Original Article

Journal of Plant Stress Physiology 2016, 2:1-8
http://scienceflora.org/journals/jpsp/
doi: 10.19071/jpsp.2016.v2.3025

Phosphorus and zinc interaction influence leaf area index in fine versus coarse rice (*Oryza sativa* L.) genotypes in Northwest Pakistan

Amanullah[1]*, Inamullah[1], Zahir Shah[2], Shad Khan Khalil[1]

[1]Department of Agronomy, The University of Agriculture, Peshawar, Pakistan, [2]Department of Soil and Environmental Sciences, The University of Agriculture, Peshawar, Pakistan

Received: 10.12.2015
Accepted: 08.04.2016
Published: 12.04.2016

***Address for Correspondence:**
Amanullah, Department of Agronomy, The University of Agriculture, Peshawar, Pakistan.
E-mail: amanullah@aup.edu.pk

ABSTRACT

Leaf area index (LAI) is a measure of leafiness per unit ground area and denotes the extent of photosynthetic machinery is an important growth and yield-determining factor because it is a major determinant of light interception and transpiration. Phosphorus (P) and zinc (Zn) are the most important factors affecting LAI of rice (*Oryza sativa* L.). A field experiment was conducted to assess the impact of phosphorus (0, 40, 80, 120 kg P/ha) and zinc levels (0, 5, 10, 15 kg Zn/ha) on LAI of rice (*O. sativa* L.) genotypes (fine [Basmati-385] and coarse [Fakhr-e-Malakand and Pukhraj]). The experiment was conducted on farmer field at Batkhela, Malakadnd in Northwest Pakistan during summer 2011 and 2012. When combined over the 2 years, the data revealed that the highest LAI at three different growth stages (tillering, heading, and physiological maturity [PM]) was obtained with application of the highest P level (120 kg/ha) being at par with 80 kg P/ha, while the lowest LAI was recorded when P was not applied. Similarly, the highest LAI was obtained with application of the two higher Zn levels (10 and 15 kg Zn/ha), while the lowest LAI was recorded when Zn was not applied. In the case of rice genotypes, the highest LAI was obtained from Pukhraj than other two genotypes at all growth stages. The other two rice genotypes (Fakher-e-Malakand and Basmati-385) produced statistically similar LAI at different growth stages. The higher LAI of Pukhraj was attributed to its long and wider leaves that resulted in higher mean single leaf area, leaf area per tiller, per hill, and per square meter. The LAI was the highest at heading stage than at early (tillering) and later (PM) growth stages. The increase in LAI was attributed to the increase in tillers number and leaf area/hill. The increase in LAI showed a positive impact on crop growth rate, dry matter, and yield. Application of 120 kg P+10 kg Zn/ha to rice genotype Pukhraj was more beneficial in terms of higher LAI and productivity in the study area.

KEY WORDS: Genotypes, leaf area index, *Oryza sativa* L., P levels, rice, Zn levels

INTRODUCTION

Rice (*Oryza sativa* L.) 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). Rice plays a pivotal role in the agro-based and occupies a prominent position in agricultural economy of Pakistan. Rice is the second most important crop which brings economic prosperity of the growers as well as earns billions of rupees through its export for country. Rice, an important food and cash crop, is the third largest crop of Pakistan after wheat and cotton. It is planted on an area of over 2.5 million ha (11% of the total cropped area) and accounts for 17% of the total cereals produced annually. The annual production of milled rice is about 5.5 million tonnes sharing 5.5% in agriculture sector and 1.1% in gross domestic product. Rice occupies a conspicuous position in the predominately agricultural economy of Pakistan. Thus attention is required to improve its growth, yield, and quality.

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). The desire to improve the Zn and P acquisition efficiency of rice roots arises because P and Zn fertilizers are not always adequate to overcome the crop production constraints. 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). Phosphorus is the most important element which interferes on zinc uptake by plants. About the interaction of zinc and phosphorus, numerous studies have been done and all confirms this point that zinc and phosphorus imbalance in the plant, as a result excessive accumulation of phosphorus, causing zinc imposed deficiency (Salimpour *et al.*, 2010; Khorgamy and Farnia, 2009; Das *et al.*, 2005). Metabolism defect in plant cells that is related to zinc and phosphorus imbalance, so by increasing the phosphorus concentration, zinc tasks is impaired at specific positions in the cells (Mirvat *et al.*, 2006). High soil phosphate levels are one of the most common causes responsible for zinc deficiency in crops (Cakmak, 2000) which is one of the most widespread micro-nutritional disorders of food crops the world over (Alloway, 2009).

Phosphorus is second to nitrogen (N) in total application to crops yet is used by plants in much lower quantities. Unlike N, soil P readily forms weakly soluble mineral compounds in the soil, and thus resulting in poor mobility and requiring plant roots to explore new regions in the soil to facilitate P uptake (Nichols *et al.*, 2012). Screening rice genotypes using internal P utilization efficiency of rice grown in low P solution at seedling stage as screening index and subsequently testing in field trial would probably be an effective alternative to screen rice genotype with high P utilization efficiency (Li *et al.*, 2005). Zinc deficiency was first diagnosed in rice on calcareous soils of northern India (Yoshida and Tanaka, 1969). It was subsequently found to be a widespread phenomenon in lowland rice areas of Asia, and, next to nitrogen (N) and phosphorus (P) deficiency; Zn deficiency is now considered the most widespread nutrient disorder in lowland rice (Quijano-Guerta *et al.*, 2002). 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 (Qadar, 2002). Zn deficiency can be corrected by adding Zn compounds to the soil or plant, but the high cost associated with applying Zn fertilizers in sufficient quantities to overcome Zn deficiency places considerable burden on resource-poor farmers and it has therefore been suggested that breeding efforts should be intensified to improve the tolerance to Zn deficiency in rice cultivars (Quijano-Guerta *et al.*, 2002; Singh *et al.*, 2003). Due to clayey, alkaline and calcareous nature of soils in Pakistan, Zn fertilizer is mainly fixed by soil particles, and a very low amount is available and uptake by rice crop plants (Tahir *et al.*, 1991).

Measuring the leaf area index (LAI, leaf area per unit ground area) of paddy rice fields provides information on crop growth dynamics and has the potential to be a good indicator of the status of paddy rice throughout the growing season (Xiao *et al.*, 2002). Besides, it is highly correlated with rice biomass and productivity (Dobermann and Pampolino, 1995). Moreover, the LAI monitoring of paddy rice is crucial in outlining an efficient water management policy in dry areas because paddy rice is grown on flooded soils. Knowledge of growth and development of rice cultivars is fundamental for its appropriate management (Fageria and dos Santos, 2013). LAI is a measure of leafiness per unit ground area and denotes the extent of photosynthetic machinery. LAI influences the interception and utilization of solar radiation, and consequently, growth and yield (Amanullah *et al.*, 2007; 2008). According to Fageria *et al.* (2006), LAI is an important yield-determining factor for field grown crops because LAI is a major determinant of light interception and transpiration. Rapid leaf area expansion is a desirable trait in the early growth stages of cereal crops grown in low-rainfall areas, because it leads to rapid canopy closure, thereby reducing the evaporation from the soil surface, and thus increasing crop water-use efficiency (Richards *et al.*, 2002). In more favorable conditions, fast canopy development will make the crop more competitive with weeds for light interception (Lemerle *et al.*, 2001). Moreover, Van den Boogaard *et al.* (1996) showed, in a controlled - environment study, that a fast leaf area expansion rate in wheat was positively correlated with above-ground biomass and grain yield. A plant growth analysis is generally expressed as indexes of growth such as crop growth rate, relative growth rate, net assimilation rate, leaf area ratio, and LAI (Fageria *et al.*, 2006) that provide the first clue toward an understanding of variation in growth rates among genotypes or species (Lambers, 1987). Studies on the proper combination of Zn and P levels on rice growth analysis have not been carried out in Khyber Pakhtunkhwa in general and in Malakand Agency in particular. For sustainable rice production in Malakand Agency, research on the interactive effect of Zn and P levels on rice genotypes is indispensable. The main objective of this experiment was to investigate whether there is any difference in the LAI of rice genotypes at various P and Zn levels or not?

MATERIALS AND METHODS

Site Description

A field experiment was conducted to investigate the impact of zinc (Zn) and phosphorus (P) levels on three rice (*O. sativa* L.) genotypes and their residual effects on the yield and yield components of subsequent wheat (*Triticum aestivum* L., cv. Siran) 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 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), 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). Weather data for the rice-wheat cropping system during 2011-12 and 2012-13 is given in Figure 1.

Experimentation

The experiment was conducted in RCB design with a split-plot arrangement using three replications. The combination of factor-A (varieties) and B (P levels) was allotted to main plots, while factor-C (Zn levels) was 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 N/ha as urea and 60 kg K_2O/ha (sulfate of potash [SOP] or muriate of potash) was applied to all treatments. All potassium, P (triple super phosphate) and Zn (zinc sulfate) were 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 the movement of water/nutrients among different treatments. Water to each treatment was separately applied from water channel.

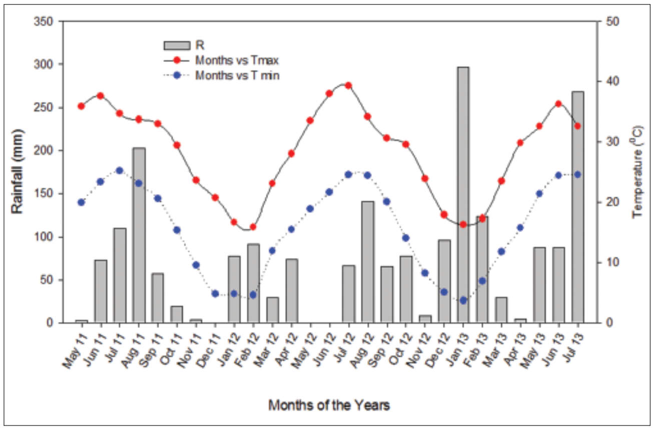

Figure 1: Rainfall and temperature data in the experimental site for the two growing seasons of rice in rice-wheat cropping system

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 LAI which was recorded according to the procedures described by Amanullah *et al*. (2007). The first number of leaves per tiller were counted by randomly selecting 10 tillers within each treatment at each growth stage (tillering, heading and PM), and then, average leaves per tiller were worked out. A number of leaves per hill were calculated at each stage by multiplying the number of leaves per tiller into number of tillers per hill.

Leaves per hill = leaves per tiller × tillers per hill

At each growth stage, the leaf lengths and widths of all leaves on the 10 selected tillers were measured and then average leaf length and width was worked out. The average leaf area (cm^2) was calculated using the formula as follows:

Average leaf area = Leaf length × Leaf width × factor

The factor used in this experiment was 0.67 at tillering and PM, and 0.75 at heading (Yoshida, 1981).

Leaf area (cm^2) per tiller and per hill at tillering, heading and PM was calculated using the formula:

Leaf area per tiller = Average leaf area × number of leaves per tiller

Leaf area per hill = Leaf area per tiller × number of tillers per hill

Then, LAI at different growth stages, i.e., at tillering, heading and PM was calculated using the following formula as follows:

LAI = Leaf area per hill ÷ Ground area per hill

Statistical Analysis

Data on all parameters of rice and wheat crops were subjected to analysis of variance (ANOVA) 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 ($P \leq 0.05$). A brief summary of ANOVA combined over the 2 years is given in Table 1.

Table 1: Mean square and significance level for LAI at tillering, heading and PM of rice genotypes as affected by phosphorus and zinc application

SOV	DF	LAI at tillering		LAI at heading		LAI at PM	
		MS	Significant	MS	Significant	MS	Significant
Years (Y)	1	0.83	ns	2.98	ns	2.35	ns
Rep. (within years)	4						
Genotypes	2	2.83	***	39.9	***	16.5	***
Y×G	2	0.02	ns	1.30	ns	0.08	ns
Phosphorus (P)	3	8.15	***	45.3	***	10.3	***
Y×P	3	0.11	ns	0.52	ns	0.03	ns
P×G	6	0.08	ns	3.91	***	0.52	***
Y×P×G	6	0.07	ns	0.33	ns	0.33	**
Pooled error-I	44	0.12		0.73		0.09	
Zinc (Zn)	3	1.15	***	3.95	***	0.95	***
Y×Zn	3	0.09	ns	0.28	ns	0.17	ns
Zn×G	6	0.04	ns	0.22	ns	0.20	ns
Y×Zn×G	6	0.08	ns	0.37	ns	0.20	ns
P×Zn	9	0.06	ns	0.29	ns	0.04	ns
Y×P×Zn	9	0.10	ns	0.38	ns	0.10	ns
P×Zn×G	18	0.05	ns	0.65	ns	0.20	*
Y×P×Zn×G	18	0.06	ns	0.19	ns	0.07	ns
Pooled error-II	144	0.07		0.44		0.12	
Total	287						
CV of main plots (%)		19.9		19.2		12.8	
CV of sub plots (%)		15.2		15.0		14.2	

MS: Mean square, ns: Non-significant, *,** and *** stands for significant at 5%, 1%, and 0.1% level of probability, PM: Physiological maturity, LAI: Leaf area index, CV: Coefficient of variation, SOV: Source of variance, DF: Degree of freedom

Table 2: Leaf area index at tillering of rice genotypes as affected by phosphorus and zinc application

Treatments	Years		Mean
	2011	2012	
Phosphorus (kg/ha)			
0	1.40	1.20	1.30^{d}
40	1.75	1.65	1.70^{c}
80	1.98	1.88	1.93^{b}
120	2.08	2.07	2.07^{a}
$LSD_{0.05}$	0.12	0.19	0.11
Zinc (kg/ha)			
0	1.68	1.47	1.58^{c}
5	1.79	1.70	1.75^{b}
10	1.84	1.77	1.80^{a}
15	1.90	1.85	1.87^{a}
$LSD_{0.05}$	0.11	0.13	0.08
Genotypes			
B-385 (fine)	1.64	1.56	1.60^{c}
F-Malakand (coarse)	1.77	1.66	1.71^{b}
Pukhraj (coarse)	2.01	1.87	1.94^{a}
$LSD_{0.05}$	0.1	0.17	0.97
Years mean	1.80	1.70	

Interactions	Level of significance
Y×P	ns
Y×Zn	ns
Y×G	ns
P×Zn	ns
P×G	ns
Zn×G	ns
P×Zn×G	ns

Means of the same category followed by different letters are significantly different at 5% level of probability using LSD test. ns: Non-significant, *,** and *** stands for significant at 5%, 1% and 0.1% level of probability, respectively. LSD: Least significant difference

RESULTS

LAI at tillering was significantly affected by P and Zn level, and genotypes (Table 2). Year and all interactions had no significant effect on LAI at tillering. Maximum LAI (2.07) was produced with 120 kg P/ha, while minimum LAI (1.30) was observed in P control plots. In the case of Zn, maximum LAI (1.87) was recorded with the highest rate of 15 kg Zn/ha being at par with 10 kg Zn/ha (1.80). Zinc control plots produced minimum LAI (1.58). Among rice genotypes, Pukhraj produced maximum LAI (1.94), followed by F-Malakand (1.71), while minimum LAI (1.60) was observed with fine genotype (B-385).

At heading LAI was significantly affected by P and Zn levels, and genotypes (Table 3). Year and all interactions except P × G had no significant effect on LAI at heading. Maximum LAI (5.06) was produced with 120 kg P/ha being at par with 80 kg P/ha (4.90), while minimum LAI (3.30) was observed in P control plots. In the case of Zn, maximum LAI (4.67) was recorded with 15 kg Zn/ha being at par with 10 kg Zn/ha (4.54). Zinc control plots produced minimum LAI (4.12). Among rice genotypes, Pukhraj produced maximum LAI (5.19), while minimum LAI (4.02) was observed for F-Malakand being at par with B-385 (4.13). Interaction of P x G indicated that LAI at heading of genotype Pukhraj was increased with increase in P level. LAI of F-Malakand and B-385 was increased with increase in P levels up to 80 kg P/ha and further increase in P level did increased the LAI in both genotypes (Figure 2).

The LAI at physiological maturity (PM) was significantly affected by P and Zn levels, and genotypes (Table 4). Among interactions, P × G and P × Zn × G were also significant. However, year had no significant effect on LAI at PM. Maximum LAI (2.68) was produced with 120 kg P/ha, while minimum LAI (1.85) was observed in P control plots. In the case of Zn, maximum LAI (2.53) was recorded with the highest rate of 15 kg Zn/ha being at par with 10 kg Zn/ha (2.45), while the Zn control plots produced minimum LAI (2.26). Among rice genotypes, Pukhraj produced maximum LAI (2.86), followed by F-Malakand (2.30), while minimum LAI was recorded with B-385 (2.05). Interaction of P × G indicated that LAI at PM of Pukhraj was increased with increase in P levels. LAI of F-Malakand and B-385 was increased with increase in P levels up to 80 kg P/ha and further increase in P level did not increased the LAI in both genotypes

Table 3: Leaf area index at heading of rice genotypes as affected by phosphorus and zinc application

Treatments	Years		Mean
	2011	2012	
Phosphorus (kg/ha)			
0	3.10	3.51	3.30^{c}
40	4.45	4.59	4.52^{b}
80	4.77	5.02	4.90^{a}
120	5.05	5.06	5.06^{a}
$LSD_{0.05}$	0.36	0.44	0.28
Zinc (kg/ha)			
0	3.94	4.30	4.12^{c}
5	4.42	4.49	4.45^{b}
10	4.41	4.66	4.54^{ab}
15	4.60	4.74	4.67^{a}
$LSD_{0.05}$	0.26	0.31	0.20
Genotypes			
B-385 (fine)	4.16	4.10	4.13^{b}
F-Malakand (coarse)	3.87	4.17	4.02^{b}
Pukhraj (coarse)	5.00	5.37	5.19^{a}
$LSD_{0.05}$	0.32	0.38	0.24
Years mean	4.34	4.55	

Interactions	Level of significance	Figure
Y×P	ns	
Y×Zn	ns	
Y×G	ns	
P×Zn	ns	
P×G	***	Figure 2
Zn×G	ns	
P×Zn×G	ns	

Means of the same category followed by different letters are significantly different at 5% level of probability using LSD test. ns: Non-significant, *,** and *** stands for significant at 5%, 1% and 0.1% level of probability, respectively. LSD: Least significant difference

Table 4: Leaf area index at physiological maturity of rice genotypes as affected by phosphorus and zinc application

Treatments	Years		Mean
	2011	2012	
Phosphorus (kg/ha)			
0	1.74	1.96	1.85^{c}
40	2.35	2.56	2.45^{bc}
80	2.56	2.69	2.62^{ab}
120	2.59	2.76	2.68^{a}
$LSD_{0.05}$	0.32	0.21	0.11
Zinc (kg/ha)			
0	2.13	2.38	2.26^{c}
5	2.24	2.50	2.37^{b}
10	2.43	2.47	2.45^{a}
15	2.44	2.61	2.53^{a}
$LSD_{0.05}$	0.30	0.20	0.10
Genotypes			
B-385 (fine)	1.96	2.14	2.05^{c}
F-Malakand (coarse)	2.18	2.41	2.30^{b}
Pukhraj (coarse)	2.80	2.92	2.86^{a}
$LSD_{0.05}$	0.20	0.23	0.09
Years mean	2.31	2.49	

Interactions	Level of significance	Figures
Y×P	ns	
Y×Zn	ns	
Y×G	ns	
P×Zn	ns	
P×G	***	Figure 3
Zn×G	ns	
P×Zn×G	*	Figure 4

Means of the same category followed by different letters are significantly different at 5% level of probability using LSD test. ns: Non-significant, *,** and *** stands for significant at 5%, 1% and 0.1% level of probability, respectively. LSD: Least significant difference

(Figure 3). Interaction of P × Zn × G exhibited that increase in LAI of Pukhraj was observed with increase in P and Zn levels up to 120 kg/ha and 10 kg/ha, respectively. The requirement of these two nutrients for optimum LAI of the remaining two genotypes was lower than Pukhraj (Figure 4). Moreover, the higher LAI in all genotypes was observed when both P and Z were applied combined while sole P and Zn application reduced the LAI in all three genotypes (Figure 4).

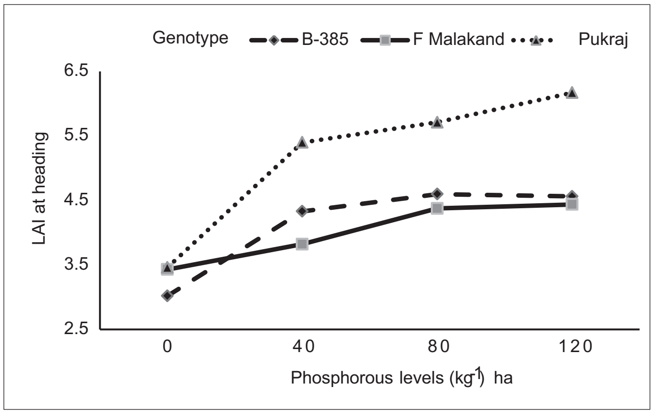

Figure 2: Leaf area index at heading of rice as affected by phosphorus into genotype (P × G) interaction

DISCUSSION

The LAI was increased with application of higher P (80 and 120 kg P/ha) and higher Zn rates (10 and 15 kg Zn/ha), and the increase was more when both nutrients were applied in combination than sole applications. The LAI was decreased with application of lower P (0 and 40 kg P/ha) and lower Zn rates (0 and 5 kg Zn/ha). The increase in LAI due to P application probably may be due the role of P in promoting plant growth and development, increase in number of tillering, and root development that resulted in higher LAI in rice. On the other hand, P deficiency in rice is referred to as a “hidden hunger” is characterized by an abnormal bluish green color of the foliage with small leaf, relatively few tillers, and decreased root mass probably may be the main reason to decrease the LAI in rice. Pellerin *et al*. (2000) reported that P deficiency in the control plots (P not applied) had negative effects on LAI and its subsequent effect on PAR absorption, C-nutrition, and maize yields. Among the various environmental factors, N and P have the most marked effect on LAI by

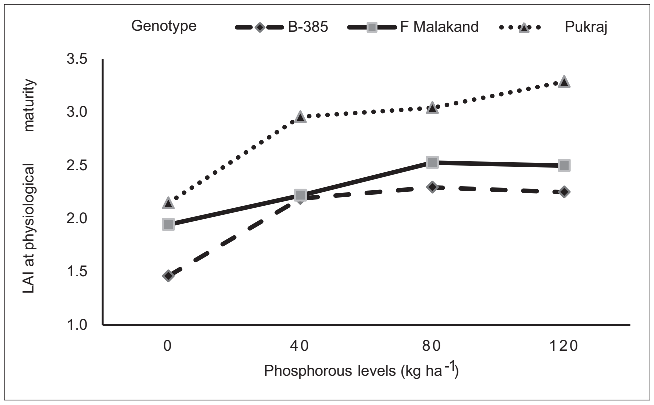

Figure 3: Leaf area index at physiological maturity of rice as affected by phosphorus into genotype (P × G) interaction

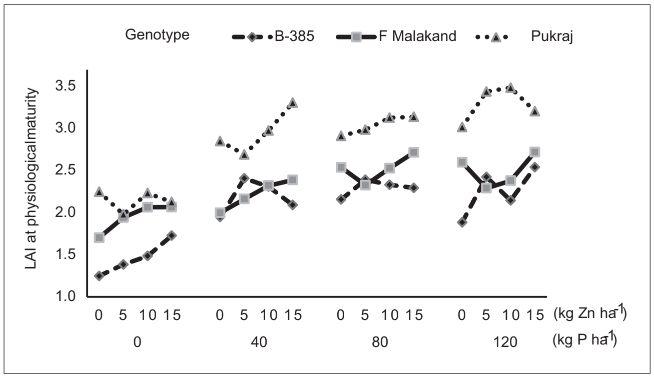

Figure 4: Leaf area index at physiological maturity of rice as affected by phosphorus into zinc into genotype (P × Zn × G) interaction

increasing number of tillers as well as leaf size (Fageria *et al.*, 1997). Plenet *et al*. (2000) reported that reduction in LAI of maize is the consequence of reduction in the leaf area. Amanullah *et al.* (2013) found that combined application of N + P or sole application of P had more favorable influence to increase number of leaf and leaf area per plant that resulted in higher LAI at the later growth stages (60 and 90 days after emergence) of oats than at the early growth stage (30 days after emergence) when compared with control (P and N not applied). The increase in LAI with higher rates of Zn application probably may be due to the role of Zn in many physiological functions, including the maintenance of the structural and functional integrity of biological membranes and the facilitation of protein synthesis. On the other hand, Zn deficiency in lowland rice, as it grows in waterlogged soils which are conducive to Zn deficiency. In flooded rice the increase in concentrations of soluble P and bicarbonate ions, this can exacerbate problems of Zn deficiency that resulted in lower tillering capacity, less mean leaf area and so lower LAI in. The increase in LAI of rice due to increase in Zn level might be attributed to the role of Zn as a cofactor in the enzymatic reactions of the anabolic pathways in plant growth. These results are supported by Metwally (2011) who reported that application of Zn increase LAI.

The highest LAI was obtained for the high yielding coarse genotype (Pukhraj), followed by another coarse genotype (Fakher-e-Malakand), while the lowest LAI was recorded with fine genotype (Basmati-385) at all three growth stages. According to Richards *et al.* (2002), rapid leaf area expansion leads to rapid canopy closure, thereby reducing the evaporation from the soil surface, and thus increasing crop water-use efficiency. The species with more rapidly elongating leaf showed a faster increase with leaf position in leaf expansion rate, leaf width and leaf area, higher relative leaf area expansion rates, and more biomass allocation to leaf sheaths and less to roots (Bultynck *et al.*, 2004). Van den Boogaard *et al.* (1996) reported that a fast leaf area expansion rate in wheat was positively correlated with above-ground biomass and grain yield. The increase in the total dry weight/plant showed a negative relationship with LAR, but the response was different among the four crop species. Baligar *et al.* (2001) reported that efficiency of acquisition, transport and utilization of nutrients varies with crop species and genotypes within species, and their interactions with the environment. More leaf remains green during grain filling period is a desirable characteristic of rice cultivars. Slow senescence of upper two or three leaves is desirable because, it allows active photosynthesis and grain filling until the grain is fully mature (Jennings *et al.*, 1979). Preventing or slowing of accelerated senescence of leaf seems to be a key for high yielding rice cultivars (Fageria, 2007). A recent analysis of multi-species and/or multi-site data sets report substantial variation in LAI with ranges between 1 and 10 and more (Ewert and Pleijel, 1999; Choudhury, 2001; Cowling and Field, 2003). Youshida (1981) reported that an LAI of 5-6 is necessary to achieve maximum crop photosynthesis during the reproductive growth stage. According to Fageria *et al*. (2006), plant genetics, number of tillers per unit area, plant densities, and spacing are the major factors influencing the leaf area of plants grown under field conditions. Youshida (1981) reported that photosynthesis of an erect leafed canopy was 20% higher compared to droopy leafed canopy when the LAI was extremely greater than 7. Fageria (2007) reported that during the spikelet filling growth stage, the LAI will decrease due to leaf senescence. This is a normal process in the growth cycle of rice. However, it is important to maintain as many active, green leaves as possible until the linear phase of spikelet growth is completed. Because the mobile carbohydrates, proteins, and mineral nutrients, which are stored in leaf, stems, and roots of the plant, move to the panicles at later growth stage of rice and the plant gradually becomes senescent. Dry matter production in rice has been reported to be significantly related to intercept photosynthetically active radiation (Kiniry *et al*., 2001).

CONCLUSIONS

LAI is a measure of leafiness per unit ground area is an important growth and yield-determining factor. Phosphorus and zinc management is one of the most important factors improving LAI and yield in rice. Numerous studies indicated that interaction of zinc and phosphorus imbalance in the plant results excessive phosphorus accumulation causing zinc imposed deficiency. The results from this study confirm that combine application of phosphorus and zinc at higher rates (i.e., 120 kg P + 15 kg Zn, 120 kg P + 10 kg Zn, 80 kg P + 15 kg Zn, and 80 kg P + 10 kg Zn) was more beneficial in terms higher LAI at different growth stages of rice. The coarse rice genotype (Pukhraj) produced higher LAI than the other two genotypes. The higher LAI of Pukhraj was attributed to its long and wider leaves that resulted in higher mean single leaf area, leaf area per tiller and per hill. The improvement in LAI with better management of P and Zn management could increase crop growth rate, dry matter accumulation and yield in rice. It is recommended that growing rice hybrid "Pukhraj" with application of P at the highest rate (120 kg P/ha) + 10 kg Zn/ha was found most suitable for improving the LAI and yield in Northwest Pakistan.

ACKNOWLEDGMENTS

We are highly thankful to Prof. Dr. Paigham Shah, Agricultural University Peshawar (retired) for the statistical analysis of the data. We are also thankful to Mr. Imran Khan, M.Sc (Hons) student of Agronomy for helping while writing this manuscript.

REFERENCES

Alloway BJ. Soil factors associated with zinc deficiency in crops and humans. Environ Geochem Health 2009;31:537-48.

Amanullah, Hassan MJ, Nawab K, Ali A. Response of specific leaf area (SLA), leaf area index (LAI) and leaf area ratio (LAR) of maize (i L.) to plant density, rate and timing of nitrogen application. World Appl Sci J 2007;2:235-43.

Amanullah, Hidayatullah, Jan A, Stewart BA. Growth dynamics and leaf characteristics in oats (A*vena sativa* L.) differ at excessive nitrogen and phosphorus application. Pak J Bot 2013;45:853-63.

Baligar VC, Fageria NK, He ZL. Nutrient use efficiency in plants. Commun Soil Sci Plant Anal 2001;32:921-50.

Bultynck L, Ter Steege MW, Schortemeyer M, Poot P, Lambers H. From individual leaf elongation to whole shoot leaf area expansion: A comparison of three *Aegilops* and two *Triticum* species. Ann Bot 2004;94:99-108.

Cakmak I. Possible roles of zinc in protecting plant cells from damage by reactive oxygen species. New Phytol 2000;146:185-205.

Choudhury BJ. Estimating gross photosynthesis using satellite and ancillary data: Approach and preliminary results. Remote Sens Environ 2001;75:1-21.

Confalonieri R, Bocchi S. Evaluation of crop syst for simulating the yield of flooded rice in northern Italy. Eur J Agron 2005;23:315-32.

Cowling SA, Field CB. Environmental control of leaf area production: Implications for vegetation and land-surface modeling. Glob Biogeochem Cycles 2003;17:1-14.

Das K, Dang R, Shivananda TN, Sur P. Interaction between phosphorus and zinc on the biomass yield and yield attributes of the medicinal plant stevia (*Stevia rebaudiana*). ScienceWorld Journal 2005;5:390-5.

Dobermann A, Pampolino MF. Indirect leaf area index measurement as a tool for characterizing rice growth at the field scale. Commun Soil Sci Plant Anal 1995;26:1507-23.

Ewert F, Pleijel H. Phenological development, leaf emergence, tillering and leaf area index, and duration of spring wheat across Europe in response to CO_2 and ozone. Eur J Agron 1999;10:171-84.

Fageria NK, Baligar VC, Clark RB. Root architecture. In: Physiology of Crop Production. Binghamton, NY, USA: The Haworth Press; 2006. p. 23-59.

Fageria NK, Baligar VC, Jones CA. Growth and Mineral Nutrition of Field Crops. 2nd ed. NY: Marcel Dekker, Inc.; 1997.

Fageria NK, dos Santos AB. Lowland rice growth and development and nutrient uptake during growth cycle. J Plant Nutr 2013;36:1841-52.

Fageria NK, Moraes OP, Vasconcelos MJ. Upland rice genotypes evaluation for phosphorus use efficiency. J Plant Nutr 2013;36:1868-80.

Fageria NK. Yield physiology of rice. J Plant Nutr 2007;30:843-79.

Ismail AM, Heuer S, Thomson JT, Wissuwa M. Genetic and genomic approaches to develop rice germplasm for problem soils. Plant Mol Biol 2007;65:547-70.

Jennings PR, Coffman WR, Kauffman HE. Rice Improvement. Los Banos, Philippines: International Rice Research Institute; 1979.

Khorgamy A, Farnia A. Effect of phosphorus and zinc fertilization on yield and yield components of chick pea cultivars. Afr Crop Sci Conf Proc 2009;9:205-8.

Lambers H. Does variation in photosynthetic rate explain variation in growth rate and yield? Netherlands J Agric Sci 1987;35:505-19.

Lemerle D, Gill GS, Murphy CE, Walker SR, Cousens RD, Mokhtari S, *et al*. Genetic improvement and agronomy for enhanced wheat competitiveness with weeds. Aust J Agric Res 2001;52527-48.

Li Y, Luo A, Wang W, Yang C, Yang X. An approach to the screening index for low phosphorus tolerant rice genotype. Ying Yong Sheng Tai Xue Bao 2005;16:119-24.

Marschner H. Mineral Nutrition of Higher Plants. 2nd ed. San Diego, CA: Academic Press; 2002.

Metwally TF. Performance of Egyptian hybrid rice under different rates, time and methods of zinc application. J Agric Res Kafer El-Sheikh Univ 2011;37:642-57.

Mirvat EG, Mohamed MH, Tawfik MM. Effect of phosphorus fertilizer and foliar spraying with zinc on growth, yield and quality of groundnut under reclaimed sandy soils. J Appl Sci Res 2006;2:491-6.

Nichols BA, Hopkins BG, Jolley VD, Bruce L, Greenwood BG, Buck JR. Phosphorus and zinc interactions and their relationships with other nutrients in maize grown in chelator-buffered nutrient solution. J Plant Nutr 2012;35:123-41.

Pellerin S, Mollier A, Plenet D. Phosphorus deficiency affects the rate of emergence and number of maize adventitious nodal roots. Agron J 2000;92:690-7.

Plenet D, Mollier A, Pellerin S. Growth analysis of maize field crops under deficiency. Radiation-use efficiency, biomass accumulation and yield components. Soil Sci J 2000;165:259-72.

Qadar A. Selecting rice genotypes tolerant to zinc deficiency and sodicity stresses. I. Differences in zinc, iron, manganese, copper, phosphorus concentrations, and phosphorus/zinc ratio in their leaves. J Plant Nutr 2002;25:457-73.

Quijano-Guerta C, Kirk GJ, Portugal AM, Bartolome VI, McLaren GC. Tolerance of rice germplasm to zinc deficiency. Field Crops Res 2002;76:123-30.

Richards RA, Rebetzke GJ, Condon AG, van Herwaarden AF. Breeding opportunities for increasing the efficiency of water use and crop yield in temperate cereals. Crop Sci 2002;42:111-121.

Rose TJ, Impa SM, Rose MT, Pariasca-Tanaka J, Mori A, Heuer S, *et al.* Enhancing phosphorus and zinc acquisition efficiency in rice: A critical review of root traits and their potential utility in rice breeding. Ann Bot 2013;112:331-45.

Salimpour S, Khavazi K, Nadian H, Besharati H, Miransari M. Enhancing phosphorous availability to canola (*Brassica napus* L.) using P solubilizing and sulfur oxidizing bacteria. Aust J Crop Sci 2010;4:330-4.

Singh B, Natesan SK, Singh BK, Usha K. Improving zinc efficiency of cereals under zinc deficiency. Curr Sci 2003;88:36-44.

Steel RG, Torrie JH, Dickey D. Principles and Procedures of Statistics. USA: McGraw-Hill; 1996.

Tahir M, Kausar MA, Ahmad R, Bhatti SA. Micronutrient status of Faisalabad and Sheikhupura soils. Pak J Agric Res 1991;12:134-40.

Xiao X, He I, Salas W, Li C, Moore B, Zhao R, *et al*. Quantitative relationships between field-measured leaf area index and vegetation index derived from vegetation images for paddy rice fields. Int J Remote Sens 2002;23:3595-604.

Yoshida S, Tanaka A. Zinc deficiency of the rice plant in calcareous soils. Soil Sci Plant Nutr 1969;15:75-80.

Youshida S. Fundamental of Rice Crop Science. Philippines: International Rice Research Institute (IRRI); 1981.