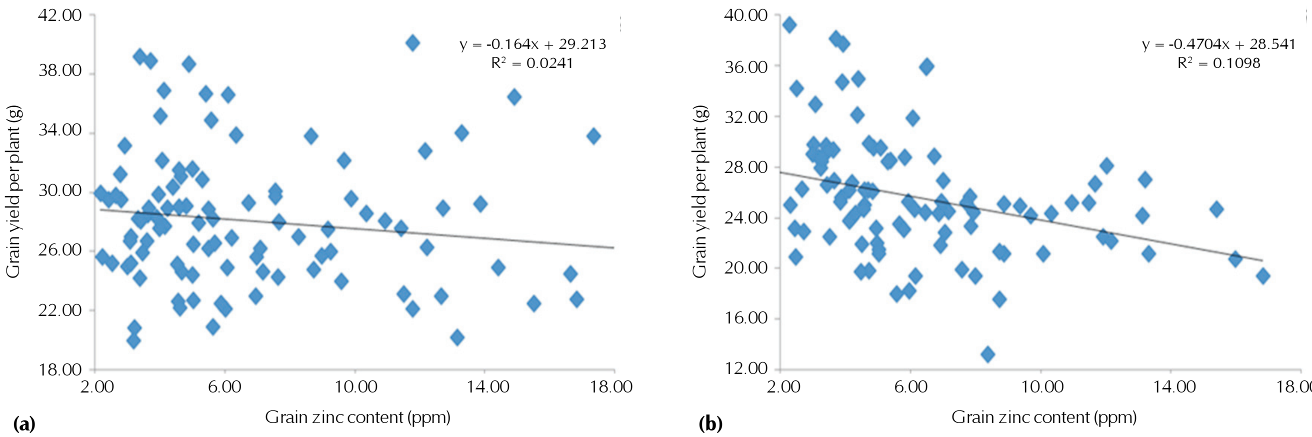

Figure 4: Relationship between grain Zinc content and grain yield per plant in doubled-haploid lines grown under (a) Flooded condition (b) Aerobic condition, during *Kharif*-2013

condition, the phenotypic path-coefficient analysis indicated high positive direct effect of panicle length, number of productive tillers per plant, test weight, root weight, root length, grain Zn and plant height on grain yield per plant. Similar results were reported by Raju *et al.* (2004); Rajeshwari and Nadarajan (2004); Shashidhar *et al.* (2005); Suman *et al.* (2005); Panwar *et al.* (2007); Nagesh *et al.* (2012) for high positive direct effect of number of productive tillers per plant on grain yield per plant. Akhtar *et al.* (2011) for high positive direct effect of test weight on grain yield per plant. Bekele *et al.* (2013b) for high positive direct effect of number of productive tillers and plant height on grain yield per plant. Mohankumar *et al.* (2011) reported positive direct effects of different root traits on grain yield. Nagesh *et al.* (2012) and Bekele *et al.* (2013b) reported lowest positive direct effects of grain Zn on grain yield per plant. This indicated that grain Zn content had no contribution towards grain yield.

During Summer-2013 under aerobic condition, panicle length (0.993) had the highest positive direct effect of followed by number of productive tillers per plant (0.895), test weight (0.708), root weight (0.686), root length (0.656), grain zinc (0.195) and plant height (0.011) towards grain yield per plant. Among the characters studied, root volume (-1.104) had the highest negative direct effect towards grain yield per plant. Whereas, number of tillers (-0.014) had lowest negative direct effect towards grain yield per plant. Root weight (2.124) had highest positive indirect effect via number of roots at 15 cm from the base on grain yield. Grain Zn content (0.000) *via* root volume had lowest positive indirect effect on grain yield per plant. Root weight (-2.530) *via* root number at 15 cm from the base had highest negative indirect effect on grain yield. Grain Zn content (-0.002) via root number at 15 cm from the base had lowest negative indirect effect on grain yield (Table 3b).

During *Kharif*-2013 under aerobic condition, number of productive tillers (1.822) had the highest positive direct effect of followed by panicle length (1.282), root number at 15 cm from the base (0.977), test weight (0.708), root length (0.563), grain Zn (0.387) and grain iron content (0.113) towards grain yield per plant. Among the characters studied, number of tillers (-1.571) had highest negative direct effect towards grain yield per plant. Whereas, straw yield per plant (-0.072) had the lowest negative direct effect towards grain yield per plant. Root weight (2.823) had highest positive indirect effect via number of roots at 15 cm from the base on grain yield per plant. Grain Fe content (0.000) *via* root weight had lowest positive indirect effect on grain yield per plant. Root number (-2.113) *via* root length had highest negative indirect effect on grain yield. Grain Fe content (-0.001) *via* root length number at 15 cm from the base had lowest negative indirect effect on grain yield (Table 4b).

Under flooded condition, among the characters studied root weight highest positive indirect effect *via* number of productive tillers, plant height *via* grain Zn content had lowest positive indirect effect on grain yield per plant. Akhtar *et al.* (2011) reported high positive indirect effect of number of tillers and plant height on grain yield per plant. Under aerobic condition, among the characters studied, root weight had highest positive indirect effect *via* number of roots at 15 cm from the base on grain yield. Mohankumar *et al.* (2011) reported positive direct and indirect effects of different root traits on grain yield. Grain Zn content *via* root volume had lowest positive indirect effect on grain yield per plant.

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