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Research Article

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Phosphorus Deficiency Stress Tolerance of Six High-Yielding Wheat Genotypes of Pakistan

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Abstract

Phosphorus (P) is an essential nutrient for wheat production and about half of total P fertilizers are consumed by only wheat in Pakistan. Hence, keeping in mind the ever-increasing input cost of P fertilizers, it becomes highly imperative to identify modern wheat genotypes for their P-use-efficiency. The experiment was consisted two factor completely randomized design (CRD) with three replications. Factor A comprised of two levels of soil applied P i.e.0 Kg ha^{-1} (Control) and 90 Kg ha^{-1}, while factor B involved six wheat genotypes (Benazir, Imdad -2005, TD-I, Kiran-95, Tj-83, Sindhu). Results showed that as against its deficient condition, adequate P nutrition (90 kg P ha^{-1}) enhanced shoot length (28%), root length (8.9%), fresh shoot weight (97%), fresh root weight (20%), no of leaves per plant (9.3%), leaf area index (130%), dry weight of shoot (83%), dry weight of root (16.5%) of wheat genotypes. Wheat genotype exhibited wide genotypic variation for their P biomass efficiency. Most interestingly, the Phosphorus efficiency ratio (PER) of the wheat genotypes was greater for TJ-83 and Sindhu. The genotype TJ-83 and Sindhu were the most biomass productive genotypes followed by Benazir and Kiran-95 in the uthal region of the Baluchistan. The study concluded that under P deficiency stress, enhanced efficient wheat genotypes determines their growth and biomass production. The genotype Sindhu was categorized as 'efficient-responsive' wheat genotype in terms of biomass production, most desirable both for low and high input sustainable agriculture system, Further validation of these results is required under field conditions at Uthal region Balochistan.

Keywords: *Genotypes, Adequate P, Deficient P, Biomass production, P nutrition*

Introduction

Wheat (*Triticum aestivum* L) belongs to family Poaceae family includes major cropping plants such as wheat (*Triticum aestivum* L.), is the most widely grown cereal crop in the world, covering about 237 million hectares annually, accounting for a total of 420 million tones in1990. In 2020 wheat productions for Pakistan was 24,946 thousand tones. Wheat production of Pakistan increased from 6,476 thousand tones in 1971 to 24,946 thousand tones in 2020 cropping at an average annual rate of 3.11%. Pakistan and the rest of the globe both depend heavily on wheat as a primary food crop. Wheat, however, grows slowly on average for a variety of reasons. A significant contributing component is nutrient insufficiency. P deficit follows the universal deficiencies of nitrogen and phosphorus. Nearly 50% of the soils in the world are used to grow biomass. Numerous soil and environmental conditions, such as low soil organic matter, high soil pH, calcareousness, water logging, and arid climate, are to blame for low soil P. To solve the widespread issue of P insufficiency, various strategies have been researched. These include P supplements, which are useful for the growth of the wheat plant and supply nutrients as well as being beneficial for the creation of biomass. A useful way to address wheat crops' P shortage for plant development is to increase the P content of those crops. P fertilization can raise the P content of crops, but farmers with limited resources cannot afford the relatively high cost of P fertilizers (Yaseen *et al.*, 2008; Rahim *et al.*, 2010; Havlin *et al.*, 2016; Bilal *et al.*, 2018). Around the world, crops frequently fail to produce enough phosphorus. According to estimates, P is insufficient for crop production on more than 40% of the world's cultivated land. The creation of biomass and wheat crop growth are both strongly controlled by phosphorus (Havlin *et al.*, 2016). For appropriate growth and biomass production, the wheat crop needed phosphorus in the early stages (Grant *et al*., 2005; Kim *et al*., 2016; Liu *et al*., 2021). A sufficient amount of phosphorus promotes the establishment of wheat crops' roots and biomass output (Blue,1990). As a fundamental nutrient, phosphorus is essential for the production of plant biomass (Grant CA. 2001). Additionally, phosphorus enhances the tillering stage of wheat crops and promotes uniformity during the heading stage. Additionally, it raises the crop plant's WUE, which raises the grain yield potential of wheat (Ahmed and Rashid, 2003). Unwise use of inorganic sources is extremely dangerous for the environment even though they speed up crop development (Tiwary, 1998). While natural sources not only provide sufficient NPK but also have a positive impact on plant development and growth, water holding capacity (WHC), soil fertility, and biological features (Cooke,1982). Out of all the organic fertilizer sources, poultry dung is the most affordable and effective source of phosphorus. Excreta from farm birds called poultry manure slowly degrade and have a higher P content than any other organic nutrient source about 2.63 percent of it is phosphorus (Babu and Ibraham, 2006). Crop growers may be persuaded to apply inexpensive and easily accessible natural waste as phosphorus fertilizer and all essential macro nutrients in the presence of increasing fertilizer rates, shortages at planting time, and a dearth of sources for inorganic fertilizers (Nisar, 2000). This method might improve the soil's P organic matter and micronutrient availability (Timsina and Connor, 2001). However, applying solely organic manure is insufficient to promote growth. Because they contain a relatively lower percentage of nutrients, organic manures must be applied in greater quantities to meet crop needs (Yamoah, 2002; Han, 2016; Kubar *et al*., 2022). For improving FUE and reducing the risks brought on by the careless use of synthetic fertilizers, respectively, complementary use of organic and inorganic fertilizers is crucial (Bayu, 2006). It is generally accepted that increased phosphorus fertilizer application rates are necessary to evaluate high-potential novel cultivars (Clark, 1990). Wheat genotypes with higher PUE that are adapted to soils with low P availability in farmed soils will aid in the growth of wheat crops (MacDonald, 2011; Kubar *et al*., 2016). Therefore, the significance of phosphorus (P) fertilizer as a significant crop nutrient was set to examine the relative effects of sources of phosphorus (P) fertilizer (synthetic and organic) that are used solely or in various combinations on PUE (phosphorus use efficiency) and the growth and biomass production of wheat. The objectives of the study were: (1) Assess the growth, biomass production of wheat genotypes under deficient and adequate phosphorus nutrition. (2) Determine the relationship of wheat growth and biomass production at deficient and adequate phosphorus nutrition.

Materials and methods

Site description: The experiments were conducted in the Rabi season of 2021–2022 at the greenhouse of the department of soil science Lasbela University of Agriculture Water and Marine Sciences (25.8420° N, 66.6248° E). The area's climate is tropical, with an average annual rainfall of roughly 30.48 mm in the summer and average maximum and minimum temperatures of 40°C and 2.3°C, respectively. In the winter, the average minimum temperature is 10.5°C and maximum temperature of 26.1°C.

A pot experiment was done in the glass house of the Department soil Science, Faculty of Agriculture, Lasbela University of Agriculture Water and Marine Science in Uthal Baluchistan in order to assess the effects of various phosphorus levels on the growth, development, and biomass output of wheat genotypes. The details of materials used and methods employed in this study are covered in the following paragraphs.

Site of research work: This pot study was conducted at the glass-house of the Lasbela University of Agriculture Water & Marine Sciences, Uthal, Balochistan.

Detail of wheat genotypes: The experiment involved six modern and classical high-yielding wheat genotypes, viz. Benazir, Imdad -2005, TD-I, Kiran-95, Tj-83.

Experimental design and treatment detail: In plastic pots with 2.5 kg of soil inside, the experiment was started using a two-factor completely randomized design (CRD) with three replications. Factor B involved six wheat genotypes, while Factor A involved two quantities of soil applied P, namely 0 kg ha^{-1} (Control) and 90 kg ha-1 (Kiran-95, Tj-83, Sindhu, imdad-2005, Benazir, TD-I).

Fertilizer application: The crop received the recommended amounts of potassium and nitrogen (100 kg ha-1) (60 kg ha-1). Urea (46 percent N) was used to supply the nitrogen, and K2SO4, SOP, was used to supply the potassium (50 percent K). Phosphorus was applied using diammonium phosphate (DAP) at a rate of 90 kg ha-1 (18 percent N and 46 percent K2O5). Prior to filling the pots, the soil was mixed with the full doses of phosphatic and potassic fertilizers and half of the required N. After 20 days of sowing, the remaining N dose was administered.

Soil preparation for pot experiment: A 20 cm depth of soil from the Karri River in Uthal, Balochistan was investigated in this pot study. The soil was then sieved for use in a pot study using a garden sieve (4 mm).

Filling of pots with treated soil: The required quantity of soil of thirty six experimental pots was spread on to big plastic sheet to homogenize it properly. The soil was then divided into two equal batches. To one batch, half of the recommended N fertilizer and full dose of the phosphorus fertilizers were added, mixed and properly homogenized. To the batch leftover, similar practice was performed, however, no phosphorus fertilizer was added. These fertilizer treated batches of soils were filled to polyethylene lined plastic pots at 2.5 kg soil each, as per treatment plan.

Sowing and harvesting: The sowing was done on November 29, 2021. In each pot, ten seeds were planted by making a 2 cm deep hole with a pencil. After that, for 45 days, only two seedlings of the same size were permitted to grow in each pot. The plants were harvested on 12 January, 2022.

Agronomic and other practices: The crop received the appropriate amount of irrigation. Daily inspection and manual weed removal throughout the crop's lifespan were used to keep the crop weed-free. Throughout the crop's life, all other advised agronomic techniques were followed. To avoid any external influences, the pots were turned twice a week.

Recording of growth and biomass production parameter: At maturity 45 days after sowing, the plants were harvested and the data for various growth and biomass parameters of wheat were recorded, viz. Shoot length and root length, number of per plant leaves, fresh and dry weight of shoots and roots were recorded.

Statistical analyses: Using "Statistix ver.8.1," the necessary statistical analyses were performed on the acquired data. Following a two-factor completely randomized design, the analysis of variance was carried out. Tukey's honestly significant difference test (alpha 0.05) separated the treatment means. Through correlation analysis, the correlations between several growth and biomass metrics were discovered.

Results

This pot study aimed at evaluating the impacts of varying levels of phosphorus (P) on the growth and biomass production of wheat genotypes. The results of this pot experiment in relation to the effect of P on growth and different biomass production besides P relations, are presented below. All the plant attributes of the wheat genotypes under study were affected by adequate P feeding significantly ($p < 0.05$). The differences between the wheat genotypes for the various plant traits at two P levels were also statistically significant ($p < 0.05$). As a result, the interaction between these two sources of variance was likewise very significant, and it had distinct effects on various wheat genotypes' plant attributes.

Shoot length (cm):In comparison to no phosphorous application adequate phosphorus application increased the shoot length of wheat plants by up to 28%. The behavior of genotypes in producing shoot length at the two distinct amounts of phosphorous was different, though. Maximum (24.0 cm) shoot length was reported for TD-I under P deficiency stress, whilst minimal shoot length was noted for Imdad-2005 (19.0 cm) When wheat plants received sufficient phosphorus, Sindhu (33.9 cm) had the longest shoots, and Imdad-2005 had the shortest shoots (23.5 cm)

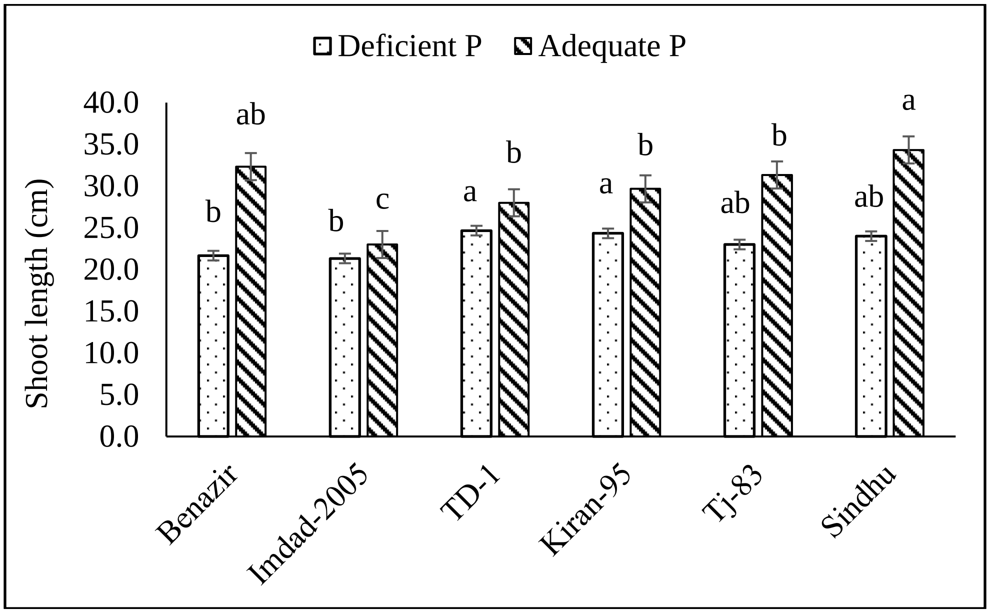

Figure 1. Shoot length of wheat genotypes as affected by adequate and deficient phosphorus nutrition.

Root length (cm): When compared to no phosphorous was applied wheat plants' roots grew up to 8.9% longer with adequate phosphorus application. But when it came to producing root length at two different phosphorous levels, genotypes acted in different ways. Maximum (19.0) root lengths were reported for Sindhu under P deficient stress, whilst minimal root lengths were noted for Kiran-95 (14.0). Sindhu (2.0) had the largest root length when wheat plants received enough phosphorous, but TJ-83 had the shortest root length (11.5).

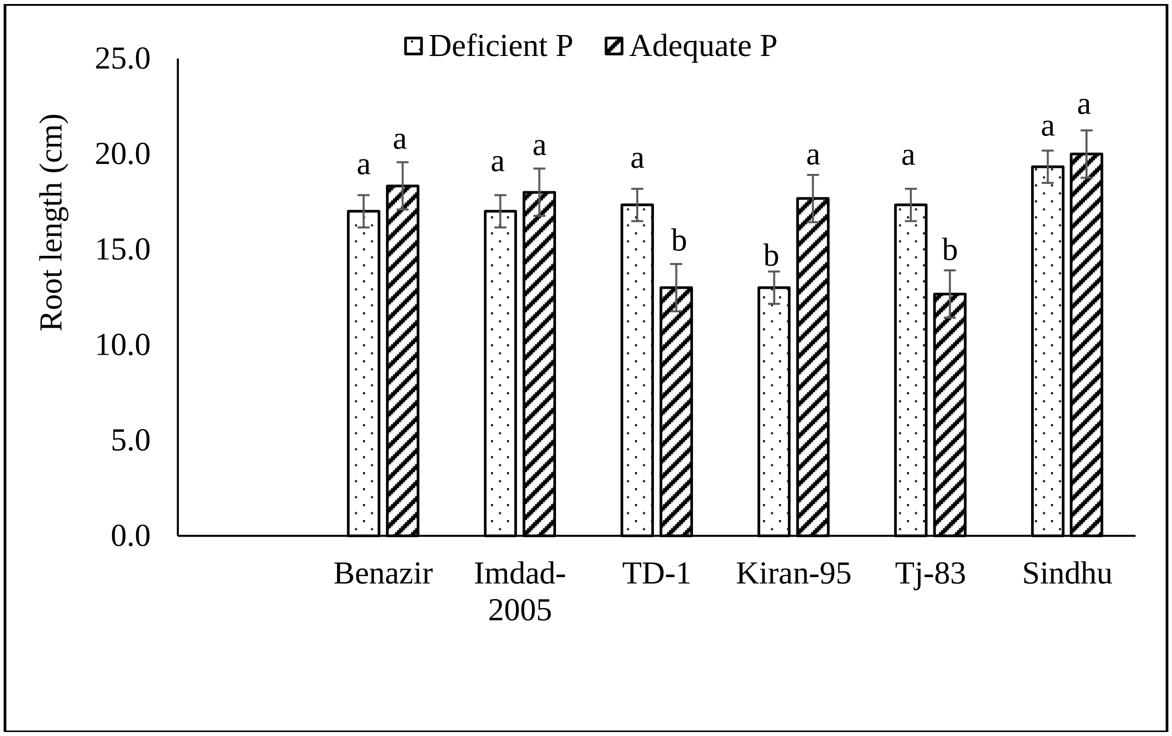

Figure 2. Root length of wheat genotypes as affected by adequate and deficient phosphorus nutrition.

Fresh shoot biomass (g): When compared to no phosphorous application adequate phosphorus application increased the fresh shoot weight of wheat plants by up to 97%. But when it came to developing fresh shoot weight at two distinct phosphorous levels, genotypes acted in different ways. Imdad-2005 had the highest fresh shoot weight (4.0) under P deficiency stress, whereas TJ-83 had the lowest fresh shoot weight (3.0). Maximum fresh shoot weights were measured on TJ-83 (9.0), whereas minimal fresh shoot weights were discovered on Imdad-2005 when phosphorous was sufficiently provided to wheat plants.

Fresh root biomass (g): In comparison to no phosphorous application adequate phosphorus application increased the fresh root weight of wheat plants by up to 20.8%. However, at two distinct phosphorous levels, the behavior of genotypes in producing fresh root weight varied. Benazir had the highest fresh root weight (2.8) under phosphorous deficiency stress, whereas Kiran-95 had the lowest fresh root weight (1.6) When wheat plants received enough phosphorous, Sindhu (3.9) had the highest fresh root weight and TD-1 had the lowest fresh root weight (1.0).

Number of leaves per plant: When application of suitable amount of phosphorus wheat plants produced 9.3% more leaves compared to the control treatment (Fig. 1). However, there was a lot of variety across wheat genotypes, and they each produced a different amount of leaves. While Sindhu generated the fewest leaves (4.0) and TD-1 produced the most leaves (5.1), Imdad-2005 produced the most leaves (5.5) and Sindhu produced the fewest leaves (4.0) while under phosphorous deficiency stress (4.5).

L**eaf area index:** When application of an acceptable quantity of (P) phosphorus wheat plants produced 9.3% more leaf area compared to the treatment without phosphorous. Although there was a lot of heterogeneity across wheat genotypes, different leaf area indices were developed. However, under P deficit stress, TJ-83 produced maximum leaf area index (17.0), while minimum leaf area index was seen on Imdad-2005. Under phosphorous deficiency condition, Benazir produced maximum leaves (7.0), while minimum leaves were counted on TJ-83 (7.0).

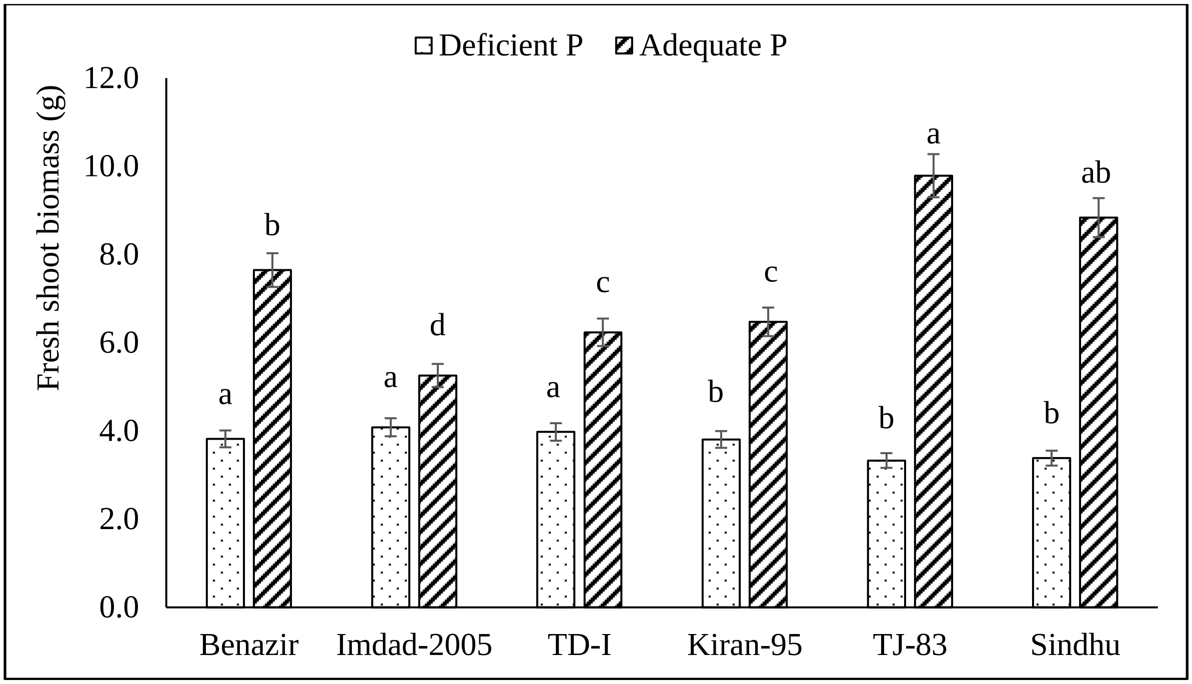

Figure 3. Fresh shoot biomass of wheat genotypes as affected by adequate and deficient phosphorus nutrition.

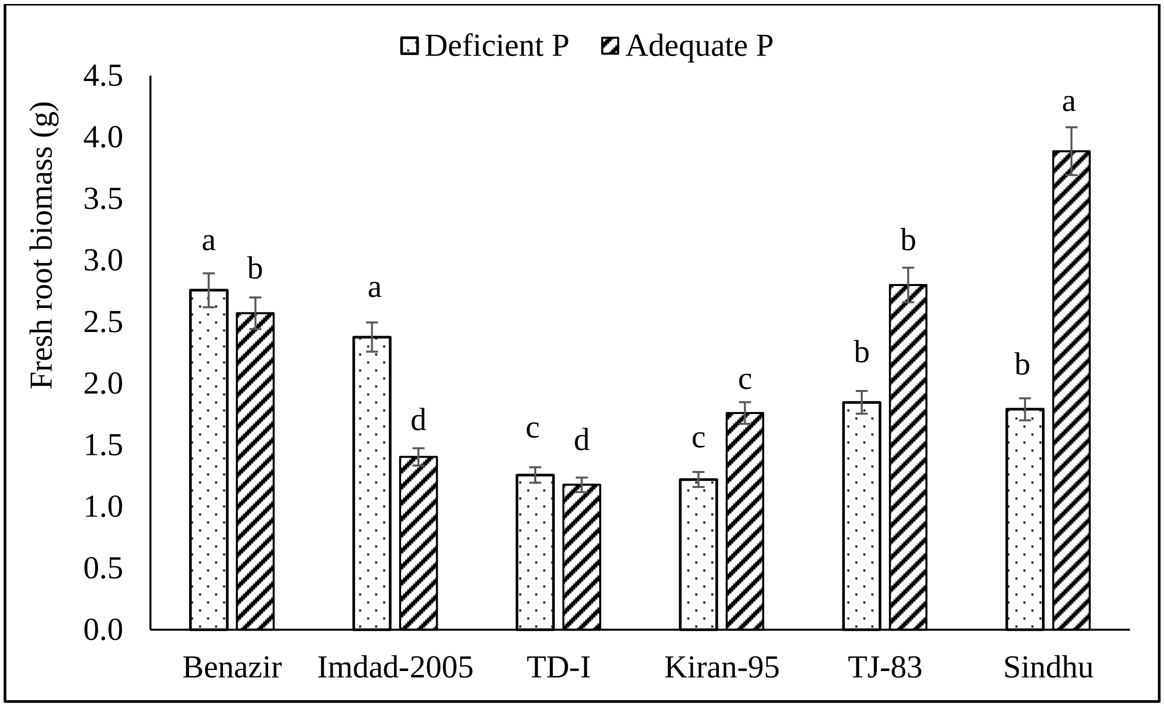

Figure 4. Fresh Root biomass of wheat genotypes as affected by adequate and deficient phosphorus nutrition.

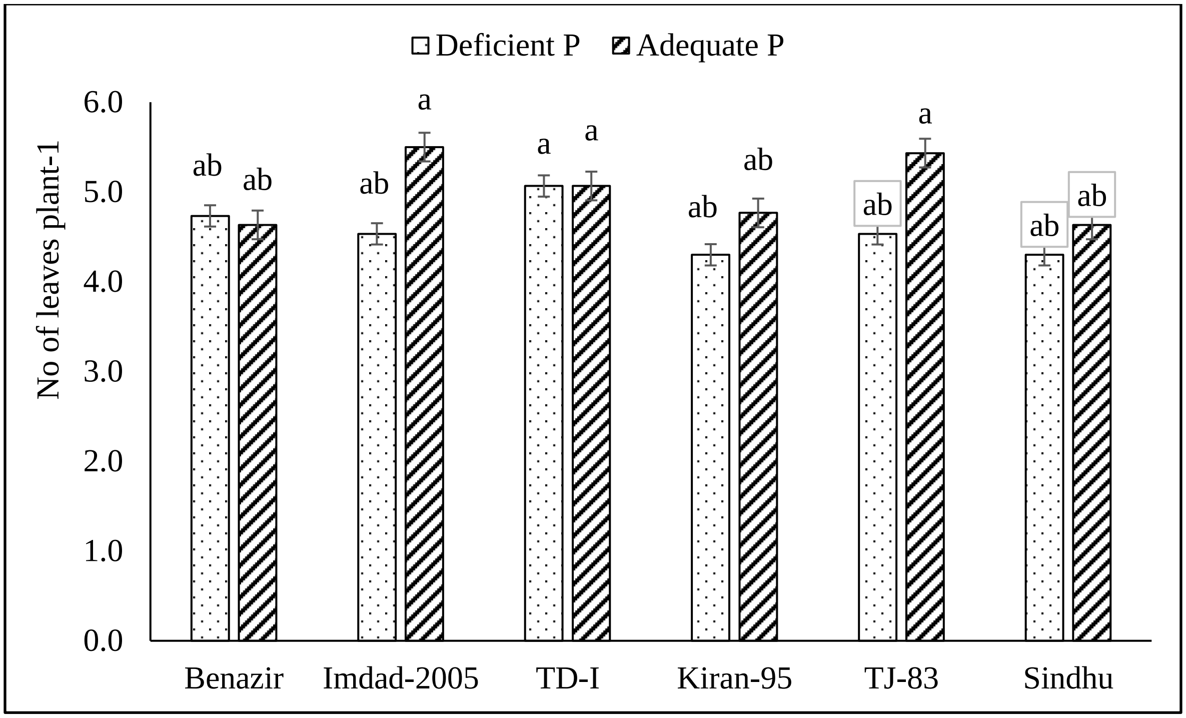

Figure 5. Number of leaves of wheat genotypes as affected by adequate and deficient phosphorus nutrition.

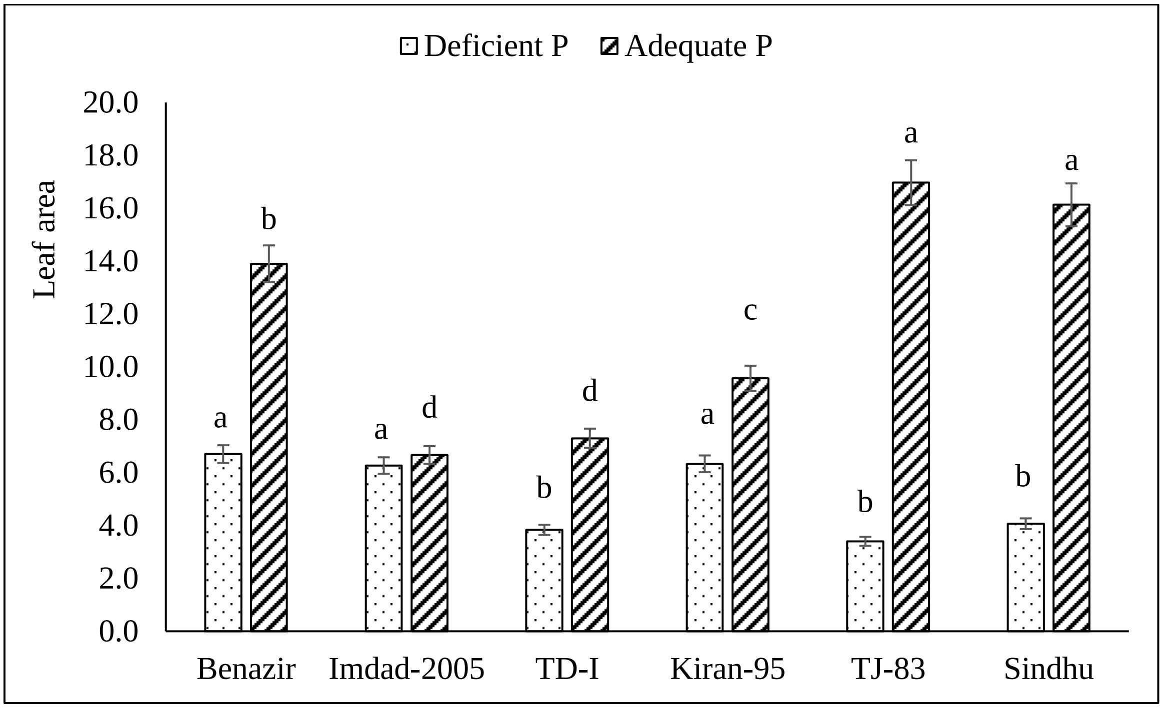

Figure 6. Leaf area of wheat genotypes as affected by adequate and deficient phosphorus nutrition.

Shoot dry biomass (g): When wheat plants were given enough phosphorus application their shoot dry weight increased by up to 83%. However, at two phosphorous levels, this effect of P feeding was extremely genotype specific. When P was insufficient, TD-1 produced the highest shoot dry weight (1.1), while TJ-83 produced the lowest (0.8). TJ-83 responded better than any other genotype to P-adequate conditions and generated the most shoot dry weight per plant (2.2), whereas Imdad-2005 produced the least (1.3).

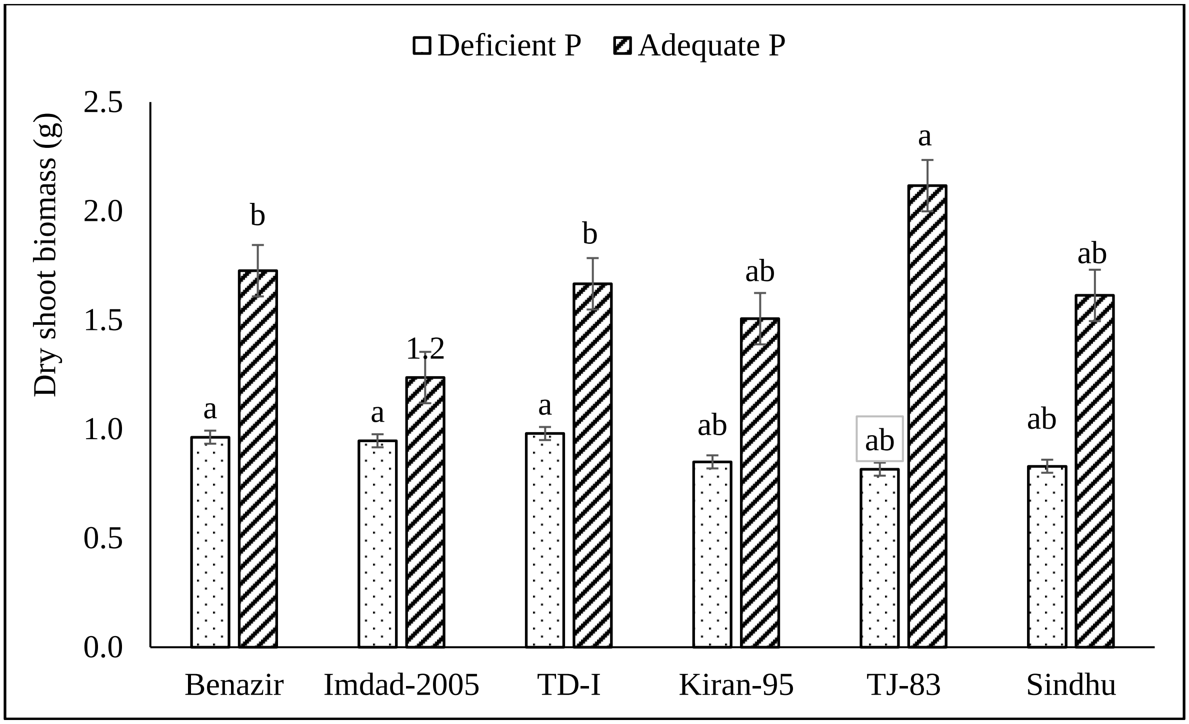

Figure 7. Dry shoot biomass of wheat genotypes as affected by adequate and deficient phosphorus nutrition.

Root dry weight (g): When wheat plants given enough (P) phosphorus application their root dry weight increased by up to 16%. However, at two phosphorous levels, this effect of P feeding was extremely genotype specific. Benazir generated the highest root dry weight possible (1.7) at low P levels, while Kiran-95 produced the lowest (0.4). When phosphorous was enough, Sindhu responded more than any other genotype and generated the most root dry weight per plant (1.9), compared to TD-l east I's amount (0.5s).

Phosphorus efficiency Ratio: Phosphorus efficiency ratio of different high yielding wheat genotypes was significantly varied. The maximum phosphorus efficiency ratio was observed for the TJ-83 with 38% followed by the Sindhu genotype 51% and 55% for Kiran-95 wheat genotype. Overall genotypes ranked the order for phosphorus efficiency ratio: TJ-83,>Sindhu>Kiran-95>Benazir>TD-I>Imdad-2005

Relationship of fresh shoot biomass with growth parameters under deficient and adequate P conditions: The relationship of fresh biomass with some growth determining parameters under deficient and adequate P conditions is presented in Table 1. The correlation analysis (Table 1) revealed that fresh biomass was significantly related with shoot fresh weight (0.45**), shoot dry weight (0.83**), fresh root weight (0.60***), root length (0.98**), leaf area (0.73*), number of leaves per plant (0.04ns, root length (0.35*), and shoot length (0.67**). The correlation analysis further revealed that there was no significant relation between fresh biomass and number of leaves

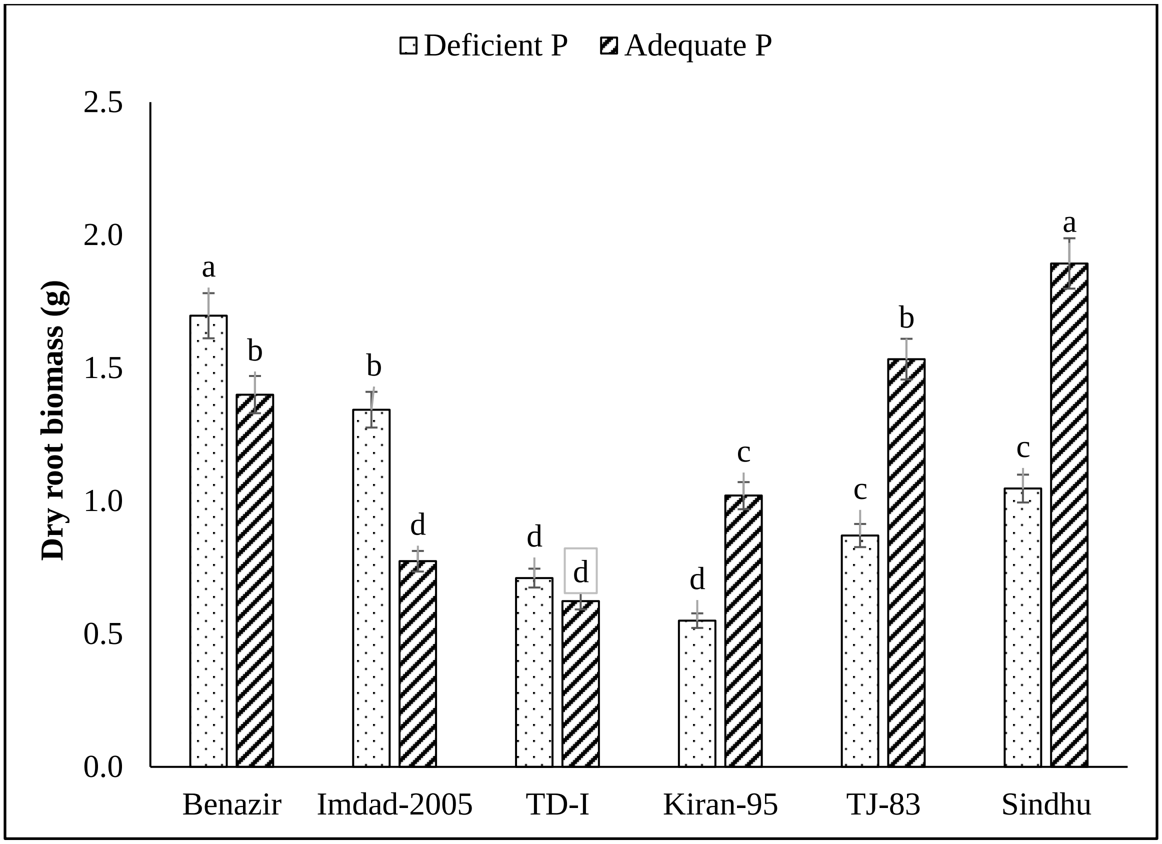

Figure 8. Dry root biomass of wheat genotypes as affected by adequate and deficient phosphorus nutrition.

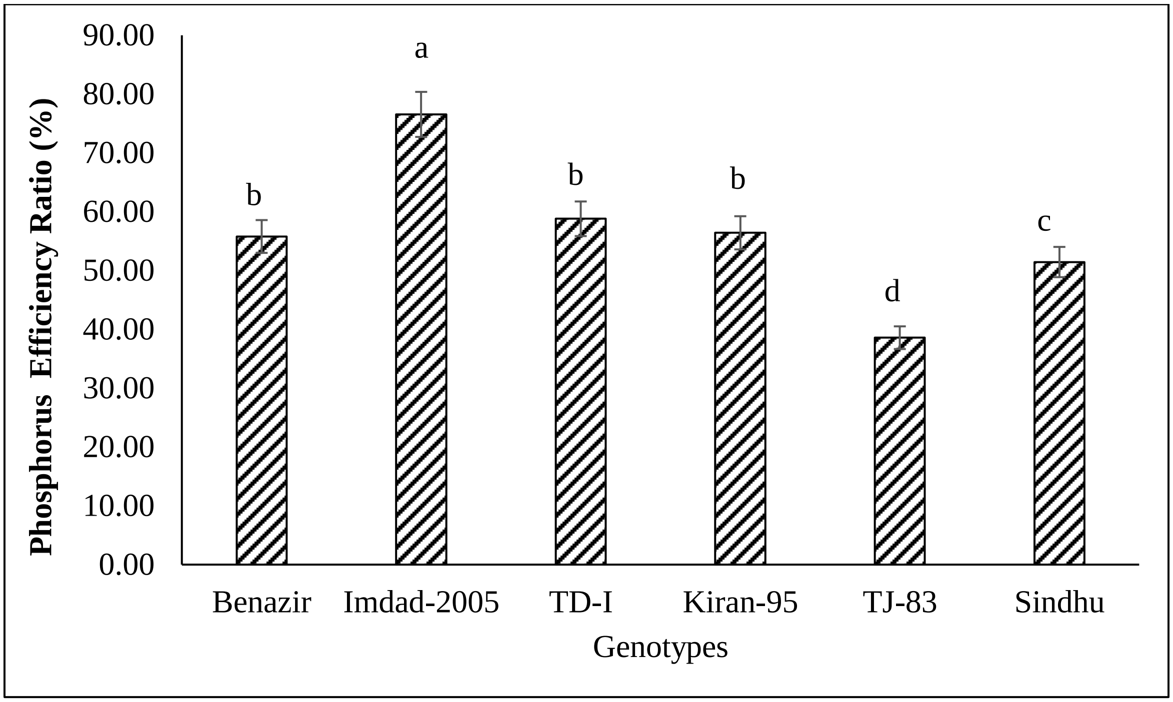

Figure 9. Phosphorus efficiency ratio of wheat genotypes tested at Uthal region Balochistan

Table 1. Relationship of fresh shoot biomass with growth parameters under deficient and adequate P conditions

	DWOR	DWOS	FRW	FSW	LAI	NOLPP	RL
DWOR	0.28ns						
FRW	0.90**	0.28ns					
FSW	0.45**	0.83**	0.60**				
LAI	0.48**	0.55**	0.59**	0.73**			
NOLPP	-0.07ns	0.35*	-0.26ns	0.04ns	0.02ns		
RL	0.42**	0.31*	0.40*	0.34*	0.21ns	0.09ns	
SL	0.47**	0.69**	0.48**	0.67**	0.61**	0.03ns	0.48**

FRW: Fresh root weight, DWOS: Dry weight of shoot, FSW: Fresh shoot weight, LAI: Leaf area index, NOLPP: Number of leaves per plant, RL: Root length, SL: Shoot length

Discussion

The wheat genotypes differ significantly in biomass,growth and phosphorus efficiency ratio response under deficient and adequate phosphorus nutrition. This study reported that as against its deficient condition, adequate P nutrition significantly enhanced shoot length, root length, fresh shoot weight, fresh root weight, no of leaves per plant, leaf area index, dry weight of shoot, and dry weight of root in wheat genotypes. The genotype TJ-83 and Sindhu were the most biomass productive genotypes followed by Benazir and Kiran-95 in the uthal region of the Baluchistan. The genotypes with more biomass, TJ-83 and Sindhu are wanted since they can be suitable into the greater range of phosphorus environments without cooperating the yield. Similar to this, wheat genotypes like TJ-83 and Sindhu are desired because they can be suitable in a wider range of phosphorus settings without compromising production Osborne and Rengel (2002). These genotypes had higher biomass output at both P levels. However, the most crucial factor for selecting P efficient genotypes may be the amount of dry matter generated or grain yield in P deficient conditions (Yaseen *et al*., 2008; Rahim *et al*., 2010; Bilal *et al*., 2018). Gill *et al*. (1994) and Yaseen *et al*. (1998) also revealed genetic variations for shoot dry matter at different P values. For the proportional reduction in shoot biomass production at a P deficiency level, genotypes varied significantly. Three more studies by Gill *et al*. (2002), Kosar *et al*. (2002), and Yaseen *et al*. (2004) reported variations in shoot dry matte rand total dry matter at deficient and appropriate P levels. P is a crucial macronutrient that is needed for plant development, growth, and reproduction. According to our findings, decreased P limits plant growth both during vegetative and reproductive, but more severely during the earlier stage of growth. However, P deficiency intensifies with time, making deficiency symptoms more noticeable in the later stages of growth. Due to competition with growing flowers, which may serve as a stronger sink for P than roots, P may not be effectively utilized for root biomass synthesis during reproductive growth. As a result, it is crucial to administer P fertilizers in accordance with the growth phase of the plants: high P throughout vegetative growth and adequate P during reproductive stage, which is in line with early research in field crops (Grant *et al*., 2001).

Deng *et al*. (2014) investigated the effects of eight P supply rates in a field experiment and seven P supply rates in a pot experiment on maize root growth. Similar trends were evident in the field experiment results (the roots have been harvested 57 days after planting). The authors also discovered that the P level that generated significant alterations in root growth coincided with the P level that caused the induction of six Pi starvation-induced marker genes. These findings suggested that a critical soil Olsen-P level exists below which root growth first slightly increases and then sharply decreases (the precise level varied between the pot experiment and the field experiment) Wen *et al*. (2017). 28 days after planting, this experiment looked at how 11 P intake rates affected the growth of maize roots. P levels that were added to the soil varied from 0 to 1,200 mg/kg. The results once again revealed that root growth is improved by a mild P deficiency but lowered by a severe P deficiency, even though the critical P level for suppressing root growth in this study (Wen *et al*., 2017) was different from that in Deng *et al*. (2014). Various study teams may have utilized different genotypes or cultivar of maize, which could explain why the reactions of maize to P deprivation varied. One genotype of maize responded more quickly than the other when the reactions of two genotypes to three P treatments were tested (Hajabbasi and Schumacher, 1994). Four genotypes of maize, including a low P-tolerant, a low P-susceptible, an acid-tolerant, and a commercial genotype, were examined by Gaume *et al*. (2001) for their root responses to low-P stress. The RSA of various genotypes of maize at the six-leaf stage in the field was examined by Liu *et al*. (2018). The TRL length of all other lines dropped, with the exception of one paternal inbred line that displayed a modest increase in TRL during low-P conditions. Zhou *et al*. (2020) examined the root growth of maize plants that were grown in the field for 36 days at the five-leaf stage under natural light, low light, and various amounts of Olsen P. TRL, total root area (TRA), and the proportion of fine roots all rose when soil Olsen-P declined from 80 to 20 mg/kg and increased with natural light, peaking at an Olsen-P level of 10 mg/kg. Different biomass characteristics and root growth characteristics were shown to be significantly correlated. The enhanced synthesis of cytokinin's from roots, which are responsible for biomass partitioning, is assumed to be implicated in the positive and significant association (r> 0.5) between root characteristics and biomass and/or yield related features, Lambers *et al* (2006). This suggests that as P is absorbed and used more effectively, grain yield will increase.

Conclusions

Adequate phosphorus nutrition positively affected most of the growth and biomass production of wheat genotypes. The genotype TJ-83 and Sindhu were the most biomass productive and phosphorus efficiency ratio producing genotypes in the uthal region of the Baluchistan. The study concluded that under P deficiency stress, enhanced efficient wheat genotypes determines their growth and biomass production. The genotype Sindhu was categorized as 'efficient-responsive' wheat genotype in terms of biomass production, most desirable both for low and high input sustainable agriculture system, Further validation of these results is required under field conditions.

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