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Biomass and crop growth rate differ in rice genotypes with variable rates of phosphorus and zinc application

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ABSTRACT

Field experiment was conducted to investigate the impact of phosphorus (0, 40, 80, 120 kg P ha^{-1}) and zinc levels (0, 5, 10, 15 kg Zn ha^{-1}) on crop growth rate (CGR) and total biomass yield (BY) of lowland rice genotypes [fine (Bamati-385) versus coarse (Fakhre-e-Malakand and Pukhraj)] in Northwestern Pakistan during summer 2011 and 2012. Higher CGR at various growth stages and total BY was obtained with the integrated use of higher phosphorus (80 and 120 kg P ha^{-1}) and zinc levels (10 and 15 kg Zn ha^{-1}). The lower CGR and BY was recorded when P and Zn were not applied (control) or when P and Zn were applied alone. In case of rice genotypes, the highest CGR and BY was recorded for Pukhraj than other two genotypes. The CGR was increased to the highest level at heading than at tillering and physiological maturity. The increase in CGR resulted in higher total BY. Increase in BY had positive relation with grain yield and growers income. It was concluded from the study that combine application of higher phosphorus and zinc levels to the coarse rice genotypes could increase CGR, total BY, grain yield and growers income in the study area.

Key words: *Genotypes, phosphorus, zinc, crop growth rate, biomass yield*

Rice is the staple food of mankind and provides 35%~60% of the dietary calories consumed by 3 billion people, making it inarguably the most important crop worldwide (Confalonieri and Bocchi, 2005). The demand for increasing rice production is particularly urgent, because the population of traditional rice-producing countries will require 70% more rice by year 2025 (IRRI 1995; Swaminathan 2007). Hence, the world rice production must increase by approximately 1% annually to meet the growing demand (Rosegrant *et al.* 1995). Phosphorus (P) and zinc (Zn) deficiency are two of the most important nutritional constraints to rice growth across the globe (Ismail *et al.* 2007). Zinc is absorbed by plants as cations (Zn^{2+}) and P is taken up by plants as phosphate anions ($H_2PO_4^{"1}$ or $HPO_4^{"2}$). These cations and anions attract each other, which facilitates the formation of chemical bonds that can form within the soil or the plant. If excess P binds a large quantity of Zn normally available to the plant, the result can be a P-induced Zn deficiency. This generally results in reduced shoot Zn concentration and reduced growth (Marschner 2002). Fertilizers are a costly input, such that their use limits the profitability of rice farming for high-input or low-input systems, and the use of fertilizers for these two rice nutrients is notoriously inefficient (Rose *et al.* 2013). About the interaction of Zn and P, numerous studies have been done and all confirms this point that Zn and P imbalance in the plant, as a result excessive accumulation of phosphorus, causing zinc imposed deficiency (Cakmak 2000; Das *et al.* 2005; Mirvat et al. 2006; Alloway 2009; Khorgamy and Farnis 2009; Salimpour *et al.* 2010). Next to N and P deficiency; Zn deficiency is now considered the most widespread nutrient disorder in lowland rice (Quijano-Guerta *et al.* 2002; Singh *et al.* 2003). High soil pH appears to be the main factor associated with the widespread Zn deficiency in the calcareous soils of the Indo-Gangetic plains of India and Pakistan (Tahir *et* *al.* 1991; Qadar 2002). The yield of rice is an integrated result of various processes, including canopy photosynthesis, conversion of assimilates to biomass and partitioning of assimilates to grains (Weng and Chen, 1984; Wu *et al.*, 1998; Ying *et al.*, 1998). Studies on Zn and P interaction and their impact on crop growth rate and biomass yield have not been carried out so for under flooded condition. The main objective of this experiment was to investigate whether there is any difference in the CGR and biomass yield of rice genotypes at various P and Zn levels or not?

MATERIALS AND METHODS

Site Description

Field experiment was conducted to investigate the impact of zinc (Zn) and phosphorus (P) levels on three rice (*Oryza sativa* L.) genotypes under flooded conditions and their residual effects on the yield and yield components of subsequent wheat (*Triticum aestivum* L., cv. Siren) under rice-wheat cropping system at Batkhela, Malakand Agency on farmer's field in Northwest Pakistan during 2011-12 and 2012-13. Batkhela is located at 34°37'0" N and 71°58'17" E in DMS (Degrees Minutes Seconds) or 34.6167 and 71.9714 (in decimal degrees). The soil of the experimental site is clay loam, slightly alkaline in reaction (pH = 7.3), non-saline (ECe = 1.02 dS m^{-1}), moderately calcareous in nature ($CaCO_3$ = 7.18 %), low in soil fertility containing less organic matter (0.71 %), extractable P (5.24 mg kg^{-1}) and Zn (0.93 mg kg^{-1}). Weather data for the rice-wheat cropping system during 2011-12 and 2012-13 is given in Fig. 1.

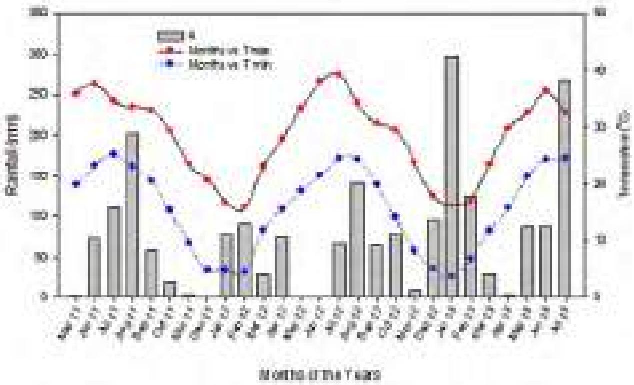

Fig. 1. Rainfall and temperature data in the experimental site for the two growing seasons of rice-wheat cropping system

Experimentation

The experiment was conducted in randomized block design with split-plot arrangement using three replications. Combination of factor-A (three rice genotypes) and B (four P levels) were allotted to main plots, while factor-C (four Zn levels) were allotted to subplots. A sub-plot size of 12 m^2 (3 m x 4 m) having 300 hills per subplot, and hill to hill distance of 20 cm apart was used. A uniform dose of 120 kg N ha^{-1} as urea and 60 kg K_2O ha^{-1} [SOP (sulphate of potash) or MOP (muriate of potash)] was applied to all treatments. All potassium, P (triple super phosphate) and Zn (zinc sulphate) was applied at the time of transplanting, while nitrogen was applied in two equal splits i.e. 50% each at transplanting and 30 days after transplanting. The amount of sulfur was maintained constantly in the Zn applied plots by adding additional sulfur using SOP. All subplots were separated by about 30 cm ridges to stop movement of water/nutrients among different treatments. Water to each treatment was separately applied from water channel and the crop was grown under flooded condition almost the whole growing period.

Data were calculated on various parameters including phenology, growth analysis, dry matter partitioning, yield and yield components, harvest index, shelling percentage, grain quality and profitability. This paper presents the data on crop growth rates (CGR) and biomass yield of rice. At tillering, heading and physiological maturity five hills within each treatment were harvested. Leaf, stems and panicles were separated, dried and weighed by an electronic balance to record data on dry weight of leaf, stem, and panicles (no panicles were observed at tillering). Dry weight hill^{-1} at each growth stage was calculated as sum of the dry weights of the plant components. Crop growth rate (CGR) defined as dry matter accumulation per unit ground area per unit time was determined at various growth stages (transplanting to tillering, tillering to heading, and heading to physiological maturity) according to the procedures used by Amanullah and Stewart (2013).

$$CGR \quad = W_2 - W_1 / (GA)\,(t_2 - t_1) \ldots\ldots\ldots\ldots \; (\text{g m}^{-2} \text{ day}^{-1})$$

Where

W_1 = Dry weight (g) m^{-2} at the beginning of interval

W_2 = Dry weight (g) m^{-2} at the end of interval

$t_2 – t_1$ = The time interval between the two consecutive samplings

GA = Ground area occupied by plants at each sampling

At harvest maturity, four meter square area within each treatment was harvested, the material was sun dried up to constant weight and weighed, and then was converted into biomass yield (kg ha^{-1}).

Statistical Analysis

Data were subjected to analysis of variance (Table 1) according to the methods described for randomized complete block design with split plot arrangement combined over the years (Steel et al. 1996), and means between treatments were compared using LSD (least significant difference) test (*p d” 0.05*).

RESULTS AND DISCUSSION

Crop growth rate from transplanting to tillering

Crop growth rate (CGR) (g m^{-2} day^{-1}) at the early growth stage (upto tillering) was significantly affected by P and Zn levels, genotypes and years (Table 2). The interactions Y x G, P x G and P x Zn x G were also significant for CGR. Years mean data indicated that the highest CGR (7.92 g m^{-2} day^{-1}) was associated with 120 kg P ha^{-1}, being at par with 80 kg P ha^{-1} (7.77 g m^{-2} day^{-1}). Minimum CGR (5.96 g m^{-2} day^{-1}) was observed for P control plots. In case of Zn levels, maximum CGR (7.41 g m^{-2} day^{-1}) was recorded with 15 kg Zn ha^{-1} was statistically identical with 5 and 10 kg Zn ha^{-1}. Zinc control plots reduced CGR to minimum (6.69 g m^{-2} day^{-1}). Among rice genotypes, maximum CGR (8.12 g m^{-2} day^{-1}) was recorded for Pukhraj, followed by F-Malakand (6.84 g m^{-2} day^{-1}), while minimum CGR (6.50 g m^{-2} day^{-1}) was recorded for fine genotype (B-385). The Y x G interaction (Table 2) indicated that CGR for all three genotypes was higher in year two than in year one. Year two had higher CGR (7.67 g m^{-2} day^{-1}) as compared with year one (6.64 g m^{-2} day^{-1}). The P x G interaction indicated that CGR of all genotypes was increased while increasing P level (Fig. 2) and the increase was higher for coarse genotypes (Pukhraj & F-Malakand) than fine genotype

Table 1. Mean square and significance level for crop growth rate (CGR) from transplanting to tillering (T-T), tillering to heading (T-H), heading to physiological maturity (H-PM) and biomass yield of rice genotypes as affected by phosphorus and zinc application

Source of variance	DF	CGR T-T		CGR T-H		CGR H-PM		Biomass	
		MS	Sig.	MS	Sig.	MS	Sig.	MS	Sig.
Years (Y)	1	75.8	**	7410	***	245.4	ns	56603277	ns
Rep. (within years)	4	—	—	—	—	—	—	—	—
Genotypes	2	70.0	***	9169	***	2636	***	44688057	***
Y x G	2	8.69	**	1139	***	1676	***	3416454	ns
Phosphorus (P)	3	58.5	***	4646	***	596.0	***	85343094	***
Y x P	3	4.20	ns	217	ns	52.43	ns	9035611	ns
P x G	6	3.00	*	65.9	***	92.01	ns	28039619	***
Y x P x G	6	6.71	***	11.1	ns	25.56	ns	1125688	ns
Pooled Error-I	44	1.18	—	11.5	—	46.16	—	3999861	—
Zinc (Zn)	3	7.56	***	202	***	166.2	*	23002115	***
Y x Zn	3	1.70	ns	1.53	ns	12.19	ns	356618	ns
Zn x G	6	0.94	ns	4.28	ns	6.53	ns	2206022	ns
Y x Zn x G	6	0.49	ns	39.5	***	21.26	ns	1123908	ns
P x Zn	9	1.02	ns	10.2	ns	60.06	ns	2855133	ns
Y x P x Zn	9	2.18	**	7.68	ns	41.47	ns	985953	ns
P x Zn x G	18	1.82	***	14.1	*	39.70	ns	5048345	**
Y x P x Zn x G	18	1.39	**	13.5	*	58.82	ns	1417858	ns
Pooled Error-II	144	0.67	—	7.85	—	42.91	—	2149826	—
Total	287	—	—	—	—	—	—	—	—
CV main plots (%)	15.1		8.6		19.4		11.0		
CV sub plots (%)	11.4		7.1		18.0		8.0		

Where: MS stands for mean square, Sig. for significance, ns for non-significant, while *, ** and *** stands for significant at 5, 1 and 0.1 % level of probability, respectively.

Table 2. Crop growth rate (g m^{-2} day^{-1}) from transplanting to tillering of rice genotypes as affected by phosphorus and zinc application

	Years		
Phosphorus (kg ha^{-1})	2011	2012	Combined
0	5.74	6.18	5.96 c
40	6.55	7.39	6.97 b
80	7.14	8.41	7.77 a
120	7.15	8.69	7.92 a
LSD$_{0.05}$	0.46	0.59	0.36
Zinc (kg ha^{-1})			
0	6.36	7.03	6.69 b
5	6.70	7.65	7.18 a
10	6.80	7.88	7.34 a
15	6.71	8.12	7.41 a
LSD$_{0.05}$	ns	0.38	0.27
Genotypes			
B-385 (fine)	5.91	7.09	6.50 c
F-Malakand (coarse)	6.07	7.61	6.84 b
Pukhraj (coarse)	7.94	8.30	8.12 a
LSD$_{0.05}$	0.40	0.51	0.32
Years mean	6.64 b	7.67 a	
Interactions	Level of significance	Figures	
Y x P	ns		
Y x Zn	ns		
Y x G	**		
P x Zn	ns		
P x G	*	2	
Zn x G	ns		
P x Zn x G	***	3	

Means of the same category followed by different letters are significantly different at 5% level of probability using LSD test.

ns stands for non-significant, while *, ** and *** stands for significant at 5, 1 and 0.1 % level of probability, respectively.

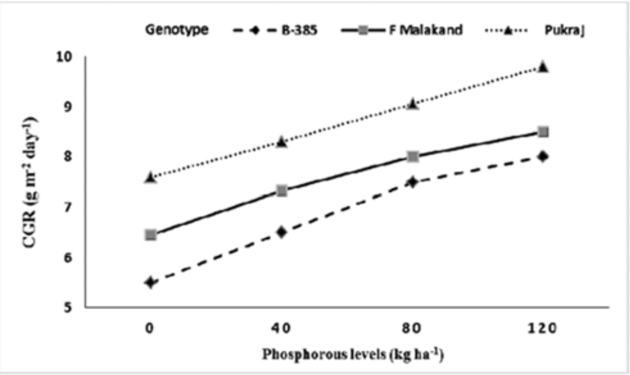

Fig. 2. Crop growth rate (g m^{-2} day^{-1}) from transplanting to tillering of rice as affected by phosphorus into genotype (P x G) interaction

(B-385). The three way interaction among P x Zn x G indicated that CGR for all three genotypes was increased with increase in P and Zn levels (Fig. 3), and both coarse genotypes (Pukhraj & F-Malakand) had higher CGR than fine genotype (B-385) at all P and Zn levels.

Crop growth rate from tillering to heading

Crop growth rate from tillering to heading was significantly affected P and Zn levels, genotypes and years (Table 3). The Y x G, P x G and P x Zn x G were also significant. The highest CGR (46.9 g m^{-2} day^{-1}) was recorded for 120 kg P ha^{-1}, while minimum CGR (28.7 g m^{-2} day^{-1}) was observed for P control plots. In case of Zn levels, maximum CGR (41.3 g m^{-2} day^{-1}) was recorded with 15 kg Zn ha^{-1}. Zinc control plots

Table 3. Crop growth rate (g m^{-2} day^{-1}) from tillering to heading of rice genotypes as affected by phosphorus and zinc application

	Years		
Phosphorus (kg ha^{-1})	2011	2012	Combined
0	25.9	31.4	28.7 d
40	33.6	43.7	38.7 c
80	38.4	49.7	44.0 b
120	40.0	53.7	46.9 a
LSD$_{0.05}$	1.45	1.84	0.99
Zinc (kg ha^{-1})			
0	32.7	42.6	37.6 d
5	33.7	43.8	38.8 c
10	35.5	45.5	40.5 b
15	36.0	46.6	41.3 a
LSD$_{0.05}$	1.36	1.27	0.79
Genotypes			
B-385 (fine)	28.2	32.5	30.4 c
F-Malakand (coarse)	34.3	42.7	38.5 b
Pukhraj (coarse)	40.9	58.7	49.8 a
LSD$_{0.05}$	1.26	1.60	1.14
Years mean	34.5 b	44.6 a	
Interactions	Level of significance	Figures	
Y x P	ns		
Y x Zn	ns		
Y x G	***		
P x Zn	ns		
P x G	***	4	
Zn x G	ns		
P x Zn x G	*	5	

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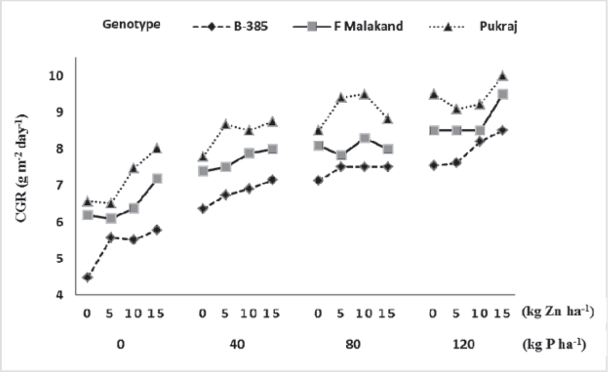

Fig. 3. Crop growth rate (g m^{-2} day^{-1}) from transplanting to tillering of rice as affected by phosphorus into zinc into genotype (P x Zn x G) interaction

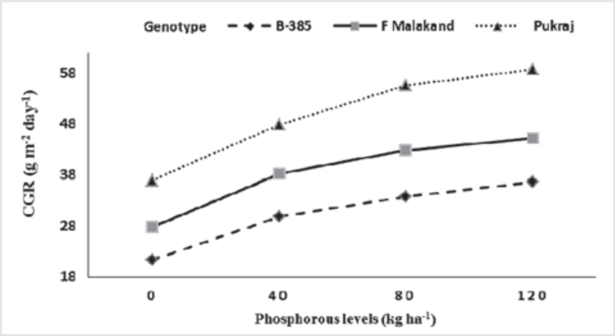

Fig. 4. Crop growth rate (g m^{-2} day^{-1}) from tillering to heading of rice as affected by phosphorus into genotype (P x G) interaction

reduced CGR to its minimum value (37.6 g m^{-2} day^{-1}). Among rice genotypes, maximum CGR (49.8 g m^{-2} day^{-1}) was recorded for Pukhraj, followed by F-Malakand (38.5 g m^{-2} day^{-1}). The minimum CGR (30.4 g m-2 day^{-1}) was recorded for B-385. In case of Y x G interaction (Table 3), increase in CGR for all genotypes was noticed in year two over year one. The CGR of coarse genotypes was more than the fine genotype. Year two had higher CGR (44.6 g m-2 day^{-1}) as compared with year one (34.5 g m-2 day^{-1}). The P x G interaction indicated that CGR of all genotypes was increased with increase in P levels (Fig. 4), and increase in CGR was observed for coarse genotypes over fine genotype. Interaction of P x Zn x G indicated that CGR of all three genotypes was increased while increasing both P and Zn levels (Fig. 5), and the CGR of coarse genotypes was more than fine genotype.

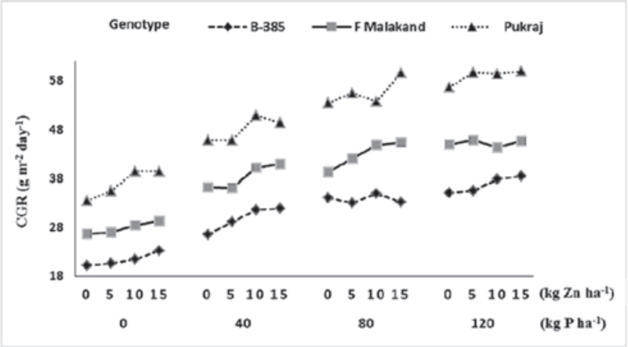

Fig. 5. Crop growth rate (g m^{-2} day^{-1}) from tillering to heading of rice as affected by phosphorus into zinc into genotype (P x Zn x G) interaction

Crop growth rate from heading to physiological maturity

The P and Zn levels, and genotypes had significantly affected CGR from heading to physiological maturity (Table 4). Years and all interactions except Y x G had no significant effect on CGR. The highest CGR (14.71 g m^{-2} day^{-1}) was recorded with the application of 120 kg P ha^{-1} which was statistically identical with 40 and 80 kg P ha^{-1}. The minimum CGR (8.60 g m^{-2} day^{-1}) was observed for P control plots. In case of Zn levels, maximum CGR (14.73 g m^{-2} day^{-1}) was recorded with 15 kg Zn ha^{-1} being at par with 10 kg Zn ha^{-1} (13.25 g m^{-2} day^{-1}). Minimum CGR (11.09 g m^{-2} day^{-1}) was recorded in zinc control plots. Among the rice genotypes, maximum CGR (13.57 g m^{-2} day^{-1}) was recorded for Pukhraj, followed by F-Malakand (11.85 g m^{-2} day^{-1}), while minimum CGR (8.25 g m^{-2} day^{-1}) was recorded for B-385. In interaction of Y x G (Table 4) indicated that CGR of F-Malakand and B-385 increased in year two than year one, in case of Pukhraj the CGR was higher in year one than year two.

Total biomass yield at harvest

Total biomass yield (BY) at harvest maturity was significantly affected by P and Zn levels, and genotypes (Table 5). Years and all interactions except P x G and P x Zn x G were found non-significant for BY. The highest BY (19114 kg ha^{-1}) was obtained with 120 kg P ha^{-1} being at par with 80 kg P ha^{-1} (18938 kg ha^{-1}). Minimum BY (16726 kg ha^{-1}) was recorded for P control plots. In case of Zn levels, maximum BY (18835 kg ha^{-1}) was obtained with 10 kg Zn ha^{-1} being at par with 15

Table 4. Crop growth rate (g m^{-2} day^{-1}) from heading to physiological maturity of rice genotypes as affected by phosphorus and zinc application

	Years		
Phosphorus (kg ha^{-1})	2011	2012	Combined
0	10.72	6.47	8.60 b
40	14.11	13.88	13.99 a
80	14.92	13.58	14.25 a
120	15.49	13.93	14.71 a
LSD$_{0.05}$	ns	4.47	2.28
Zinc (kg ha^{-1})			
0	12.53	9.65	11.09 c
5	12.99	11.97	12.48 bc
10	13.94	12.57	13.25 ab
15	15.78	13.68	14.73 a
LSD$_{0.05}$	ns	3.38	2.16
Genotypes			
B-385 (fine)	6.99	9.50	8.25 c
F-Malakand (coarse)	10.13	13.57	11.85 b
Pukhraj (coarse)	14.31	12.83	13.57 a
LSD$_{0.05}$	2.47	3.35	1.98
Years mean	13.81	11.96	
Interactions	Level of significance	Figures	
Y x P	ns		
Y x Zn	ns		
Y x G	***		
P x Zn	ns		
P x G	ns		
Zn x G	ns		
P x Zn x G	ns		

Means of the same category followed by different letters are significantly different at 5% level of probability using LSD test.

ns stands for non-significant, while *, ** and *** stands for significant at 5, 1 and 0.1 % level of probability, respectively.

Table 5. Biomass yield (kg ha^{-1}) of rice genotypes as affected by phosphorus and zinc application.

	Years		
Phosphorus (kg ha^{-1})	2011	2012	Combined
0	16555	16898	16726 c
40	17997	18239	18118 b
80	18303	19573	18938 a
120	18268	19960	19114 a
LSD$_{0.05}$	1030	922	672
Zinc (kg ha^{-1})			
0	17114	18018	17566 b
5	17453	18493	17973 b
10	18383	19286	18835 a
15	18174	18872	18523 a
LSD$_{0.05}$	678	700	483
Genotypes			
B-385 (fine)	15148	16376	15762 c
F-Malakand (coarse)	18884	19366	19125 b
Pukhraj (coarse)	19310	20259	19785 a
LSD$_{0.05}$	892	799	582
Years mean	17781	18667	
Interactions	Level of significance		Figures
Y x P	ns		
Y x Zn	ns		
Y x G	ns		
P x Zn	ns		
P x G	***	6	
Zn x G	ns		
P x Zn x G	**	7	

Means of the same category followed by different letters are significantly different at 5% level of probability using LSD test.

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kg Zn ha^{-1} (18523 kg ha^{-1}). Minimum BY (17566 kg ha^{-1}) was recorded in zinc control plots. Interaction of Y x Zn (Table 5) indicated that BY was higher at all Zn levels in year two than year one. Among the rice genotypes, maximum BY (19785 kg ha^{-1}) was recorded for Pukhraj, followed by F-Malakand (19125 kg ha^{-1}), and minimum BY (15762 kg ha^{-1}) was recorded for B-385. Interaction of P x G revealed that increase in P levels up to 80 kg ha^{-1} increased BY of Pukhraj and B-385. The BY of F-Malakand was decreased while increasing P level up to 80 kg ha^{-1}, but further increase in P level increased BY of F-Malakand (Fig. 6). The three way interaction among P x Zn x G indicated that Pukhraj had higher BY at 80 kg P + 10 kg Zn ha^{-1} (Fig. 7). Both F-Malakand and B-385 had higher BY at 120 kg P + 15kg Zn ha^{-1}. The genotype F-Malakand had higher BY at 0 kg P + 5 kg Zn ha^{-1}, while B-385 had higher BY at 80 kg P + 0 kg Zn ha^{-1}.

Crop growth rate (CGR) depends on the amount of radiation intercepted by the crop and on the efficiency of conversion of in-tercepted radiation into dry matter (Sinclair and Horie 1989). In our study the CGR at different growth stages increased with application of higher P (80 and 120 kg P ha^{-1}) and higher Zn rates (10 and 15 kg Zn ha^{-1}) and the increase was more when both nutrients were applied in combination than sole applications. The CGR decreased significantly with application of lower P (0 and 40 kg P ha^{-1}) and lower Zn rates (0 and 5 kg Zn ha^{-1}). According to Haldar and Mandal (1981), application of both P and Zn significantly increased total dry matter accumulation in rice. They reported highest increase when both P

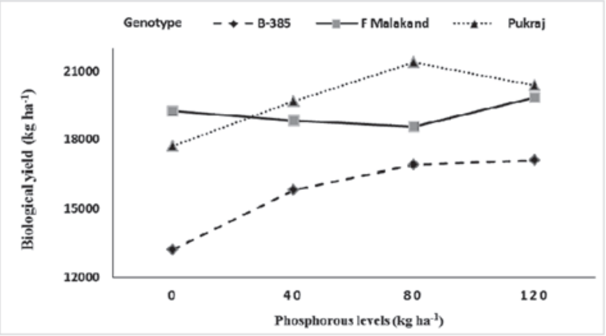

Fig. 6. Biomass yield (kg ha^{-1}) of rice as affected by phosphorus into genotype (P x G) interaction

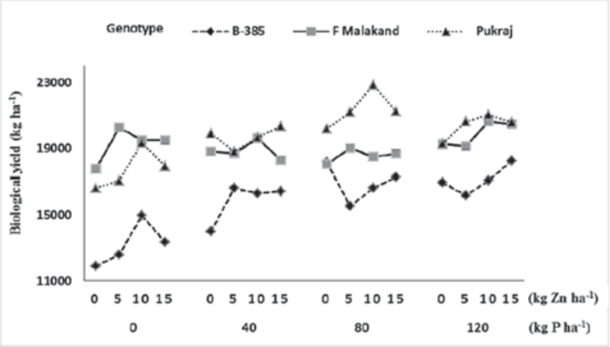

Fig. 7. Biomass yield (kg ha^{-1}) of rice as affected by phosphorus into zinc into genotype (P x Zn x G) interaction

and Zn were combined at their respective highest levels (100 and 10 ppm, respectively), the mean increase of shoots, roots and grains was 35, 39 and 25 % higher over control (PoZn0), respectively. The increase in CGR resulting from combined application of P and Zn might be due to their beneficial effect on plant metabolism. The increase in dry matter accumulation with application of P was reported by Alam *et al.* (2009), Fageria *et al.* (2003) and Fageria and Baligar (2005). Yadi *et al.* (2012) reported increase in DM accumulation with increase in Zn level. But they reported maximum dry matter production with 40 kg Zn ha^{-1}. This contradiction might be due to differences in soil and environmental conditions as well as genotypes used.

The two coarse genotypes performed better than fine genotype in term of higher CGR and crop productivity (data not shown) than fine rice genotype. According to Sharma and Singh (1994), a wide variability in photosynthetic rate (CGR) exits in rice genotypes, and (Evans 1976) reported that a high photosynthetic rate is associated with higher productivity unless the sink capacity is limiting. Alam *et al.* (2009) supports our results by reporting differences in DM accumulation while growing different rice genotypes. It was expected since coarse genotypes took more nutrients (P and Zn) from soil (data not given) which improved growth, increased dry matter accumulation and hence had higher CGR. Taniyama *et al.* (1988) reported that the difference in the CGR and CO_2 uptake in different rice genotypes was due to the variation in the amount of chlorophyll in the leaves, and that CO_2 uptake and yield are positively correlated with each other. According to Akinrinde *et al.* (2006), DM production in six rice genotypes was significantly affected by P rates. Increase in DM accumulation or higher CGR is important because it is significantly associated with grain yield and harvest index (Hasegawa 2003). In the present study the total DM accumulation was more at heading (heading > physiological > tillering). Fageria *et al.* (2006) reported reduction in shoot dry weight of upland rice from flowering to physiological maturity. Grain yield is mainly affected by the amount of carbohydrates assimilated dur-ing the ripening growth stage, especially in the high yielding modern cultivars (Hayashi 1995). The higher total dry matter indicates more translocation of assimilates from the leaf, leaf sheaths and stems to the panicles during the grain filling period, resulting in higher grain yield (Wiangsamut *et al.* 2013). In this study, the coarse rice hybrid (Pukhraj) had more dry matter accumulation and had higher CGR at different growth stages than other two genotypes. The higher DM accumulation and higher CGR of Pukhraj resulted in higher over F-Malakand and B-385. According to Wiangsamut *et al.* (2013), hybrid rice genotypes had higher efficiency in partitioning of dry matter and consequently, hybrid rice had higher grain yields than inbred lines.

Yield is defined as the amount of specific substance produced (e.g., grain, straw, total dry matter) per unit area (Soil Science Society of America 1997). The results of our current study revealed that the biomass yield in rice increased with the application of higher P (80 and 120 kg P ha^{-1}) and higher Zn rates (10 and 15 kg Zn ha^{-1}) and the increase was more when both nutrients were applied in combination than sole applications. The biomass yield decreased tremendously with application of lower P (0 and 40 kg P ha^{-1}) and lower Zn rates (0 and 5 kg Zn ha^{-1}). In our study crop growth rate showed positive relationship with biomass yield. Fageria and Filho (2007) reported an increase of 80% in biomass yield and 180% in grain yield of rice with the application of higher P rate of 131 kg P ha^{-1} over P-control plots. Fageria *et al.* (2011a) reported that P application increased grain yield of different rice genotypes and the differences in yield were attributed with an increase in panicle number and biomass yield with increasing P rate. Similarly, Fageria *et al.* (2011b) reported that biomass and grain yields of rice increased with the application of Zn in the soil. They reported maximum biomass yield with the application of 5 mg Zn kg^{-1} of soil, which was about 33% greater than Zn-control plots, and maximum grain yield was achieved with the application of 20 mg Zn kg^{-1} of soil that was about 97% more than Zn-control plots. Likewise, Yadi *et al.* (2012) reported a significant effect of Zn fertilizer on grain, biomass and straw yields as well as harvest of rice. According to Khan *et al.* (2012), straw and paddy yield showed increasing trend up to 9 kg Zn ha^{-1}. They reported the highest average paddy yield and yield components were recorded at 120 kg N + 90 kg P_2O_5 along with 9 kg Zn ha^{-1}.

Our results confirmed that both P and Zn application in combination improved crop growth, increased yield components and grain yield (data not shown) and hence biomass yield. These results are in agreement with the results of Foy (1992) and Fageria *et al.* (1996) who reported that macro- as well as micronutrient deficiencies are the most important nutritional disorders that limit crop yields. Rahman *et al.* (2011) reported that Zn and P either alone or in combination showed significantly positive effect on the grain and straw yield of rice. Similarly, Lal *et al.* (2000) found that grain yield and biomass yield in rice reached maximum with the combined application of 33 kg P + 12 kg Zn ha^{-1}. In our study higher CGR and biomass yield resulted in higher grain yield and harvest index (data not shown) of rice. Donald and Hamblin (1976) found that grain yield in cereals is related to biomass yield and harvest index. Because the biomass yield is a function of crop growth duration and crop growth rate at successive growth stages (Tanaka and Osaki, 1983). The coarse rice genotypes (Pukhraj and F-Malakand) in this study produced more grain and biomass yields than fine genotype (B-385). The increase in grain and biomass yields of coarse genotypes was attributed the higher number of panicles hill^{-1}, more filled grains panicle^{-1} and heavy grains (data not shown) than the fine genotype. Likewise, Wiangsamut *et al.* (2013) reported that the two hybrids (SL8 and Bigante) had higher grain and biomass yields than the check genotype, IR72. Yadi *et al.* (2012) reported significant differences in yield and yield parameters of different rice genotypes. Significant differences in yields have been reported among crop species and genotypes of same species in absorption and utilization of nutrients including P (Epstein and Bloom 2005; Fageria *et al.* 2006). Further increase in grain yield in cereals such as rice through breeding can only be accomplished with an increase in total biomass yield. According to Peng *et al.* (1999), grain yield improvement of lowland rice cultivars released by the International Rice Research Institute (IRRI) in the Philippines after 1980 was due to increases in biomass production. Akita (1989) and Amano *et al.* (1993) reported that when comparisons were made among the improved semi-dwarf cultivars, higher yield was achieved by increasing biomass produc-tion.

Phosphorus (P) and zinc (Zn) management is one of the most important strategy for increasing CGR and BY in lowland rice. Zinc into phosphorus interaction imbalance in the rice plant results excessive phosphorus accumulation causing zinc imposed deficiency and hence results in lower CGR and BY. The results of our study confirmed that integrated application phosphorus and zinc at higher rates was more beneficial in terms higher CGR and BY in all three genotypes under study. Sole application of P and Zn or no application (P and Zn not applied) reduced CGR and BY in lowland rice. The higher CGR of rice hybrid (Pukhraj) was attributed to its long and wider leaves that resulted in higher mean single leaf area and leaf area index. The CGR showed positive relationship with total BY. The increase in BY had positive impact on grain yield and growers income.

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