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Dry Matter Partitioning and Harvest Index Differ in Rice Genotypes with Variable Rates of Phosphorus and Zinc Nutrition

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Abstract: Phosphorus (P) and zinc (Zn) deficiencies are the major problems that decrease crop productivity under rice-wheat cropping system. Field experiments were conducted to investigate impacts of P (0, 40, 80 and 120 kg/hm^2) and Zn levels (0, 5, 10 and 15 kg/hm^2) on dry matter (DM) accumulation and partitioning, and harvest index of three rice genotypes 'fine (Bamati-385) vs. coarse (F-Malakand and Pukhraj)' at various growth stages (tillering, heading and physiological maturity). The experiments were conducted at farmers' field at Batkhela in Northwestern Pakistan for two years in summer 2011 and 2012. The two year pooled data reveled that there were no differences in percent of DM partitioning into leaves and culms with application of different P and Zn levels, and genotypes at tillering. The highest P level (120 kg/hm^2) partitioned more DM into panicles than leaves and culms at heading and physiological maturity stages. The highest Zn level (15 kg/hm^2) accumulated more DM and partitioned more DM into panicles than leaves and culms at heading and physiological maturity stages. The hybrid rice (Pukhraj) produced and partitioned more DM into panicles than F-Malakand and Bamati-385 at heading and physiological maturity stages. Higher DM accumulation and greater amounts of partitioning into panicles at heading and physiological maturity stages was noticed with increase in P and Zn levels, and the increase was significantly higher in the coarse rice genotypes than fine. We concluded that the growing hybrid rice with application of 120 kg/hm^2 P + 15 kg/hm^2 Zn not only increases total DM accumulation and partitioned greater amounts into the reproductive plant parts (panicles) but also results in higher harvest index.

Key words: dry matter partitioning; growth stage; harvest index; phosphorus level; rice; zinc level

Rice (*Oryza sativa* L.) is the staple food of mankind and provides 35%–60% of the dietary calories consumed by three 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 2025 (IRRI, 1995; Swaminathan, 2007). Phosphorus (P) and zinc (Zn) deficiencies are two of the most important nutritional constraints to rice growth (Ismail et al, 2007). Zn 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- or low-input systems, and the use of fertilizers for these two rice nutrients is extremely inefficient (Rose et al, 2013). About the interaction of Zn and P, numerous studies have been done and all confirms that Zn and P imbalance in the plant, as a result of excessive accumulation of P, causing Zn imposed

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deficiency (Cakmak, 2000; Das et al, 2005; Gobarah et al, 2006; Alloway, 2009; Khorgamy and Farnia, 2009; Salimpour et al, 2010). Next to nitrogen (N) and P deficiency, Zn deficiency is now considered as the most widespread nutrient disorder in lowland rice (Quijano-Guerta et al, 2002; Singh et al, 2005). 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 dry matter (DM) accumulation and partitioning into leaf, culm and panicle at different growth stages and harvest index (HI) of lowland rice are scanty. The hypothesis was tested that there is no difference in the DM accumulation and partitioning into various plant parts at different growth stages (tillering, heading and physiological maturity), and the HI of lowland rice genotypes when applied with variable rates of P and Zn.

MATERIALS AND METHODS

Experimentation

Field experiments were conducted to investigate the impact of different P (0, 40, 80 and 120 kg/hm^2) and Zn levels (0, 5, 10 and 15 kg/hm^2) on HI, DM accumulation and partitioning of three lowland rice genotypes 'fine (Bamati-385) vs. coarse (F-Malakand and Pukhraj)'. The experiments were carried out at farmers' field at Batkhela (34°37′0″ N, 71°58′17″ E), Malakand Agency Northwestern Pakistan during summer in 2011 and 2012. The experiments were conducted in the randomized complete block design with split-plot arrangement using three replications. Combination of three rice genotypes and four P levels (12 treatments) was allotted to main plots, while four Zn levels were allotted to subplots. A sub-plot size of 12 m^2 (3 m × 4 m) having 300 hills per subplot, and hill to hill distance of 20 cm apart was used. A uniform dose of 120 kg/hm^2 as urea and 60 kg/hm^2 SOP (sulphate of potash) or MOP (muriate of potash) were applied to all treatments. All potassium, P (triple super phosphate) and Zn (zinc sulphate) were applied at the time of transplanting, while N (urea) was applied in two equal splits, i.e. 50% each at transplanting and 30 d 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.

Site description

The soil of the experimental site was clay loam, slightly alkaline in reaction (pH, 7.3), non-saline (ECe, 1.02 dS/m), moderately calcareous in nature ($CaCO_3$, 7.18%), low in soil fertility containing less organic matter (0.71%), extractable P (5.24 mg/kg) and Zn (0.93 mg/kg). The soils in Northwestern Pakistan are pedocal, a dry soil with a high concentration of calcium carbonate and a low content of organic matter, which are characteristic of a land with low and erratic precipitation in the region (Khan, 2010).

Data recording and handling

Data were recorded on DM accumulation and partitioning at tillering, heading and physiological maturity stages, and HI. At each growth stage, five hills (plants) within each treatment were harvested. Leaves, culms and panicles were separated, dried in paper bags and weighed by an electronic balance, and then average data (g/hill) on dry weights of leaf, culm and panicle were calculated. Total dry matter (TDM) was calculated as sum of the dry weights of the plant components. At harvest maturity, an area of 4 m^2 (2 m × 2 m) within each treatment of rice crop was harvested, and the material was sun-dried up to a constant weight, weighed and then converted into biological yield (biomass) (kg/hm^2). The harvested material for biomass yield was threshed. The grains were separated and weighed, and then converted into grain yield (kg/hm^2). HI was calculated according to the following formula: Harvest index (%) = Grain yield / Biological yield × 100.

Statistical analysis

Data were subjected to analysis of variance according to the methods described for the randomized complete block design with split plot arrangement combined over the years (Steel et al, 1996), and means between treatments were compared with the LSD (least significant difference) test ($P \leq 0.05$) using Statistic 8.1 (Analytical Software, Tallahassee, USA).

RESULTS

Dry matter partitioning into culms

At the tillering stage, the culm dry matter (SDM) was significantly affected by P and Zn levels, genotypes

(G), years, P × Zn and P × Zn × G interactions (Table 1). The highest SDM (3.8 g) was produced with 120 kg/hm^2 P being at par with 80 kg/hm^2 (3.7 g), while the lowest SDM (2.8 g) was observed in P-control plots. In case of Zn levels, the maximum SDM (3.6 g) was recorded with application of 10 and 15 kg/hm^2. The Zn-control plots produced the minimum SDM (3.2 g). Among the rice genotypes, the hybrid rice Pukhraj produced the maximum SDM (3.9 g), followed by F-Malakand (3.3 g), while the minimum SDM (3.1 g) was produced by Bamati-385. The years mean indicated that the year 2012 had higher SDM (3.7 g) than 2011 (3.2 g). Interactions of P × Zn indicated that application of P at 80 kg/hm^2 + Zn either at 5 or 10 kg/hm^2 increased the SDM in rice, but application of P at 120 kg/hm^2 + Zn either at 0 or 15 kg/hm^2 increased the SDM in rice (Fig. 1). Three-way interaction of P × Zn × G indicated that SDM of all the three genotypes was increased with combine application of P and Zn, and sole application or no application of Zn and P reduced the SDM (Fig. 2).

At the heading stage, the SDM was significantly affected by P and Zn levels, genotypes and years (Table 1). The maximum SDM (18.6 g) was produced with 80 kg/hm^2 P being at par with 120 kg/hm^2 (18.5 g), and the lowest SDM (14.2 g) was observed in P-control plots. In case of Zn, the maximum SDM (17.8 g) was recorded with 15 kg/hm^2 being at par with 10 kg/hm^2 (17.6 g), and the Zn-control plots produced the minimum SDM (16.7 g). Among the rice genotypes, Pukhraj produced the highest SDM (19.5 g). The year mean data indicated that the year 2012 produced higher SDM (18.3 g) than 2011 (16.2 g).

At the physiological maturity stage, the SDM was significantly affected by P and Zn levels, and genotypes (Table 1). The highest SDM (19.4 g) was produced with 80 and 120 kg/hm^2 P, while the lowest SDM (12.5 g) was observed in P-control plots. The maximum SDM (18.2 g) was recorded with 15 kg/hm^2 Zn being at par with 10 kg/hm^2 (17.9 g), and the Zn-control plots produced the minimum SDM (15.9 g). Among the rice genotypes, Pukhraj produced the maximum SDM (18.9 g), while the minimum SDM (16.4 g) was recorded for Bamati-385 being at par with F-Malakand (16.5 g).

Table 1. Culm dry matter at different growth stages of rice genotypes as affected by phosphorus (P) and zinc (Zn). g

Treatment	Growth stage		
	Tillering	Heading	Maturity
P (kg/hm^2)			
0	2.8 c	14.2 c	12.5 c
40	3.4 b	17.7 b	17.9 b
80	3.7 a	18.6 a	19.4 a
120	3.8 a	18.5 ab	19.4 a
LSD (*P* = 0.05)	0.11	0.84	0.86
Zn (kg/hm^2)			
0	3.2 c	16.7 c	15.9 c
5	3.4 b	16.9 bc	17.1 b
10	3.6 a	17.6 ab	17.9 a
15	3.6 a	17.8 a	18.2 a
LSD (*P* = 0.05)	0.09	0.75	0.64
Genotype (G)			
Bamati-385 (Fine)	3.1 c	16.1 b	16.4 b
F-Malakand (Coarse)	3.3 b	16.1 b	16.5 b
Pukhraj (Coarse)	3.9 a	19.5 a	18.9 a
LSD (*P* = 0.05)	0.09	0.73	0.75
Year (Mean)			
2011	3.2 b	16.2 b	16.9 a
2012	3.7 a	18.3 a	17.6 a
Interaction			
P × Zn	***	ns	ns
P × Zn × G	***	ns	ns

Data in column with the same letter are not significantly different at the 0.05 level by least significant difference test; ns and *** stand for non-significant and significant at the 0.001 level, respectively.

Dry matter partitioning into leaves

At the tillering stage, the leaf dry matter (LDM) was significantly affected by P and Zn levels, genotypes,

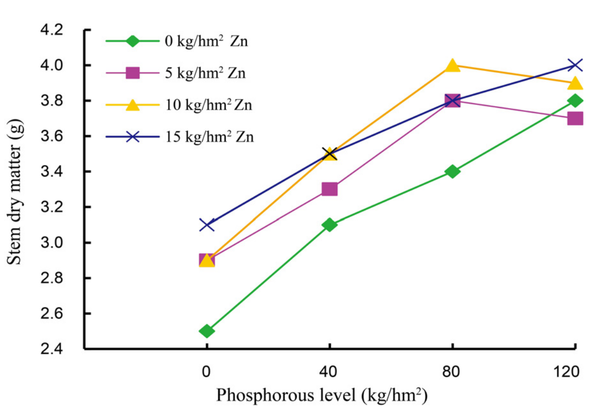

Fig. 1. Clum dry matter at rice tillering stage as affected by phosphorus and zinc (P × Zn) interaction.

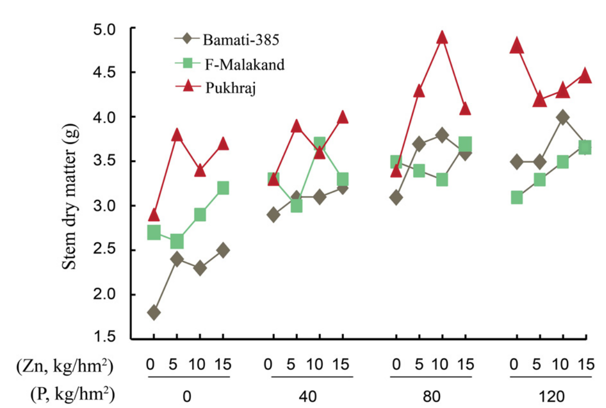

Fig. 2. Clum dry matter at rice tillering stage as affected by phosphorus, zinc and genotype (P × Zn × G) interaction.

years, P × Zn and P × Zn × G interactions (Table 2). The highest LDM (5.8 g) was produced with 120 kg/hm^2 P, while the minimum LDM (4.3 g) was observed in P-control plots. In case of Zn levels, the maximum LDM (5.4 g) was recorded with each 10 and 15 kg/hm^2. Zn-control plots produced the minimum LDM (4.8 g). Among the rice genotypes, Pukhraj produced the maximum LDM (5.9 g), followed by F-Malakand (4.9 g), while the minimum LDM (4.7 g) was observed with Bamati-385. Years mean indicated that the year 2012 produced higher LDM (5.5 g) than 2011 (4.8 g). Interaction of P × Zn indicated that increase in P level up to 80 kg/hm^2 and application of Zn either at 5 or 10 kg/hm^2 increased LDM. Application of Zn either at 0 or 15 kg/hm^2 along with the highest P level (120 kg/hm^2) had the highest LDM per hill (Fig. 3). Interaction among P × Zn × G (Fig. 4) indicated that LDMs of F-Malakand and Bamati-385 were increased with increase in P and Zn levels, while the highest LDM of Pukhraj was observed with 80 kg/hm^2 P + 10 kg/hm^2 Zn.

At the heading stage, the LDM was significantly affected by P and Zn levels, genotypes, years and P × Zn × G interaction (Table 2). Among the P levels, the maximum LDM (24.7 g) was produced with application of 120 kg/hm^2 being at par with 80 kg/hm^2 (24.6 g), while the minimum LDM (19.0 g) was observed in P-control plots. In case of Zn levels, the maximum LDM (23.3 g) was recorded with 10 kg/hm^2. However, it was statistically not different from that of 5 and 15 kg/hm^2. Zn-control plots produced the minimum LDM (22.3 g). Among the rice genotypes, Pukhraj produced the maximum LDM (24.5 g), followed by F-Malakand (23.3 g), while the minimum LDM (21.0 g) was observed for Bamati-385. Years mean data indicated that the year 2012 produced higher LDM (25.0 g) than 2011 (20.8 g). Interactions among P × Zn × G indicated that a decline in LDM of all the three genotypes was observed when P and Zn were not applied or applied alone (Fig. 5). But combine application of both nutrients had positive impact on the LDM of all the three genotypes.

Table 2. Leaf dry matter at different growth stages of rice genotypes as affected by phosphorus (P) and zinc (Zn). g

Treatment	Growth stage		
	Tillering	Heading	Maturity
P (kg/hm^2)			
0	4.3 d	19.0 c	19.2 c
40	5.0 c	23.3 b	23.5 b
80	5.6 b	24.6 a	25.1 a
120	5.8 a	24.7 a	25.3 a
LSD (*P* = 0.05)	0.17	0.57	0.83
Zn (kg/hm^2)			
0	4.8 c	22.3 b	21.9 c
5	5.1 b	22.8 ab	23.1 b
10	5.4 a	23.3 a	23.7 ab
15	5.4 a	23.2 a	24.3 a
LSD (*P* = 0.05)	0.14	0.56	0.78
Genotype (G)			
Bamati-385 (Fine)	4.7 c	21.0 c	22.0 b
F-Malakand (Coarse)	4.9 b	23.3 b	22.7 b
Pukhraj (Coarse)	5.9 a	24.5 a	25.0 a
LSD (*P* = 0.05)	0.14	0.49	0.72
Year (Mean)			
2011	4.8 b	20.8 b	21.9 b
2012	5.5 b	25.0 a	24.6 a
Interaction			
P × Zn	***	ns	ns
P × Zn × G	***	**	ns

Data in column with the same letter are not significantly different at the 0.05 level by least significant difference test; ns, ** and *** stand for non-significant, significant at the 0.01 and 0.001 levels, respectively.

At the physiological maturity stage, the LDM was significantly affected by P and Zn levels, genotypes and years (Table 2). The maximum LDM (25.3 g) was produced with 120 kg/hm^2 P being at par with 80 kg/hm^2 (25.1 g). The minimum LDM (19.2 g) was

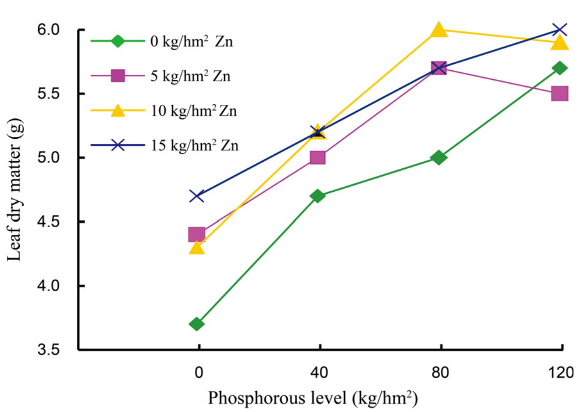

Fig. 3. Leaf dry matter at rice tillering stage as affected by phosphorus and zinc (P × Zn) interaction.

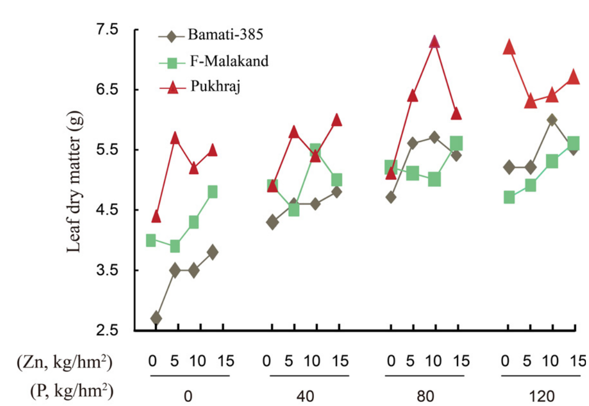

Fig. 4. Leaf dry matter at rice tillering stage as affected by phosphorus, zinc and genotype (P × Zn × G) interaction.

recorded for P-control plots. In case of Zn levels, the maximum LDM (24.3 g) was recorded with 15 kg/hm^2 being at par with 10 kg/hm^2 (23.7 g). Zn-control plots produced the minimum LDM (21.9 g). Among the rice genotypes, Pukhraj produced the maximum LDM (25.0 g). The minimum LDM (22.0 g) was recorded for Bamati-385 being at par with F-Malakand (22.7 g). The years mean data indicated that the year 2012 produced higher LDM (24.6 g) than 2011 (21.9 g).

Dry matter partitioning into panicles

At the heading stage, the panicle dry matter (PDM) was significantly affected by P and Zn levels, genotypes, years and P × Zn × G interaction (Table 3). Among the P levels, the highest PDM (33.3 g) was recorded with 120 kg/hm^2, while the minimum PDM (18.2 g) was observed in the P-control plots. Among the Zn levels, the maximum PDM (28.4 g) was recorded with 15 kg/hm^2, and the minimum (24.5 g) in Zn-control. Among the rice genotypes, Pukhraj produced the maximum PDM (35.9 g), followed by F-Malakand (25.7 g), while the minimum PDM (18.2 g) was observed in Bamati-385. The two years mean data indicated that the year 2012 had higher PDM (29.1 g) than 2011 (24.2 g). Interactions among P × Zn × G indicated that PDM of all genotypes was increased with increase in P and Zn levels, and less PDM was recorded when both nutrients were not applied (Fig. 6).

At the physiological maturity stage, the PDM was significantly affected by P and Zn levels, genotypes and years (Table 3). The highest PDM (51.7 g) was recorded with 120 kg/hm^2 P, while the minimum PDM (31.4 g) was observed in P-control plots. In case of Zn levels, the maximum PDM (47.2 g) was recorded with 15 kg/hm^2 being at par with 10 kg/hm^2 (45.1 g), and the

Table 3. Panicle dry matter at different growth stages of rice genotypes as affected by phosphorus (P) and zinc (Zn). g

Treatment	Growth stage	
	Heading	Maturity
P (kg/hm^2)		
0	18.2 d	31.4 d
40	24.7 c	43.8 c
80	30.2 b	48.5 b
120	33.3 a	51.7 a
LSD (*P* = 0.05)	0.94	1.96
Zn (kg/hm^2)		
0	24.5 d	40.5 c
5	26.1 c	42.7 b
10	27.6 b	45.1 a
15	28.4 a	47.2 a
LSD (*P* = 0.05)	0.66	2.26
Genotype (G)		
Bamati-385 (Fine)	18.2 c	29.2 c
F-Malakand (Coarse)	25.7 b	41.9 b
Pukhraj (Coarse)	35.9 a	60.5 a
LSD (*P* = 0.05)	0.81	1.70
Year (Mean)		
2011	24.2 b	39.6 b
2012	29.1 a	48.1 a
Interaction		
P × Zn	ns	ns
P × Zn × G	***	ns

Data in column with the same letter are not significantly different at the 0.05 level by least significant difference test; ns and *** stand for non-significant and significant at the 0.001 level, respectively.

Zn-control plots produced the minimum PDM (40.5 g). Among the rice genotypes, Pukhraj produced the maximum PDM (60.5 g), followed by F-Malakand (41.9 g), while the minimum PDM (29.2 g) was observed in Bamati-385. The years mean data indicated that higher PDM (48.1 g) was obtained in 2012.

Total dry matter accumulation

At the tillering stage, total dry matter (TDM) was significantly affected by P and Zn levels, genotypes, years and P × Zn × G interaction (Table 4). The highest

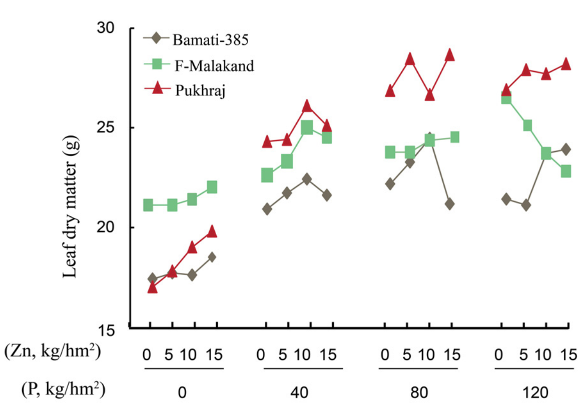

Fig. 5. Leaf dry matter at rice heading stage as affected by phosphorus, zinc and genotype (P × Zn × G) interaction.

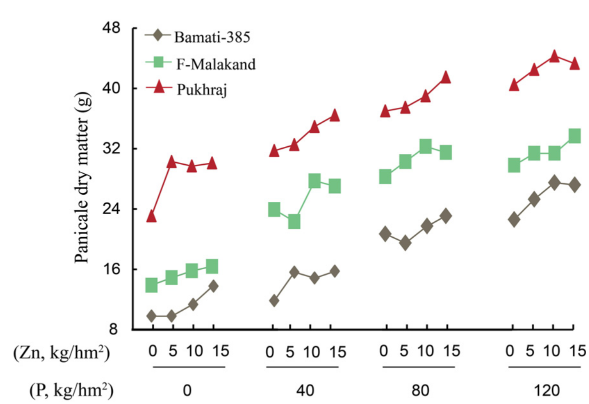

Fig. 6. Panicle dry matter at rice heading stage as affected by phosphorus, zinc and genotype (P × Zn × G) interaction.

Table 4. Total dry matter accumulation at different growth stages of rice genotypes as affected by phosphorus (P) and zinc (Zn). g

Treatment	Growth stage		
	Tillering	Heading	Maturity
P (kg/hm^2)			
0	7.2 c	51.4 d	63.1 d
40	8.4 b	65.8 c	85.2 c
80	9.3 a	73.3 b	93.0 b
120	9.5 a	76.2 a	96.4 a
LSD (*P* = 0.05)	0.44	1.64	2.86
Zn (kg/hm^2)			
0	8.0 b	63.1 c	78.3 d
5	8.6 a	65.7 b	82.9 c
10	8.8 a	68.5 a	86.8 b
15	8.9 a	69.4 a	89.7 a
LSD (*P* = 0.05)	0.32	1.32	2.68
Genotype (G)			
Bamati-385 (Fine)	7.8 c	55.3 c	67.6 c
F-Malakand (Coarse)	8.2 b	64.8 b	81.1 b
Pukhraj (Coarse)	9.8 a	80.0 a	104.5 a
LSD (*P* = 0.05)	0.38	1.42	2.47
Year (Mean)			
2011	8.0 b	61.0 b	78.4 b
2012	9.2 a	72.3 a	90.4 a
Interaction			
P × Zn	ns	ns	ns
P × Zn × G	***	ns	ns

Data in column with the same letter are not significantly different at the 0.05 level by least significant difference test; ns and *** stand for non-significant and significant at the 0.001 level, respectively.

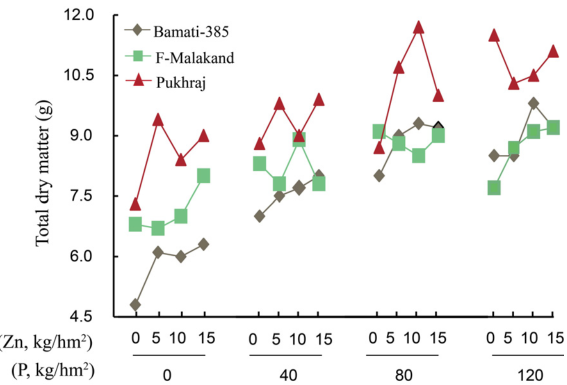

Fig. 7. Total dry matter at rice tillering stage as affected by phosphorus, zinc and genotype (P × Zn × G) interaction.

TDM (9.5 g) was produced with 120 kg/hm^2 P being at par with 80 kg/hm^2 (9.3 g), while the minimum TDM (7.2 g) was recorded for P control plots. In case of Zn levels, the highest TDM (8.9 g) was recorded with 15 kg/hm^2, being statistically at par with 5 and 10 kg/hm^2. The minimum TDM (8.03 g) was observed in Zn-control plots. Among rice genotypes, Pukhraj produced the maximum TDM (9.8 g), followed by F-Malakand (8.2 g), while the minimum TDM (7.8 g) was recorded for Bamati-385. The year 2012 produced higher TDM (9.2 g) than 2011 (8.0 g). Interaction among P × Zn × G indicated that TDM of F-Malakand and Bamati-385 was increased with increase in P and Zn levels, while the highest TDM of Pukhraj was obtained at 80 kg/hm^2 P + 10 kg/hm^2 Zn (Fig. 7).

At the heading stage, the TDM was significantly affected by P and Zn levels, genotypes and years (Table 4). The maximum TDM (76.2 g) was produced with 120 kg/hm^2 P, while the minimum TDM (51.4 g) was observed in P-control plots. Among Zn levels, the maximum TDM (69.4 g) was recorded with 15 kg/hm^2 being at par with 10 kg/hm^2 (68.5 g). The minimum TDM (63.1 g) was observed in Zn-control plots. Among the rice genotypes, Pukhraj produced the maximum TDM (80.0 g), followed by F-Malakand (64.8 g), while the minimum TDM (55.3 g) was observed with Bamati-385. The years mean data indicated that in the year 2012, higher TDM (72.3 g) was obtained as compared with that in 2011 (61.0 g).

At the physiological maturity stage, the TDM was significantly affected by P and Zn levels, genotypes and years (Table 4). Among the P levels, the highest TDM (96.4 g) was produced with 120 kg/hm^2, while the minimum TDM (63.1 g) was observed in P-control plots. In case of Zn levels, the maximum TDM (89.7 g) was recorded with 15 kg/hm^2. Zn-control plots produced the minimum TDM (78.3 g). Among the rice genotypes, Pukhraj produced the maximum TDM (104.5 g), followed by F-Malakand (81.1 g), while the minimum TDM (67.6 g) was recorded for Bamati-385. The year 2012 had higher TDM (90.4 g) than 2011 (78.4 g).

Percent of dry matter partitioning

At the early growth stage of rice (tillering), there was no difference in percent of DM partitioning into leaf (60%) and culm (40%) while using different P and Zn

Table 5. Percent of dry matter partitioning into culm, leaf and panicle at tillering, heading and physiological maturity in rice genotypes as affected by phosphorus (P) and zinc (Zn). %

Treatment	Tillering			Heading			Maturity		
	Culm	Leaf	Panicle	Culm	Leaf	Panicle	Culm	Leaf	Panicle
P (kg/hm^2)									
0	39	61	-	28	37	35	20	30	50
40	40	60	-	27	35	38	21	28	51
80	40	60	-	25	34	41	21	27	52
120	40	60	-	24	32	44	20	26	54
Zn (kg/hm^2)									
0	40	60	-	26	35	39	20	28	52
5	40	60	-	26	35	40	21	28	52
10	40	60	-	26	34	40	21	27	52
15	40	60	-	26	33	41	20	27	53
Genotype (G)									
Bamati-385	40	60	-	29	38	33	24	33	43
F-Malakand	40	60	-	25	36	39	20	28	52
Pukhraj	40	60	-	24	31	45	18	24	58

Table 6. Harvest index of rice genotypes as affected by phosphorus (P) and zinc (Zn). %

Treatment	Year		Mean
	2011	2012	
P (kg/hm^2)			
0	36.0	36.7	36.4 c
40	37.3	41.3	39.3 b
80	40.2	41.7	41.0 a
120	39.8	43.0	41.4 a
LSD (*P* = 0.05)	1.69	1.72	1.18
Zn (kg/hm^2)			
0	37.9	38.7	38.3 b
5	38.8	40.7	39.8 a
10	38.0	41.5	39.8 a
15	38.6	41.8	40.2 a
LSD (*P* = 0.05)	ns	1.45	1.15
Genotype (G)			
Bamati-385 (fine)	27.5	29.1	28.3 c
F-Malakand (coarse)	41.0	45.2	43.1 b
Pukhraj (coarse)	46.5	47.8	47.2 a
LSD (*P* = 0.05)	1.46	1.50	1.02
Year (Mean)	38.3 b	40.7 a	
Interaction			
Zn × G	ns		
P × Zn × G	ns		

Data in column with the same letter are not significantly different at the 0.05 level by least significant difference test; ns stands for non-significant.

levels, and rice genotypes (Table 5). The DM partitioning into leaf was higher than culms at the tillering stage. At later growth stages (heading and physiological maturity), the increase in P level upto the highest level accumulated more TDM and increased DM partitioning into panicles than leaves and culms at heading and physiological maturity stages. Likewise, the increase in Zn upto the highest level accumulated more TDM and partitioned more DM into panicles than leaves and culms at heading and physiological maturity stages. Among the rice genotypes, Pukhraj produced more TDM and partitioned more DM into panicles than F-Malakand and Bamati-385 at heading and physiological maturity stages. The TDM accumulation increased and greater amounts was partitioned into panicles at heading and physiological maturity stages while increasing P and Zn levels, and the increase was higher for the coarse rice genotypes than fine.

Harvest index

HI was significantly affected by P and Zn levels, genotypes and years (Table 6). Among the P levels, the maximum HI (41.4%) was calculated for 120 kg/hm^2 being at par with 80 kg/hm^2 (41.0%), while the minimum HI (36.3%) was achieved in P-control plots. In case of Zn levels, the highest HI (40.2%) was recorded with 15 kg/hm^2 being statistically at par with 5 and 10 kg/hm^2 (39.7% and 39.8%), respectively. The minimum HI (38.3%) was recorded for the Zn-control plots. Among the rice genotypes, the maximum HI (47.2%) was recorded for Pukhraj, followed by F-Malakand (43.1%), while the minimum HI (28.3%) was calculated for Bamati-385. The mean values of two years data indicated that the year 2012 had significantly higher HI (40.7%) than 2011 (38.3%).

DISCUSSION

Dry matter partitioning

In this study, the total DM accumulation and partitioning greater amounts into various plant parts was observed with the application of higher P (80 and 120 kg/hm^2) and Zn rates (10 and 15 kg/hm^2), and the increase was more when both nutrients were applied in combination than sole application. The increase in LDM with higher P and Zn levels can be attributed to the increase in leaf widths, mean single leaf area, and leaf area index (data not shown). Amanullah et al (2008) reported that the increase in leaf area index (LAI) increases light interception and so more TDM production occurres at various growth stages. According to Haldar and Mandal (1981), combine application of P and Zn significantly increases TDM accumulation in rice, and the highest increase was noted when both P and Zn were applied at their respective highest levels (100 and 10 mg/kg, respectively). The increase in dry matter accumulation with application of P-control (P not applied) was reported by many researchers (Fageria et al, 2003; Fageria and Baligar, 2005; Fageria and Filho, 2007; Alam et al, 2009; Fageria et al, 2011a). Similarly, many researchers (Fageria et al, 2011b; Khan et al, 2012; Yadi et al, 2012) reported increase in DM accumulation with increase in Zn level over control. According to Lal et al (2000) and Rahman et al (2011), combine application of Zn and P has positive effect on TDM and grain yield. In our current study, the higher DM partitioning into reproductive parts (panicles) with higher P and Zn levels at PDM had significantly increased the number of filled grains per panicle, grain weight, grain yield, HI, hulling percentage, and consequently had higher total biomass yield (data not shown). Donald and Hamblin (1976) found that grain yield in cereals is related to biomass yield and HI. Increase in DM accumulation and partitioning is important because it is significantly associated with grain yield and HI (Hasegawa, 2003). Control plots (no P and Zn applied) declined crop growth rate, yield components and grain yield (data not shown), and hence had lower total DM accumulation and partitioning. These results are in agreement with the results of Foy (1992) and Fageria et al (1996), who reported that macro- and micro-nutrient deficiencies are the most important nutritional disorders that limit crop yields.

The two coarse genotypes performed better than fine genotype in term of higher DM accumulation and partitioning. According to Sharma and Singh (1994), a wide variability in photosynthetic rate exits in rice genotypes, while Evans (1975) reported that a high photosynthetic rate is associated with higher productivity unless the sink capacity is limiting. Likewise, Alam et al (2009) found differences in DM accumulation in different rice genotypes. In this study, the coarse genotypes took more nutrients (P and Zn) from soil (data not given), which improved growth, increased LAI, crop growth rate and hence had higher DM accumulation and partitioning. According to Akinrinde and Gaizer (2006), DM production in six rice genotypes is significantly affected by P rates. The higher DM partitioning to panicles at PDM indicates the more translocation of assimilates from the leaves and culms to the panicles during the grain filling period, resulting in higher grain yield (Wiangsamut et al, 2013). In this study, the high yielding coarse rice hybrid (Pukhraj) had more DM accumulation and partitioned significantly greater amounts into panicles. Hybrid rice has higher DM partitioning efficiency and consequently has higher grain yield than inbred (Epstein and Bloom, 2005; Yadi et al, 2012; Wiangsamut et al, 2013). In our current study, the genotype with higher DM accumulation and partitioning greater amounts into reproductive parts (panicles) at PDM had significantly higher productivity and profitability (data not shown) (Pukhraj > F-Malakand > Bamati-385). Taniyama et al (1988) reported that the difference in the crop growth rate 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 Peng et al (1999), grain yield improvement of lowland rice cultivars released by the International Rice Research Institute in the Philippines after 1980 is due to increases in biomass production. Akita (1989) and Amano et al (1993) also reported that higher grain yield from rice was achieved by increasing biomass production.

Harvest index

HI in rice increased with application of higher P (80 and 120 kg/hm^2) and Zn rates (10 and 15 kg/hm^2) and the increase was more when both nutrients were applied in combination than sole application. The increase in yield components and grain yield as well as higher DM accumulation and partitioning greater amount of DM into panicles was attributed to the higher P and Zn levels that resulted in higher HI of rice and vice versa. Mafi et al (2013) reported that increasing P and Zn levels increase yield and HI in rice. Fageria et al (2011a) stated that HI increased with Zn fertilization, and the increase in HI was 32% while using 5 mg/kg Zn of soil as compared to the Zn-control plots. Yadi et al (2012) described significant effect of Zn fertilizer on HI of rice. In our study, the coarse rice genotypes (Pukhraj and F-Malakand) had higher HI than fine genotype (Bamati-385). Differences in the HI of rice genotypes have been reported by many researchers. Amano et al (1993) stated HI of 67% for japonica F_1 hybrid rice in South China. Mae (1997) described that the HI of old rice genotypes is about 30% and 50% for improved and semi-dwarf ones. In our study, the genotypes with higher HI produced higher grain yield. The increase in HI of coarse genotypes was attributed to higher DM accumulation and partitioning greater amounts into panicles. Wiangsamut et al (2013) described that the variability of genotypes in their ability to partition dry matter, and the superiority of hybrid rice, are well categorized with the sink strength and HI. In our study, the higher number of panicles per hill, filled grains per panicle, heavy grains and higher grain yield (un-published data) of coarse genotypes than the fine genotype was also the possible cause of higher HI in rice. The differences in the genetic makeup of different genotypes may also be responsible for the differences in yield components, yield and HI. Sinclair (1998) stated that HI has been an important feature related with the increases in crop yields during the 20th century. In our study, the genotypes with higher total biomass (data not published) resulted in higher HI and so higher grain yield. According to Surek and Beser (2003), higher biological yield and HI should be considered together in selection of superior genotypes of rice due to their indirect effects on each other. Song et al (1990) and Yamauchi (1994) stated that hybrid rice had a 15% greater yield than inbred rice, mainly because of an increase in biological yield rather than HI. Lafarge and Bueno (2009) reported that the yield advantage of hybrid rice over old rice cultivars in tropical environments is up to 15%. This increase in grain yield is because of higher dry matter production due to higher seedling vigor leading to quicker growth rate and higher HI. HI values varied greatly among rice cultivars, locations, seasons and ecosystems, and ranged from 35% to 62% showing the important contributing of HI in yield (Kiniry et al, 2001).

CONCLUSIONS

Phosphorus and zinc application are the most important factors for increasing total DM accumulation and partitioning greater amounts into panicles, thereby increasing HI and yield. The results of this study confirmed that increase in P and Zn levels were more beneficial in terms higher DM accumulation and partitioning greater amounts into panicles and higher HI in lowland rice genotypes. The higher DM accumulation and partitioning of greater portion into panicles as well as higher HI of hybrid rice (Pukhraj) was attributed to its longer and wider leaves, and thus in higher mean single leaf area, leaf area index, crop growth rates, yield components that resulted in higher grain yield and net returns (data not shown). Better understanding of P and Zn management for different rice genotypes in various agroecological zones can improve rice growth, crop productivity and growers income.

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