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Effect of zinc application on dry matter yield of plant parts in rice varieties of varying zinc sensitivity

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Abstract
A pot experiment was conducted in the green house of GB Pant University of Agriculture and Technology Pantnagar, to study the effect of Zn treatment on its concentration and dry matter yield in different plant parts of four rice varieties. The soil had sandy loam texture, 7.2 pH, 0.9% organic carbon and 0.47 mg DTPA extractable Zn per kg soil. Each pot received recommended dose of 25 mg N, 11.2 mg P and 20.75 mg K kg^{-1} soil. The plants of four rice varieties (PD 6, PD 16, NDR 359, PS 5) were harvested after 30, 60, 90 and 120 days after transplanting and roots were also retrieved from the soil. Plant parts were separated, dried and weighed at each stage. The data was analyzed under three factorial completely randomized design.

The main effects of type of plant parts, Zn level and varieties influenced the dry matter yield of rice plants significantly at 30 days after transplanting. The main effect of plant parts had statistically significant effect on the average dry matter yield of different plant parts of rice at 60 days after transplanting. The main effect of type of plant parts and variety affected the average dry matter yield of rice plants significantly at 90 days after transplanting. The main effect of plant parts, Zn levels and varieties had statistically significant effect on dry matter yield of rice plants at 120 days of transplanting.

Keywords: Zinc, rice, dry matter, plant parts

Introduction

Zinc has low mobility in soil solution and its uptake is limited though diffusion. Reduced phytoavailability of Zn is prevailing in calcareous soils of arid and semi- arid areas as the hydroxides and carbonates formed under such conditions are too insoluble to meet the plant requirement. Thus, sometimes plants suffer from Zn deficiency, although the total content of Zn in soil may be very high. Low amount of organic matter, alkaline pH, coarse textured soils and heavy application of phosphatic fertilizers are the factors affecting the availability of native as well as added Zn fertilizers in soil. As an essential micronutrient, Zn is required for various physiological and metabolic processes in plants. It is the only metal which is present in the six classes of enzymes: oxidoreductases, transferases, hydrolases, lyases, isomerases and ligases (Auld, 2001) [1]. Plant response to Zn deficiency occurs in terms of decrease in membrane integrity, susceptibility to heat stress, decreased synthesis of carbohydrates, cytochromes, nucleotide, auxin and chlorophyll (Marschner, 1995) [9]. Zinc efficiency which may be defined as the ability of a plant to grow and yield better under Zn deficient conditions also varies among cultivars of cereals (Graham *et al*., 1993; Erenoglu *et al*., 2000) [4]. Therefore, the knowledge dry matter yield of different plant parts of rice varieties with varying Zn sensitivity at different growth stages could help in devising selection of varieties in order to overcome Zn malnutrition under Zn deficient conditions and can also provide better breeding materials.

Materials and Methods

A pot experiment was conducted in the green house of GB Pant University of Agriculture and Technology Pantnagar, District Udham Singh Nagar, Uttarakhand. A bulk surface (0-15cm) samples of Mollisol was collected from portions of E1 plot of Norman E. Borlaug Crop research Centre of the University. The soil had sandy loam texture 7.2 pH, 0.9 percent organic carbon and 0.47 mg DTPA extractable Zn per kg soil. The processed soil (4 kg) was filled in plastic pots. Each pot received recommended dose of NPK through urea, potassium hydrogen phosphate and potassium chloride basally in liquid form. The pretreatment imposed consisted of a factorial combination of four rice varieties (PD 6, PD 16, NDR 359, PS 5) and two Zn levels (0 and 10 mg Zn kg^{-1} soil). There were two replications. Zinc was applied through a stock solution of $Zn.SO_4.7H_2O$. The plants were harvested after 30, 60, 90 and 120 days of sowing. Roots were also recovered from the soil after shoot harvest at each level. Plants were separated as shoots and roots were separated into upper lamina, lower lamina and panicle at different stages. The separated plant parts were dried and weighed for dry matter yield. The data obtained was analyzed by using 3 factorial completely randomized design.

Results

Effect of Zn application on dry matter yield of different plant parts of rice varieties at different growth stages

Dry matter yield of different plant parts of rice at 30 days after transplanting

The main effects of type of plant parts, Zn level and varieties influenced the dry matter yield of rice plants significantly at 30 days after transplanting. Different plant parts could be arranged in the following decreasing order of average dry matter yield at 30 days after transplanting: upper lamina (0.078 g) > lower lamina (0.060 g) = roots (0.058 g) > upper leaf sheath (0.035 g) = lower leaf sheath (0.030 g) > stem (0.018 g). As regards the effects of Zn application on the average dry matter yield of rice at 30 days after transplanting, application of 10 mg Zn kg^{-1} soil decreased the average dry matter yield of plant parts significantly by 8.4 per cent in comparison to no application of Zn. Among the rice varieties, the highest average dry matter yield of rice at 30 days after transplanting was recorded in the case of NDR 359 (0.052 g). The difference in average dry matter yield between NDR 359 and PD 6 was statistically significant.

The interaction effect of variety and Zn levels had significant influence on the average dry matter yield of rice at 30 days after transplanting. Application of 10 mg Zn kg^{-1} soil brought a small but statistically significant decrease in the average dry matter yield of PD 6 and NDR 359 in comparison to no application of Zn, respectively.

Dry matter yield of different plant parts of rice varieties at 60 days after transplanting

It is apparent from the data that the main effect of plant parts had statistically significant effect on the average dry matter yield of different plant parts of rice at 60 days after transplanting whereas, the main effect of Zn levels and varieties did not impart any statistically significant variation in the average dry matter yield. Among different plant parts of rice, the highest average dry matter accumulation was recorded for upper sheath (1.358 g) emerging followed by lower leaf sheath (1.293 g), panicle (1.259 g), stem (0.959 g), lower lamina (0.933 g), upper lamina (0.887 g). However, the differences in the average dry matter accumulation among upper leaf sheath and lower leaf sheath or among stem, lower lamina and upper lamina were statistically not significant. This indicated that at 60 days of transplanting the emerging panicle started accumulating dry matter in all four rice varieties. The interaction effect of plant parts and varieties had a significant effect on the average dry matter accumulation of rice at 60 days after transplanting.

From the data it appeared that in all the varieties except NDR 359, the maximum dry matter accumulated in emerging panicle and decreased downward in the plant resulting in the lowest accumulation in the roots. It was interesting to note that the highest average dry matter in panicle was recorded for PD 6 and the average dry matter for root was also the lowest for this variety whereas, in NDR 359; Zn inefficient genotype the average dry matter accumulation in roots, lower sheath, lower lamina, upper sheath and upper lamina after 60 days of transplanting was higher. This indicated that in the inefficient variety more of the dry matter accumulated in lower parts and comparatively less accumulation took place in panicle amounting to a delay in emergence of panicle as compared to the other varieties.

Dry matter yield of different plant parts of rice varieties at 90 days after transplanting

As apparent from the data, the main effect of type of plant parts and variety affected the average dry matter yield of rice plants significantly at 90 days after transplanting. As regards the influence of variety on the average dry matter yield of plant parts, the highest average dry matter production was recorded in NDR 359 followed by PS 5, PD 16 and PD 6 however, the difference in the average dry matter between NDR 359 and PS 5 was statistically not significant. The interaction effects of plant parts and varieties and plant parts and Zn levels showed statistically significant variation in the average dry matter yield of rice plants. The significant interaction effect of plant parts and Zn levels showed that the application of 10 mg Zn kg^{-1} soil significantly decreased the average dry weight of stem by 8.3 percent but increased the average dry weight of panicle by 7.8 percent over no application of Zn.

It appeared from the results that after 90 days of transplanting, the application of Zn (10 mg Zn kg^{-1}) was capable of increasing dry matter accumulation in panicle part of rice as compared to no application of Zn. Among all four varieties PD 6 maintained the lowest dry matter yield in all plant parts including panicles which reflected its lower efficiency for dry matter accumulation as compared to other four varieties.

Dry matter yield of different plant parts of rice varieties at 120 days after transplanting

The data revealed that the main effect of plant parts, Zn levels and varieties had statistically significant effect on dry matter yield of rice plants at 120 days of transplanting. Among the plant parts maximum dry weight was recorded for grains (6.26 g) followed by stem (1.54 g), upper leaf sheath (1.33 g), lower leaf sheath (1.08 g), lower lamina (0.74 g), upper lamina (0.68 g) and root (0.64 g). Application of 10 mg Zn kg^{-1} soil increased the average dry matter yield in plant parts of rice by 10.3 percent over no application of Zn. Among rice varieties, the highest average dry matter yield was recorded for PS 5 (2.11 g) followed by NDR 359 (2.05 g), PD 6 (1.59 g) and PD 16 (1.27 g) however; the average dry matter yields noted in PS 5 and NDR 359 varieties did not vary significantly from each other.

The interaction effect of plant parts and Zn levels on the average dry matter yield of rice at 120 days after transplanting was statistically significant. Application of 10 mg Zn kg^{-1} soil increased the average dry matter yield in grains only by 13.0 percent in comparison to no application of Zn. The interaction effect of Zn levels and varieties also influenced the average dry matter accumulation in rice significantly. Application of 10 mg Zn kg^{-1} soil increased the average dry matter yield only in case of NDR 359. The interaction effect of plant parts and varieties affected the dry matter yield of rice significantly. Among different plant parts, the interaction effect of plant parts, Zn levels and varieties significantly influenced the dry matter yield of only grain part. The application of 10 mg Zn $kg-^{1}$ soil increased the grain yield of NDR 359 by 41.3 percent over no application of Zn while in rest of the varieties the increase in grain yield with Zn application was statistically not significant. Application of 10 mg Zn kg^{-1} soil also increased the dry matter yield of lower sheath in PS 5 in comparison to no application of Zn.

The main effect of Zn application was more prominent at the harvest i.e. 120 days after transplanting indicating the significance of Zn in seed setting besides promontory effects on chlorophyll and indole acetic acid contents (Hemantarajan and Gray, 1988) [7]. Zinc starvation has been suggested to cause inhibition of activity of aldolase, sucrose synthase and starch synthetase in plant tissues consequently decreasing the dry matter yield in plants (Marschner, 1995) [9]. Fageria (2001) [3] observed that the adequate Zn levels in soil increased tillering and consequently the dry matter yield also increased. The average dry matter yield in all four varieties did not differ from each other significantly at 60 days after transplanting while; main effect of rice varieties significantly affected the dry matter yield at 30, 90 and 120 days after transplanting. At both the stages, PS 5 was noted with the highest dry matter yield owing to its taller plant type and greater capacity to utilize Zn. On evaluating lowland rice genotypes with distinct tolerance to Zn deficiency in a nutrient solution, Chen *et al*. (2009) noted that the efficient genotype was more efficient particularly; in internal utilization of Zn; a higher antioxidative enzyme activity was observed per unit amount of Zn in the plant tissue. At 120 days after transplanting, with the application of 10 mg Zn kg^{-1} soil highest increase in average dry matter of grain was observed over no application of Zn. In a field experiment conducted by Hafeez *et al.* (2010) [5], the grain yield was significantly influenced by Zn application in the six tested genotypes of rice and ranged from 2.15 to 7.05 tons ha^{-1}. The maximum grain yield (7.05 tons ha $^{-1}$) was produced by Bahagia rice genotype which was 47 percent higher than the control while MR 211 genotype had significantly lowest (2.15 ton ha $^{-1}$) grain yield as compared to the other six rice genotypes. Pandey *et al.* (2005) also concluded that poor grains were produced in Zn deficient plants.

However, at 30 after transplanting, with application of 10 mg Zn kg^{-1} soil a decrease of 8.4 percent was noticed in average dry matter yield in plant parts of rice as compared to no Zn application. The decrease in average dry matter yield in rice varieties has been observed at some growth stages. In the experiments conducted for evaluating the screening indices for grain yield and grain Zn mass concentration in aerobic rice, Jiang *et al*. (2008) [8] reported that higher Zn application may not necessarily increase the biomass production in all genotypes due to their low Zn use efficiency. In the same study it was observed that with increasing Zn uptake, plants first allocate the additional Zn to vegetative organs with relatively low metabolic activity (stems and sheaths), while leaves and grains only show moderate increases in Zn concentration. With continuing increase in uptake, the rate of increase in Zn concentration of the leaves changes, which coincides with the observed negative effect on dry matter accumulation. A significant Zn×V interaction at 30 days after transplanting revealed that 10 mg Zn kg^{-1} soil application brought a statistically significant decrease in average dry matter yield both in PD 6 and NDR 359 owing to poor dry matter accumulation in stem, upper leaf sheath and upper lamina in the former variety while due to poor root growth and dry matter accumulation in stem, upper leaf sheath and upper lamina in the latter variety. Rengel *et al.* (1998) [10] observed a better root growth in Zn sensitive genotypes under Zn deficient conditions and were of the opinion that possible compensation for lower capacity of Zn sensitive genotype to take up Zn from low Zn activity soil environment induced higher root growth. On the other hand Hajiboland *et al*. (2003) [6] reported strong inhibition in root growth under high bicarbonate (Zn deficiency) in Zn-inefficient genotypes of rice whereas; Zn-efficient genotypes remained unaffected or enhanced the root growth.

Table 1: Effect of Zn application on dry matter yield (g) of different plant parts of rice varieties at 30 days after transplanting

Varieties	Root			Stem			Lower sheath			Lower lamina			Upper sheath			Upper lamina			Mean of plant parts		
	Zn0	Zn10	Mean	Zn0	Zn10	Mean	Zn0	Zn10	Mean	Zn0	Zn10	Mean	Zn0	Zn10	Mean	Zn0	Zn10	Mean	Zn0	Zn10	Mean
PD6	0.048	0.048	0.048	0.024	0.008	0.016	0.042	0.041	0.041	0.064	0.058	0.061	0.044	0.026	0.035	0.089	0.053	0.071	0.052	0.039	0.045
NDR359	0.073	0.060	0.066	0.024	0.013	0.019	0.049	0.034	0.041	0.061	0.061	0.061	0.046	0.037	0.042	0.093	0.071	0.082	0.058	0.046	0.052
PD16	0.053	0.071	0.062	0.016	0.014	0.015	0.028	0.045	0.036	0.056	0.065	0.061	0.029	0.032	0.030	0.068	0.072	0.070	0.042	0.050	0.046
PS5	0.060	0.048	0.054	0.021	0.026	0.024	0.031	0.035	0.033	0.060	0.058	0.059	0.036	0.029	0.033	0.084	0.092	0.088	0.049	0.048	0.048
Mean	0.059	0.057	0.058	0.021	0.015	0.018	0.037	0.039	0.038	0.060	0.061	0.060	0.039	0.031	0.035	0.084	0.072	0.078	0.050	0.046	0.048
	PP			Zn			V			PP×Zn			Zn×V			PP×V			PP×Zn×V		
SEm±	0.002			0.001			0.002			0.003			0.004			0.002			0.006		
CD(p≤0.05)	0.006			0.003			0.005			NS			0.011			NS			NS		

Table 2: Effect of Zn application on dry matter yield (g) of different plant parts of rice varieties at 60 days after transplanting

Varieties	Root			Stem			Lower sheath			Lower lamina			Upper sheath			Upper lamina			Emerging Panicle			Mean of plant parts		
	Zn0	Zn10	Mean	Zn0	Zn10	Mean	Zn0	Zn10	Mean	Zn0	Zn10	Mean	Zn0	Zn10	Mean	Zn0	Zn10	Mean	Zn0	Zn10	Mean	Zn0	Zn10	Mean
PD6	0.421	0.367	0.394	1.260	1.271	1.266	0.976	1.223	1.099	0.688	0.919	0.803	1.289	1.170	1.229	0.782	0.775	0.778	1.588	1.579	1.583	1.001	1.044	1.022
NDR359	0.632	0.537	0.585	0.766	0.704	0.735	1.686	1.380	1.533	1.063	1.056	1.059	1.586	1.528	1.557	1.099	1.169	1.134	0.534	0.684	0.609	1.053	1.008	1.030
PD16	0.460	0.407	0.434	1.123	0.975	1.049	1.121	1.056	1.089	0.919	0.981	0.950	1.046	1.173	1.109	0.748	0.809	0.778	1.568	1.466	1.517	0.998	0.981	0.990
PS5	0.492	0.393	0.443	0.743	0.828	0.785	1.528	1.370	1.449	1.009	0.831	0.920	1.540	1.536	1.538	0.906	0.811	0.859	1.295	1.360	1.327	1.073	1.019	1.046
Mean	0.502	0.426	0.464	0.973	0.944	0.959	1.328	1.257	1.293	0.919	0.947	0.933	1.365	1.352	1.358	0.884	0.891	0.887	1.246	1.272	6.751	1.031	1.013	1.022

	PP	Zn	V	PP×Zn	Zn×V	PP×V	PP×Zn×V
SEm±	0.043	0.023	0.033	0.061	0.087	0.046	0.122
CD (p≤0.05)	0.122	NS	NS	NS	NS	0.131	NS

Table 3: Effect of Zn application on dry matter yield (g) of different plant parts of rice varieties at 90 days after transplanting

Varieties	Root			Stem			Lower sheath			Lower lamina			Upper sheath			Upper lamina			Panicle			Mean of plant parts		
	Zn0	**Zn10**	**Mean**	**Zn0**	**Zn10**	**Mean**	**Zn0**	**Zn10**	**Mean**	**Zn0**	**Zn10**	**Mean**	**Zn0**	**Zn10**	**Mean**	**Zn0**	**Zn10**	**Mean**	**Zn0**	**Zn10**	**Mean**	**Zn0**	**Zn10**	**Mean**
PD6	0.620	0.491	0.555	1.677	1.603	1.640	0.875	0.898	0.887	0.807	0.860	0.833	1.408	1.232	1.320	0.788	0.705	0.747	1.650	2.258	1.954	1.116	1.150	1.134
NDR359	0.843	0.718	0.780	2.905	2.505	2.705	1.780	1.752	1.766	1.192	1.337	1.264	1.587	1.628	1.608	0.917	0.973	0.945	3.578	3.610	3.594	1.829	1.789	1.809
PD16	0.550	0.624	0.587	2.022	1.902	1.962	1.255	1.065	1.160	1.050	0.907	0.978	1.390	1.185	1.288	0.728	0.910	0.819	4.152	4.472	4.312	1.592	1.581	1.587
PS5	0.555	0.651	0.603	2.887	2.697	2.792	1.255	1.365	1.310	0.838	1.010	0.924	1.768	1.833	1.801	0.918	0.817	0.868	3.968	4.050	4.009	1.741	1.775	1.758
Mean	0.642	0.621	0.631	2.373	2.177	2.275	1.291	1.270	1.281	0.972	1.028	1.000	1.538	1.470	1.504	0.838	0.851	0.845	3.337	3.598	3.467	1.570	1.534	1.572
				PP			Zn			V			PP×Zn			Zn×V			PP×V			PP×Zn×V		
SEm±.				0.041			0.022			0.031			0.058			0.081			0.044			0.115		
CD (p≤0.05)				0.115			NS			0.087			0.163			NS			0.123			NS		

Table 4: Effect of Zn application on dry matter yield (g) of different plant parts of rice varieties at 120 days after transplanting

Varieties	Root			Stem			Lower sheath			Lower lamina			Upper sheath			Upper lamina			Grain			Mean of plant part		
	Z0	**Z10**	**Mean**	**Z0**	**Z10**	**Mean**	**Z0**	**Z10**	**Mean**	**Z0**	**Z10**	**Mean**	**Z0**	**Z10**	**Mean**	**Z0**	**Z10**	**Mean**	**Z0**	**Z10**	**Mean**	**Z0**	**Z10**	**Mean**
PD6	0.544	0.717	0.630	1.377	1.368	1.373	1.003	0.872	0.938	0.717	0.688	0.703	1.302	1.102	1.202	0.614	0.510	0.562	5.655	5.771	5.713	1.618	1.567	1.593
NDR359	0.845	0.688	0.766	1.365	1.425	1.395	1.178	1.463	1.321	0.832	0.920	0.876	1.668	1.405	1.537	0.948	0.842	0.895	6.253	8.833	7.543	2.239	2.041	2.140
PD16	0.586	0.652	0.619	1.473	1.785	1.629	0.915	0.822	0.868	0.682	0.518	0.600	1.250	1.360	1.305	0.550	0.662	0.606	3.211	3.308	3.259	1.252	1.294	1.273
PS5	0.484	0.581	0.533	1.610	1.952	1.781	0.962	1.462	1.212	0.652	0.902	0.777	1.408	1.175	1.292	0.540	0.778	0.659	8.398	8.660	8.529	2.045	2.197	2.121
Mean	0.615	0.659	0.637	1.456	1.633	1.544	1.015	1.155	1.085	0.720	0.757	0.739	1.407	1.260	1.334	0.663	0.698	0.681	5.879	6.643	6.261	1.788	1.775	1.782
				PP			Zn			V			PP×Zn			Zn×V			PP×V			PP×Zn×V		
SEm±.				0.048			0.026			0.036			0.068			0.096			0.051			0.136		
CD (p≤0.05)				0.14			0.07			0.10			0.19			0.27			0.15			0.39		

Conclusion

The main effect of Zn application was more prominent at the harvest i.e. 120 days after transplanting. The rice variety; PD 16 also had lower dry matter accumulation than NDR 359 and PD 6 at initial stage and at harvesting. The interaction effect of plant parts and Zn levels had no significant influence on the average dry matter yield of rice at 30, 60 and 90 days after transplanting. As regards the grain yield, Zn application at the rate of 10 mg Zn kg^{-1} soil stimulated the increase in grain yield most prominently in NDR 359 (41.3 %) while the increase in grain yields of PS 5, PD 16 and PD 6 was statistically not significant. It was apparent from the data that NDR 359 had the lowest tolerance towards Zn deficiency as the grain production was significantly less with no Zn application and increased substantially with the Zn application.

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