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Full Length Article

Yield of Triticale (*Triticosecale* Wittmack) in Relation to Phosphorus Concentration in Various Plant Parts

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Abstract

This research was conducted to examine the relationship between grain yield and phosphorus (P) concentration at different growth stages of winter triticale. Five triticale varieties (Karma, Melez, Mikham, Presto and Tatlicak) plus four rates of P (0, 30, 60 and 120 kg ha^{-1} P_2O_5) were used under field conditions. The results showed that 60 kg P ha^{-1} and the Melez cultivar produced the highest yields of straw and grain in both years. The highest P concentration was found in vegetative plant parts at the tillering (TL) stage and in grain after harvest. Phosphorus concentration of all plant parts increased as P rates increased and, finally, the application of 120 kg ha^{-1} P_2O_5 had the highest P concentration. Presto and Mikham were the superior cultivars for forage based on P concentration of cultivars for both years. The Pearson correlation, regression, and path coefficient indicated that P concentration in the flag leaf (FL) was the most effective on grain yield. Path coefficient analysis indicated that the maximum direct positive effect on P concentration in grain was contributed by P concentration in tillers and straw.

Keywords: Grain yield; Growth stage; Path coefficient; Pearson correlation; Phosphorus; Triticale

Introduction

Triticale (*Triticosecale* Wittmack) is crop developed by crossing wheat (*Triticum* sp. L.) and rye (*Secale cereale* L.), which is adapted to harsh, low-input and sustainable farming systems (Ammar *et al*., 2004). Triticale has until now been used mostly for animal feed and cover crop (Musunda *et al*., 2015); however, it can be consumed by humans in the form of biscuits, cookies, and unleavened breads such as tortillas and chapattis (Horlein and Valentino, 1995). One of the reasons triticale was developed is that it is more efficient in nutrient deficient soil than wheat cultivars (Cakmak *et al*., 1998).

Fertilizer application is of great importance in increasing biomass per unit area. After nitrogen, phosphorus (P) is the most important major nutrient element in crop production. Phosphorus plays an important role in photosynthesis, nucleotides, enzyme synthesis, as well as other physiological and biochemical metabolisms (Marschner, 2012).

Despite the fact that a large amount of P is present in soil, available P is low. This problem is dealt with by applying P fertilizer in most cereal-growing areas. Since the rooting and tillering of cereals are affected by P deficiency, cereals require P during the early growth stages to enhance grain yield and yield components. Phosphorus deficiency in soil is a serious restraint to triticale productivity as well as to growth of other plants. Ortiz-Monasterio *et al*. (2002) and Madic *et al*. (2013) reported that P application resulted in a significant increase in grain yield and its components of triticale.

There is a need to determine the proper ratio and amount of P in triticale genotypes because little research is available on the application of P rates. The objectives of this study were to investigate the genotypic straw and grain yield performance of triticale at different P rates, to determine P concentrations in plant parts at growth stages, and reveal relationships between both grain yield and grain P concentrations with P concentrations in vegetative plant parts.

Materials and Methods

The Location, Design and Treatments

The experiments were conducted in Eskisehir, Turkey (39º48′ N; 30º31′ E; 789 m elevation) over two consecutive years, 2009 and 2010. The experimental design was a split-plot in randomized block design with four replicates. The main plots consisted of five triticale varieties (Karma, Melez, Mikham, Presto, and Tatlicak) and the subplots consisted of four P levels (P0; 0, P30; 30, P60; 60 and P120; 120 kg ha^{-1} P_2O_5). Triticale cultivars were planted in six rows of 8 m long parcels in October. Distance between the

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rows was 25 cm. A seed rate of 450 seeds m^{-2} was used in each plot. Half of the N was applied while sowing seeds and the other half was added during stem elongation. P fertilizer was applied using triple super phosphate (0-43-0). The plants were harvested with pruning shears in July when they reached the grain complete ripening period based on Zadoks 94 (Zadoks *et al*., 1974). After that, the plants were threshed with a hand harvester after measuring total plant weight.

The Climate and Soil Characteristics of the Location

Climate conditions were quite different across the two study years due to variances in precipitation and temperature. Total annual precipitation was 346 mm during the first year and 310 mm in the second year, measured from planting (October) to harvest (July). The mean temperature was 8 2°C during the first year and 9 5°C in the second year, measured during the same period (Fig. 1).

Soil samples (0–30 cm) were taken at seeding, air-dried, passed through a 2 mm sieve, and then analysed for the following properties: pH (1:2.5 soil/water), electrical conductivity (EC), lime (Scheibler Calcimeter), organic matter (Walkley–Black method), and texture (hydrometer method). Some of the soil properties were relatively similar across the two years (Table 1), with slightly alkaline, low organic matter, calcareous, and loamy but high in potassium content. Phosphorus levels in the soil were measured and found to be insufficient at planting. According to the analysis of trace elements, zinc, iron, and manganese were also found to be low while copper was satisfactory.

Plant Sampling and Analysis

Whole plant samples were taken from an area of 0 5 m^2 in each plot at the following stages: tillering (TL) at Zadoks-28, flag leaf elongation (FL) at Zadoks-37, heading (HD) at Zadoks-57, and straw and grain at harvest time at Zadoks-94. Crushed samples were dried at 70°C for 48 h, and then ignited at 550°C for 6 h. Ash obtained from the incineration was extracted with 3.3% HCl and then filtered with blue band paper filter. These samples were measured spectrophotometrically according to the Barton (1948) method. The analysis results were confirmed by NIST Reference Material 8436 Status Wheat Flour. Yields of straw and grain were weighed with a precision scale and calculated as ton ha^{-1}. Harvest index (HI) was calculated as the ratio of the grain yield to the total biomass.

Variance analyse, comparison of means with Duncan's test, Pearson correlation and linear regression analyses were performed using the IBM SPSS 20 (IBM, Armonk, NY, USA) statistical package program. A path analysis diagram was drawn with the IBM SPSS AMOS 22 (IBM, Armonk, NY, USA) package program, direct and indirect effects (path coefficient) of other characters were determined for grain yield and grain P concentrations (Byrne, 2016).

Results

P Concentrations in Whole Plant, Straw and Grain of Triticale

The P rates, cultivars (C), and "P x C" interaction were significant ($p<0.01$) for P concentrations at TL, FL and HD stages, grain and straw of triticale in both years, with the exception of P concentrations at FL for cultivars in the first year. There was a difference in P concentration in plants between years. The highest P concentration in all vegetative stages for straw and grain was found at the rate of P120 (Fig. 2). The P concentration in whole plants decreased from the TL stage to HD stage; however, triticale grains had the highest P concentration. In vegetative stages, the highest P concentration was found in Presto plants in the first year and Mikham plants in the second year. The P concentration in straw and grain was the highest in Mikham cultivar in both years.

Table 1: Some physical and chemical characteristics of the experimental area (0-30 cm)

Years	pH (1:2.5)	Texture	Organic matter (%)	$CaCO_3$ (%)	Available P (mg kg^{-1})	Available K (mg kg^{-1})	Available (mg kg^{-1}) Zn	Fe	Mn	Cu
I.	8.4	Loamy	1.67	10.36	3.65	450.1	0.55	1.94	9.02	1.47
II.	7.9	Loamy	1.71	11.14	3.72	390.7	0.60	1.91	8.93	1.51

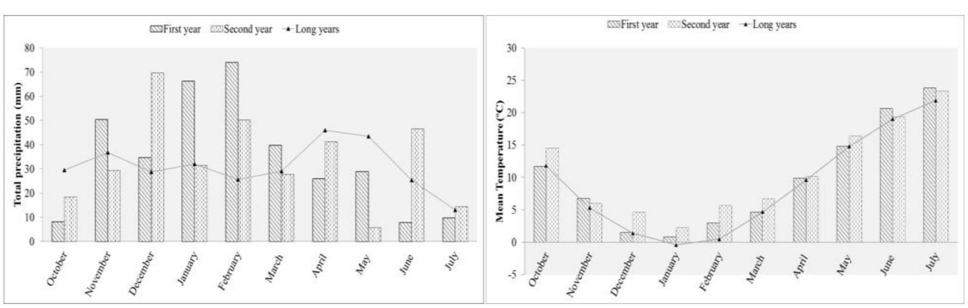

Fig. 1: Climatic conditions during the growing seasons and long years (1970-2008)

Table 2: Regression coefficient and model summary for grain yield via P concentration of whole plant at tillering, flag leaf elongation and heading stage, straw and grain at harvest time

Dependent Variables	Independent Variables	Pearson Correlation	Multiple Linear Regression			
			b	Beta	Adj. R^2	Regression ($P \leq 0.01$)
Grain Yield	Constant		2.03**		0.31	**
	TL_P	0.18**	-3.07**	-0.36		
	FL_P	0.49**	5.44**	0.41		
	HD_P	0.43*	3.58**	0.34		
	ST_P	0.32**	0.66 ns	0.03		
	GR_P	0.31**	0.88 ns	0.09		
Grain P Concentration	Constant		0.12**		0.44	**
	TL_P	0.56**	0.48**	0.57		
	FL_P	0.55**	0.13 ns	0.10		
	HD_P	0.56**	0.01 ns	0.01		
	ST_P	0.22**	0.67**	0.33		

* $p \leq 0.05$, ** $p \leq 0.01$; (TL_P: P concentration of tillering stage, FL_P: P concentration of flag leaf elongation stage, HD_P: P concentration of heading stage, ST_P: P concentration of straw in harvest stage, GR_P: P concentration of grain in harvest stage)

Straw, Grain Yields and Harvest Index

Grain yield in both years; while the straw yield and HI in second year were significantly ($p<0.01$) affected by P rates and differed significantly among cultivars. The interactions of "P x C" were found to be significant for straw yield, grain yield, and HI in both years. Straw yields varied from 10.3 ton ha^{-1} (Karma; P0) to 18.0 ton ha^{-1} (Melez; P60) in the first year and 10.4 ton ha^{-1} (Karma; P0) to 16.2 ton ha^{-1} (Melez; P60) in the second year (Fig. 3). Grain yields changed from 2.16 ton ha^{-1} (Mikham; P0) to 3.90 ton ha^{-1} (Melez; P60) in the first year and from 2.11 ton ha^{-1} (Mikham; P0) to 3.77 (Melez; P60) ton ha^{-1} in the second year (Fig. 3). The HI varied from 13.6% (Mikham; P0) to 24.2% (Tatlıcak; P30) in the first year and from 13.6% (Karma; P30) to 22% (Tatlıcak; P60) in the second year (Fig. 3). The highest straw and grain yields came from P60 rates and the Melez cultivar in each year. Tatlicak produced the highest HI in both years, but P rate was different in both years.

Relationships between Grain Yield and P Concentration

While considering the Pearson correlation coefficients, all P concentrations were significantly (*p< 0.01*) and positively correlated with the grain yield (Table 2). In addition, the relationship between grain yield and FL stage P concentration was stronger than other P concentrations. According to linear regression analysis, the effects of P concentration in the TL stage on grain yield were found to be significant and negative; however both FL stage P concentration and HD stage P concentration were significant ($p<0.01$) and positive by supporting the Pearson correlation coefficient (Table 2). In addition, there were no significant effects of straw and grain P concentration on grain yield. Grain P concentration was significantly and positively related to other plant part P concentration. Straw P concentration and TL stage P concentration had the highest effect on grain P concentration according to regression analyses.

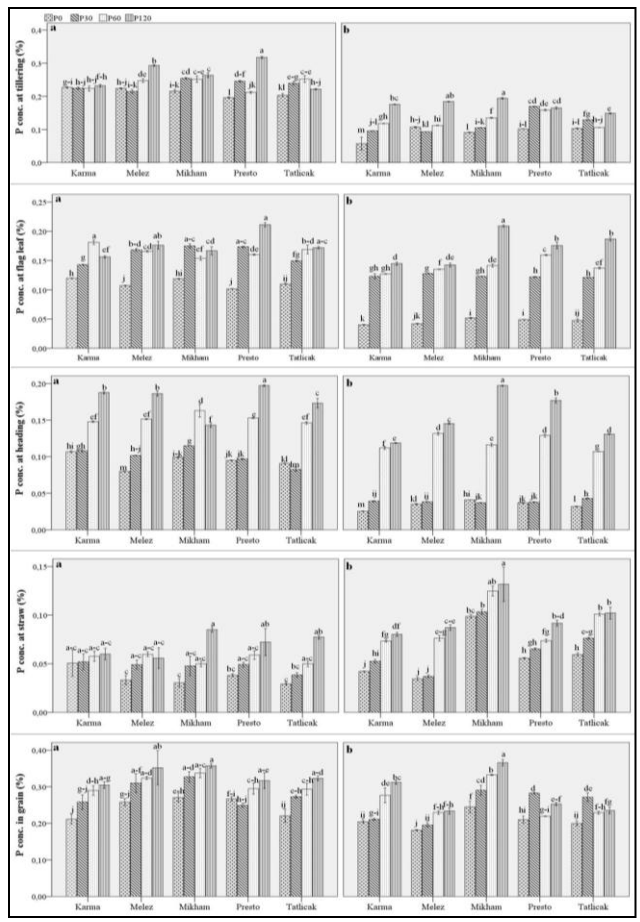

Fig. 2: P concentrations in plant part of triticale cultivars at vegetative and harvest stage. (a) First year (b) Second year (P doses, cultivar (C) and "P x C" interactions significant at ** $p \leq 0.01$ in both years) Data are means±SE of four individual replicates. Mean values followed by different letters are significantly different

The regression model indicated that the predictive power of equalities was 31% for grain yield and 44% for grain P concentration (Table 2). Therefore, it is possible to say that selected independent variables had indirect and unexplained effects via each other alongside the direct effects. Since the direct effects of P concentration in plant parts on grain yield, grain and straw P concentrations were determined; path analyses were suitable according to these findings.

A path diagram showing grain yield and grain P concentration is presented in Fig. 4. The direct effect of TL, FL, and HD stage P concentration on grain yield was approximately 36, 52 and 27%, respectively (Fig. 3a). The highest indirect effects on grain yield were TL and HD stage P concentration via FL stage P concentration. The highest positive direct effect on the grain P concentration was the tillers P concentration (0.55) and straw P concentration (0.32). The indirect effects of the FL and HD stage P concentration via the TL stage P concentration were high (0.36 in both) (Fig. 3b).

Discussion

The P concentrations in cultivars at all stages increased with applied P in both years and the highest P concentrations for all cultivars were determined at P120. Rauw *et al*. (2012) determined that the peak values for P concentration at the TL stage of triticale changed from 0.30 to 0.43% after applying fixed P fertilizer. Kaiser *et al*. (2014) reported that P concentration in the FL stage for wheat ranged from 0.20 to 0.50%. Phosphorus concentration in winter triticale and wheat cultivars at the HD stage has been reported to be between 0.10 and 0.30% in different studies (Rauw *et al*., 2012; Wang *et al*., 2013). Their values were higher than findings in the present study. The P concentration at all stages increased with the rate of P fertilizer applied and varied according to cultivars. Presto and Mikham cultivars also tended to accumulate greater amounts of P in vegetative plant parts. This could be explained by the fact that P concentration in the whole plant at various stages differs according to the genotype and environment. Also, there was a difference in P concentrations across the two years; this could be due to the low precipitation and high temperature seen during the second growing year. It is known that P concentration in parallel with P uptake in plant parts depends mostly on temperature, moisture, and P availability in soil (Kaiser *et al*., 2014). Increasing P rate increased the P concentration in whole plants at all growth stages. Phosphorus nutrition is controlled by two major factors: nutrient availability and the ability of plants to acquire the limiting nutrient (Raghothama, 1999). However, a decrease in P concentration as the plants matured was determined to be due to the effects of dilution. An increase in dry matter, which is dependent on growing, diluted the P concentration in plant tissue (Xue *et al*., 2016).

Triticale delivers a higher yield of straw than many other types of small-grain cereals and has been reported to be the basis for all domestic animal feed in developing countries as its nutritional value almost matches with wheat

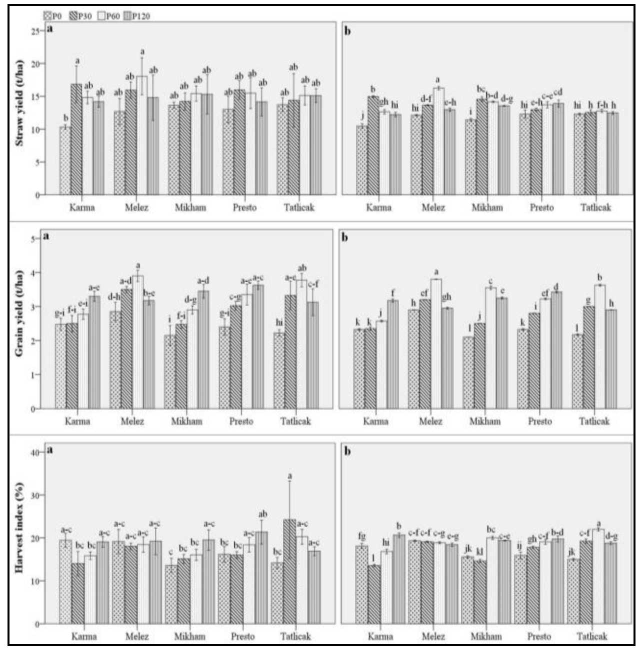

Fig. 3: Straw yield, grain yield and harvest index of triticale cultivars. (a) First year (P doses (ns, **,ns), C (ns, **, ns) and "P x C" interactions significant at * $p \leq 0.05$ (b) Second year (P doses, C and "P x C" interactions significant at ** $p \leq 0.01$) Data are means±SE of four individual replicates. Mean values followed by different letters are significantly different

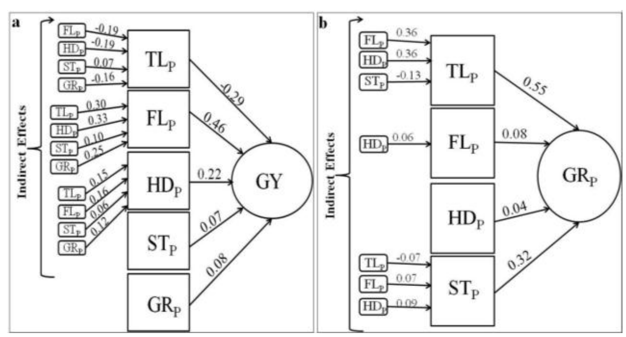

Fig. 4: Direct and indirect effects of whole plant part P concentrations on grain yield (a) and grain P concentration (b) in different growth stages (TL_P: P concentration of tillering stage, FL_P: P concentration of flag leaf elongation stage, HD_P: P concentration of heading stage, ST_P: P concentration of straw in harvest stage, GR_P: P concentration of grain in harvest stage, GY: grain yield). (Only significant effects were shown)

straw (Peyraud *et al*., 2014). Therefore, knowledge of the P concentration in straw is crucial. In this study, P concentrations in the straw of triticale cultivars ranged from 0.031 to 0.132% in both years (Fig. 2). Phosphorus rates increased P concentrations in triticale straw. The response of cultivars to increasing P fertilizer rates showed significant differences and increments with regard to P concentrations in straw. Rahim *et al.* (2010) found that increasing P fertilizer application raised P concentration in the straw of wheat.

Our results showed that P concentration in grain was affected by P fertilizer rates, and the highest P concentration was found at the rate of P120. Mikham had the highest P concentration for both years. The mean P concentration in grain ranged from 0.211 to 0.357% in the first year and from 0.181% to 0.366% in the second year (Fig. 2). Grain had the highest P concentration over all parts of the plant. This is because P accumulates in the vegetative parts of the plant until flowering, after which it moves to grain (Marschner, 2012). Phosphorus stored in grain is used for respiration, phosphorylation, and related processes during germination (Azeke *et al*., 2011). The findings for P concentration in the grain of triticale or wheat by various other authors (Ortiz-Monasterio *et al*., 2002; Atilgan and Helvaci, 2008; Panhwar *et al*., 2014) varied between 0.27% and 0.37%.

The P nutrition of triticale is very important to increase straw and grain yields because these from triticale are good alternatives to other feed cereals (wheat, barley and corn, etc.). The highest straw and grain yields were obtained from P60 rate in both years. The optimum P rate in this study is closely supported by Ortiz-Monasterio *et al.* (2002), who determined that the highest grain yield for triticale was obtained when P was applied at 80 kg ha^{-1}. The variation in the straw and grain yields of triticale cultivars was significant. Genotypic differences in the straw and grain yields of triticale and wheat regarding applied P rates have been reported by some researchers (Ortiz-Monasterio *et al*., 2002; McDonald *et al*., 2015; Zhan *et al*., 2015). In this study, Melez also produced the highest straw and grain yields in both years. Melez has a good potential for producers interested in both grain and straw production.

The HI of triticale cultivars differed under various applied P rates; in addition, Tatlicak had the highest HI in both years. The increase in straw and grain yield, as well as increased dry matter accumulation and partitioning greater amount of dry matter into grains, could be attributed to rates of P30 in the first year and P60 in the second year (which resulted in a higher HI of triticale). Generally, HI is the commonly known measure for the efficiency of the process and source-sink balance (Wnuk *et al*., 2013). In our study, due to Tatlicak's higher efficiency in partitioning dry matter in grain than in straw, its HI was higher than the other genotypes. There is little information regarding the effect of P rate on the HI of triticale. Bashir *et al*. (2015) observed that P levels significantly affected significantly the HI; however, contrasting results were found by Hussain *et al*. (2008). Who found a non-significant effect of different levels of P on the HI of wheat.

Correlation, regression, and path coefficient showed that the FL stage P concentration was strongly correlated and this was the stage that mostly contributed to grain yield. For example, a one unit gain of flag leaf P concentration caused 5.4 unit increases of grain yield, and had the most direct and indirect contribution to grain yield. Crop yields depend on photosynthesis, and photosynthesis mostly depends on P containing compounds. For this reason, effective use of P in photosynthesis might be a major determinant for the P concentration of plant tissues (Culvenor *et al*., 2012) and utilization of P from plants (Veneklaas *et al*., 2012). The flag leaf supplies a large portion of photosynthetic assimilates to the grains, which is important for cereal yield (Reynolds *et al*., 2009). Gaj (2012), Kaiser *et al*. (2014) and Javid *et al*. (2015) reported (for wheat and maize, respectively) that the P concentration in the vegetative parts of plant correlated positively and strongly with grain yield. Furthermore, P is an important nutrient for increased yield. In light of this information and these research findings, P concentration in flag leaf makes the biggest contribution to grain yield.

The highest direct contributions to the grain P concentration were from the TL stage (78%) and straw P concentration (67%). Phosphorus concentration in other plant parts (via tiller's P concentration) supplied the high positive indirect contribution toward grain P concentration. Phosphorus accumulation continues until anthesis in cereals such as wheat, and will rely on redistribution of P from vegetative tissues to supply the P demands of filling grain (Rose *et al*., 2010). In this study, the P translocation to grain of triticale may be due to the fact that plants contain the highest P concentration during the TL stage.

Conclusion

Our research showed that triticale cultivars differed significantly in straw yield, grain yield, and P concentrations in plant parts during both years. The yields of triticale cultivars could be ranked as Melez > Mikham > Presto > Karma = Tatlicak for straw yield and Melez > Presto > Tatlicak > Mikham > Karma for grain yield. When considering the P concentration of cultivars, Presto was superior and Mikham was inferior in responding to different P rates at the vegetative stage depending on the mean values of both years. The application of P60 rate produced the highest straw and grain yields, although an increasing P rate increased the P concentration of triticale cultivars and P120 application produced the highest P concentration in all parts of triticale. Phosphorus concentration in various parts decreased while the plants were growing, with the exception of that in grain. The highest P concentration was found at the TL stage during the vegetative period; however, grain contained the highest P concentration. The Pearson correlation, regression, and path coefficient indicated that P concentration in the FL was the most effective variable on grain yield. At the same time, the P concentration of straw and TL stage highly contributed to high grain P concentration. In conclusion, Presto and Mikham cultivars with P_2O_5 of 120 kg ha^{-1} may be recommended for forage and grazing to animals and poultry. However, if straw and grain of triticale are used, Melez is recommended, with an application of 60 kg ha^{-1} P_2O_5 for optimum yields. It is suggested that optimum P fertilizer for triticale should be applied because P loss from over-fertilized soil contribute to water eutrophication.

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