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ORIGINAL PAPER

THE EFFECT OF PHOSPHORUS APPLICATION ON NUTRIENT UPTAKE AND TRANSLOCATION IN WHEAT CULTIVARS

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Abstract

Phosphorus (P) in soils is ultimately deficient plant nutrient that has astonishing impacts over crop production, especially under rain-fed agricultural conditions. Typically, P deficiency in plants is to stimulate root growth. This response influences the balance of all plant nutrients, including P nutrition, in varieties with different root / stem development. For this reason, the effects of P fertilization on nutrient composition of both straw and grain for 12 bread and 3 durum wheat varieties, which are widely cultivated in the Mediterranean Region under rain-fed conditions, were studied with and without P application. The experiment was set-up in a completely randomised design in a factorial arrangement with three replications. In the experiment, nitrogen (N), potassium (K) and zinc (Zn) were applied to all pots; P was administered at a dose of 0 and 50 mg kg^{-1}. Nitrogen, P, K, calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), copper (Cu), Zn and manganese (Mn) concentrations were determined in both the straw and grains of the harvested plants. Phosphorous fertilization affected the concentration of P, N and Mn in the grain positively, while it affected the concentration of Ca, Mg, Na, Fe, Cu and Zn negatively, while K did not change the concentration. In straw, N concentration was not affected by P fertilization; Fe and Na concentrations were to accumulate in the straw; Cu, Mn, Zn, P, Ca, Mg and K concentrations were to decrease. On the other hand, varieties showed different responses to P fertilization in terms of their nutrient composition. Consequently, the susceptibility of the varieties to phosphorus deficiency significantly changed the nutrient uptake and partition of the plant nutrients between grain and straw.

Key words: Phosphorus, Wheat, Nutrients, Pot Experiment

INTRODUCTION

Turkey wheat area constitutes 3.5% of the world wheat acreage (USDA, 2017). These ag-lands also constitute 33% of total cultivated farmland in Turkey (TUIK, 2018) as total acreage was 78.9 million ha in the 2015/2016 growth period. Hence either bread wheat or durum wheat is traditionally main energy, protein and fibre sources of Turkish people and elsewhere in the World.

Phosphorus is an essential nutrient for crop production due to its ubiquitous physiological functions. Phosphorus is a structural component of nucleic acids, phospholipids, phosphor-proteins, dinucleotides, and adenosine triphosphate and plays a crucial role in reproductive growth. The energy required for photosynthesis, glycolysis, amino acid metabolism, fat metabolism, sulphur metabolism, biological oxidations and many other metabolisms is supplied by high energy phosphorus-bonds. Therefore, the performance of any crop is largely dependent on the supplementation of required P. However, calcareous soils of arid regions often suffer from P deficiency (Faye et al., 2006; Gucdemir 2006) and this should be corrected by crop-based or seasonal regular fertilization to minimize yield losses. The crop-plants, including wheat are highly sensitive to P deficiency as cropped under rain-fed conditions because lack of adequate water is the most significant of the key factors controlling the availability of P to plants (Tisdale et al., 1985). Therefore, cropping P efficient cultivars can minimize yield losses due to drought-induced P deficiency problem.

Balligar et al. (1998) found that P had a significant effect on root development in cereals and legume crops and root growth in plants significantly increased. In contrast, when P deficiency is evident, plants accelerate the root growth by stopping or slowing the growth of above ground parts (AGP) resulting in the increased root / AGP ratio (Smith et al., 1990; Lynch et al., 1991). Either deficiency or sufficiency of P is to change the root development and anatomy. Under P-deficient conditions root weight and length increase whereas root diameter decreases (Anghinoni and Barber, 1980; Fageria and Moriera, 2011, Bargaz et al., 2017). Researches have shown that root surface area increases in plants if there is not enough phosphorus. In addition, Liebersbach et al. (2004) reported that the large amounts of root exudates (i.e., mainly mucilage) from plants in dry soil counteract P deficiency under water scarce conditions. This indeed differentiates P uptake as well as the uptake of other nutrient elements of any plant. There are also plant species- and cultivar- dependent responses to P deficiency. Even the growth technique can influence it. For example, greater root allocation to deeper soil layers was reported for P-deficient intercropped wheat and soybean (Bargaz et al., 2017). Phosphorus amendment influenced the above-ground concentration of some nutrient under saline conditions (Hussain et al., 2016). An important strategy for increasing P uptake involves in taking advantage of the symbiosis between the roots and mycorrhiza, which in turn increase effective root surface area and eventually enhance both the growth and the uptake of P, Zn, Cu, Mn, and Fe (Bagayoko et al., 2000).

Specific and non-specific nutrient interactions became apparent in soils and plant upon fertilization practices. The specific interactions can occur between elements with similar physicochemical properties as competition for adsorption and absorption sites or transport within the xylem and/or phloem (Robinson and Pitman, 1983; Wilkinson et al., 2000). Non-specific interactions become apparent when the concentrations of the elements in question are within the deficiency or toxicity limits. Consequently induced deficiencies, toxicities, modified growth responses and/or mineral composition may result in the plants. These interactions were highly inter-species and intra-species-dependent along with different environmental conditions such as soil, climate, agricultural and management practices. Therefore, a pot experiment was conducted to explore the effects of P fertilization on grain and straw nutrient composition of 12 bread wheat and 3durum wheat cultivars. It may provide useful information on the selection of P-resistant wheat for field crop production with minimal yield losses.

MATERIALS AND METHODS

Experimental soil

Composite surface layer (0-30 cm) soil samples were taken from Çamköy soil series in Serik district of Antalya. The soil was air-dried and screened through a 4 mm sieve for pot experiment and 2 mm sieve for soil characterisation. The routinely determined soil physico-chemical parameters and their brief methods (Kacar, 2012) were given in Table 1. The experimental soil is typical Mediterranean region soil with a reddish colour, non-saline nature. This soil was specifically selected because of very low available P and low organic carbon which enhance fixation of P (Uygur and Karabatak, 2009).

Experimental set-up

The experiment was carried out in open air conditions with conservation measure of netting to avoid from bird hazard. The experimental design used was completely randomised design with 3 replications in a factorial arrangement. The factors were phosphorus fertilization (P0, 0 and P50, 50 mg P kg^{-1}) and cultivars (12 bread wheat and 3 durum wheat) commonly cultivated in the Mediterranean region of Turkey. Scoops of 3 kg of air-dried soil were filled in the conical plastic pots and amended with 5 mg Zn kg^{-1} as $Zn(NO_3)_2$. 50 mg kg^{-1} of nitrogen was applied as basal fertilizer supplied in ammonia form from ammonium sulphate (AS) for Po treatment and ammonium phosphate + AS for P50 treatment. The rest of the nitrogen, 100 mg N kg^{-1} N, as NH_4NO_3 was added before spiking and 20 mg K kg^{-1} as KNO_3 (three weeks after N fertilization) was applied in solution, respectively. 50 mg P kg^{-1} dose of phosphorus fertilization was made at sowing as a solution prepared from mono ammonium phosphate (MAP).

The used wheat cultivars were: i) bread wheat cultivars: Adana-99, Ahmetağa, Bagira, Cömert, Destan, Ghayta, Karatopak, Konya-2002, Lazarka-331, Merilin, Mihelca, and Renan and ii) durum wheat cultivars: Mirzabey-2000, Tiziana, and Traubadur. Fifteen seeds of wheat cultivars were planted in each pot and thinned to 3 seedlings one week after the emergence. The irrigation frequency was dependent on the moisture loss that the evapo-transporated moisture was checked in two days' interval and, if required, irrigated by weighing at 90% of the pot capacity to avoid from drainage.

Table 1. Properties of experimental soils and related analysis methods

Parameters	Unit	Methods	Results	Evaluation
pH	-	Saturation paste	7.1	Slight alkaline
CCE	(%)	Calcimetre	2.20	Low
Soluble salts	(%)	Saturation paste	0.011	Non-saline
Saturation	(%)	Saturation paste	44.0	Texture: Loam
Organic matter	(%)	Modified Walkley-Black	1.61	Low
Total nitrogen	(%)	Kjeldahl	0.085	Low
Olsen-P	kg P_2O_5 da^{-1}	Olsen-TS 8340	1.21	Low
Extractable K	kg K_2O da^{-1}	Ammonium acetate (Thomas, 1982)	40.6	Sufficient
Extractable Ca	kg CaO da^{-1}		1127	Sufficient
Extractable Mg	kg MgO da^{-1}		98.7	Sufficient
Extractable Fe	mg kg^{-1}	DTPA (Lindsay and Norwel 1978)	7.42	Sufficient
Extractable Mn	mg kg^{-1}		16.84	Sufficient
Extractable Zn	mg kg^{-1}		0.22	Low
Extractable Cu	mg kg^{-1}		1.00	Sufficient

CCE calcium carbonate equivalent

Plant and statistical analysis

The plants were harvested at the fully matured stage just above the soil surface. The straw and grains were separated and the materials were washed and rinsed with deionised water to remove possible contaminants. The samples were oven dried at 65°C for two days before grinding to reduce particle size below 0.5 mm to get homogenous scoops of samples. A scoop of 0.500 g either wheat flour or straw samples were digested with $H_2SO_4/HClO_4$ mixture (4:1 on volume base) and the concentrations of Ca, Mg, Na, K, Fe, Cu, Zn, and Mn in the digests were determined on Atomic Absorption Spectroscopy (AAS-Varian, FS 240) and P on spectrophotometer (T-80). The nitrogen concentration of the samples was determined by conventional Kjeldahl method by the steam distillation.

The data set was subjected to ANOVA analysis in factorial arrangement in SPSS environment. Separation of main effects was made by Duncan test at $p < 0.05$.

RESULTS AND DISCUSSION

Nutritional composition of grain

The main effects of both P fertilization and cultivars on mineral composition of the grain were significant at $p<0.05$ level (the detailed ANOVA results were not shown). Pair-wise comparison of the main effect of P fertilization on the grain nutrient composition was given in Table 2. Besides K, the concentrations of the nutrient elements were significantly influenced by P fertilization. Extra K fertilization before or at (for low vernalisation requiring cultivars) spiking stage may be responsible for such results because at any stages plants had no K induced stress. The Ca, Mg and Na concentrations of grain in control treatment without P addition were 4236, 3216 and 227 mg kg^{-1} and those for P treatment were 3685, 2954 and 166.3 mg kg^{-1}, respectively (Table 2). The average concentrations of these two elements were higher in non-P treated cultivars. Besides Mn, the average concentrations of cationic microelements were higher in non-P treatments. Nitrogen concentration of grains apparently showed different behaviour than the abovementioned nutrient elements that its average concentration was higher for P treated grains.

Table 2. Pair-wise comparison of phosphorus (P) fertilization's main-effect on grain mineral composition

Nutrient elements	Phosphorous treatments	Mean	Standard error	Lower limit	Upper limit	p
P (mg kg^{-1})	-	1697	15.56	1665	1728	0.000
	+	2589	8.03	2572	2605	0.000
Ca (mg kg^{-1})	-	4236	46.28	4142	4330	0.000
	+	3685	23.90	3636	3733	0.000
Mg (mg kg^{-1})	-	3216	11.65	3192	3239	0.000
	+	2954	6.02	2942	2966	0.000
K (mg kg^{-1})	-	364.1	6.70	350.6	377.7	0.129
	+	375.8	3.46	368.8	382.9	0.129
Na (mg kg^{-1})	-	227.4	0.555	226.3	228.6	0.000
	+	166.3	0.287	165.8	166.9	0.000
N (%)	-	2.20	0.031	2.14	2.26	0.000
	+	2.32	0.016	2.29	2.35	0.000
Fe (mg kg^{-1})	-	113.7^{a}	1.424	110.8	116.6	0.000
	+	99.1	0.735	97.63	100.6	0.000
Cu (mg kg^{-1})	-	11.39^{a}	0.103	11.18	11.60	0.000
	+	10.738	0.053	10.63	10.85	0.000
Mn (mg kg^{-1})	-	25.14^{a}	0.501	24.13	26.16	0.000
	+	31.23	0.259	30.71	31.76	0.000
Zn (mg kg^{-1})	-	48.19	0.370	47.44	48.94	0.000
	+	41.92	0.191	41.53	42.31	0.000

- Without P fertilization, + P fertilization at 50 mg/kg rate

The interaction between the ions of some elements and the effect of some substances can influence the uptake and accumulation of the nutrient elements in plant tissues (Jarrell and Beverly, 1981; Canny, 1984). The reason of such behaviour may be related to P-deficiency induced root biomass or accumulation effect. Decreases in dry-matter accumulation induced by any growth restricting physiological and/or environmental stresses factor, resulting from P deficiency in this study was accompanied by increases in the concentrations of most of the plant nutrient elements. When the available amount of any element is high in soil solution with a limiting element, the respective available element is to accumulate under restricted biomass production. Vice versa, P-fertilization that result in shoot-dry-weight increases in wheat cultivars would result in a 'dilution effect' whereby essential mineral-element concentrations in the grain would decrease as shoot dry matter and grain yield increased. Increases in biomass production, resulting from application of fertilizers under optimal growth conditions, will be gone with decreases in plant mineral concentrations (Davis, 2009).

The plants are typically smaller stature and root development is significantly limited under P-deficient growth conditions (Marschner, 1995; Kacar, 2013). This leads to limitations and interactions in absorbed and translocated amounts of other nutrients. On the other hand, the stronger root development results in the more changes in the rhizosphere region thus the availability of nutrients are to increase (Hinsinger, 2004).

Table 3. Duncan multiple comparison of grain mineral composition of the cultivars

Cultivars	Ca	P	N	K	Mg	Na	Fe	Cu	Mn	Zn
	(mg kg^{-1})		(%)	(mg kg^{-1})						
Adana	4193abc	2173c	2.1ghi	305fg	2566k	141h	103.8cd	15.53a	39.87a	49.47a
Ahmetağa	3742de	2213bc	3.2a	294g	2934ij	166f	104.9cd	10.60f	33.83b	48.12ab
Bagira	4395a	2063d	2.4ef	486a	3454c	141hi	88.7fg	8.60ij	25.03ef	36.53f
Cömert	3943cd	2345a	2.6bc	461ab	2932ij	137j	110.8bcd	11.23de	33.80b	46.89bc
Destan	3257f	2348a	2.6cd	354de	2583k	136j	95.3ef	9.87g	29.40cd	36.68f
Ghayta	4219ab	2332a	2.5de	435bc	4344a	151g	91.4fg	8.10j	25.43ef	37.11f
Konya	3523e	2201bc	2.7bc	319efg	3065g	207d	106.7cd	12.37b	38.93a	43.55d
Karatopak	3017fg	1977e	1.7k	339def	3171f	213c	118.0ab	12.17bc	33.13b	41.27e
Lazarka	3255f	2115d	2.8b	363d	2200l	138ij	87.3fg	9.07hi	25.30ef	30.14g
Merilin	3730de	1937ef	2.6cd	334def	2869j	192e	112.4abc	10.77ef	31.53bc	45.90c
Mihelca	2861g	2241b	2.3fg	401c	3251e	142h	102.3de	11.73cd	37.60a	46.44bc
Mirzabey	4348a	2241b	1.9j	421c	1954m	227a	119.2a	12.03bc	29.17cd	49.47a
Renan	3993bcd	2231bc	2.0ij	429bc	3683b	208d	102.4de	11.38d	27.30de	50.26a
Tiziana	4430a	1971e	2.1hij	303fg	3316d	221b	104.2cd	10.65f	27.77de	38.51f
Troubadur	3266f	1910f	2.1gh	348de	2949h	165f	84.2g	9.23gh	23.37f	41.48e
Average	3745	2153	2.4	373	3018	172	102.1	10.89	30.76	42.79

The main effect of wheat varieties on grain mineral composition was also significant for all of the measured plant nutrients (Table 3). The nutrient ranges of the cultivars were 3017-4348 mg Ca kg^{-1}, 1910-2348 mg P kg^{-1}, 1.7-3.2 N %, 294-486 mg K kg^{-1}, 1954-4344 mg Mg kg^{-1}, 137-227 mg Na kg^{-1}, 84.2-119.2 mg Fe kg^{-1}, 8.10-15.5 mg Cu kg^{-1}, 23.37-38.87 mg Mn kg^{-1} and 30.14-50.26 mg Zn kg^{-1}. The concentration of each element was highly cultivar dependent. In terms of richness of grains for nutrient elements, Adana, Bagira, Ghayta, Mirzabet, Tziana for Ca (4193-4430 mg kg^{-1}), Cömert and Destan for P (~1350 mg kg^{-1}), Ahmetağa for N (3.2%), Bagira and Cömert for K (461-486 mg kg^{-1}), Ghayta for Mg (4344 mg kg^{-1}), Mirzabey for Na (227 mg kg^{-1}), Karatopak and Mirzabey for Fe (118-119 mg kg^{-1}), Adana for Cu (15.5 mg kg^{-1}), Adana and Konya for Mn (38.9-39.9 mg kg^{-1}) and Adana, Ahmetağa, Mirzabey and Renan for Zn (48.12-50.26 mg kg^{-1}) performed better.

The Brasilian wheat floor was reported to have average values of 270 mg Ca kg^{-1}, 350 mg Mg kg^{-1}, 1710 mg K kg^{-1}, 192 mg P kg^{-1}, 1.8 mg Cu kg^{-1}, 37.8 mg Fe kg^{-1}, 8.2 mg Mn kg^{-1} and 9.4 mg Zn kg^{-1} (Araujo et al., 2008). In a similar manner, Korean wheat cultivars' mineral composition ranges were 313-463 mg Ca kg^{-1}, 2882-3833 mg K kg^{-1}, 1136-1686 mg Mg kg^{-1}, 2862-4165 mg P kg^{-1}, 1.2-7.1 mg Cu kg^{-1}, 28.9-58.9 mg Fe kg^{-1}, 16.5-44.8 mg Mn kg^{-1}, 25.8-66.8 mg Zn kg^{-1} (Choi et al., 2013). As can be seen from the above reported mineral compositions and obtained results in this study there are very large differences between the mineral compositions for each element. This suggested that there may be numerous factors affecting the mineral composition including genotype, soil conditions, climatic conditions, fertilization practices, pest management methods, etc. There are also considerable variations in the same genotype grown different locations. For example, Zhang et al. (2010) investigated the genotypic and environmental effects on mineral compositions of wheat grains grown in different locations and reported a large variation for all mineral elements.

Nutritional composition of straw

Mineral composition of straw was significantly affected by P fertilization over control treatment (Table 4). Of the mineral elements, N was the only element did not respond to P fertilization. The 'dilution effect' was apparently significant for P, Ca, Mg, K, Cu, Mn, and Zn upon P treatment. That is to say that these nutrient elements accumulated in the straw and their transport to grain was limited in the presence of P deficiency. In other words, the increase of biomass production induced by P fertilization resulted in different degrees of decreases depending on the element, availability, mobility in soil or plant. In contrast, Na and Fe concentrations were increased by P addition.

The interaction of P in either grain or straw with other nutrient elements especially K, Mg and Ca is regarded as a critical factor for partition of nutrient elements in straw and grain. For example, the translocations of these elements to seeds were limited towards the final stage of the filling period of the grains that phytic acid acts as a cation trap mechanism to hinder excessive cellular concentration of K and Mg (Marschner, 2012). This process can result in further nutrient element translocation to the grains. In fact, this causes increased concentrations of the cationic elements in straw. Since the grain yield decreased by P-deficiency the translocation of the cationic elements sufficiently available in soil from leaves to grain more evidently blocked and therefore the nutrient element concentration become apparently higher in the straw as in the current case.

The mineralogical composition ranges of straw for the experimental cultivars were 11297-16493 mg Ca kg^{-1}, 1033-1438 mg P kg^{-1}, 0.40-072 N %, 1167-1850 mg K kg^{-1}, 1229-3184 mg Mg kg^{-1}, 511-781 mg Na kg^{-1}, 164-340 mg Fe kg^{-1}, 2.87-14.8 mg Cu kg^{-1}, 19.0-44.1 mg Mn kg^{-1} and 22.1-39.2 mg Zn kg^{-1} (Table 5). In terms of nutrient element contents, Traubadur, Lazarka and Bagira for Ca (about 16000 mg kg^{-1}), Destan and Ahmetağa for P (~1450 mg kg^{-1}), Destan for N (0.72%), Lazarka and Cömert for K (~1850 mg kg^{-1}), Renan for Mg (3184 mg kg^{-1}), Adana for Na (781 mg kg^{-1}), Lazarka for Fe (340 mg kg^{-1}), Cömert for Cu (14.8 mg kg^{-1}), Lazarka and Cömert for Mn (42.5-44.1 mg kg^{-1}) and Renan for Zn (39.2 mg kg^{-1}) performed better.

Table 4. Pair-wise comparison of phosphorus (P) fertilization's main-effect on straw mineral composition

Variable	P treatment	Average	Std. Error	Lower	Upper	P
P (mg kg^{-1})	-	1275	13.7	1248	1303	0.000
	+	1199	7.05	1185	1213	0.000
Ca (mg kg^{-1})	-	15217	98.7	15018	15417	0.000
	+	14790	51.0	14687	14893	0.000
Mg (mg kg^{-1})	-	3749	7.38	3734	3764	0.000
	+	1986	3.81	1978	1993	0.000
K (mg kg^{-1})	-	1902	20.6	1860	1944	0.000
	+	1461	10.6	1439	1482	0.000
Na (mg kg^{-1})	-	515	0.396	514	515	0.000
	+	656	0.205	655	656	0.000
N (%)	-	0.508	0.0096	0.488	0.527	0.296
	+	0.496	0.0050	0.486	0.506	0.296
Fe (mg kg^{-1})	-	198	1.91	194	202	0.000
	+	241	0.99	239	243	0.000
Cu (mg kg^{-1})	-	10.8	0.118	10.6	11.1	0.000
	+	6.80	0.061	6.68	6.926	0.000
Mn (mg kg^{-1})	-	32.9	0.524	31.8	33.9	0.049
	+	31.7	0.271	31.1	32.2	0.049
Zn (mg kg^{-1})	-	36.2	0.349	35.5	36.9	0.000
	+	27.3	0.180	26.9	27.6	0.000

- Without P fertilization, + P fertilization at 50 mg kg^{-1} rate

Straw mineral composition of cultivars showed very large significant differences. Despite only 15 varieties were used in this study the nutrient element concentrations had 5-14 similarity groups according to Duncan multiple comparison tests depending on the element. Magnesium and Na showed the highest number of groups as 13 and 14, respectively. The occurrence of such variation in the mineral element concentration may be attributed to genetic potential of the cultivars, the duration of the green period, yield potential, mobility of elements in the plant, addition of the element to growth media as fertilizer and fertilization related interferences among the elements, etc. The varieties having higher yield potential can be able to translocate larger amounts of nutrient elements to the grain which reduce the straw concentration. In a similar manner a variety with a longer green period can induce increases in the magnitude of translocated nutrients. For example, it was reported that plant nutrient concentrations, including P, exert a distinct decrease upon advancement of plant age that concretize the ‘dilution effect’ (Osaki, 1995; Fageria et al., 2006, 2013; Fageria, 2013). The time- dependent nature of plant nutrient and translocation could have a specific aspect among the cultivars of the same plant species with different vegetation duration which accompanied different environmental conditions.

Table 5. Multiple comparison of nutritional composition of wheat straw belonging to different cultivars

	Ca	P	N	K	Mg	Na	Fe	Cu	Mn	Zn
Cultivars	(mg kg^{-1})		(%)	(mg kg^{-1})						
Adana	15913b	1033e	0.58b	1568de	1948i	781a	231f	10.2c	31.1c	22.1h
Ahmetağa	13892de	1468a	0.52cde	1301h	1720l	667d	183hi	3.50g	20.3f	29.0cd
Bagira	16264ab	1321b	0.39f	1440fg	2208g	572i	182hi	4.10g	37.7b	24.6fg
Cömert	14034de	1272bc	0.48e	1833ab	1229n	565k	287c	14.8a	44.1a	28.3d
Destan	15712b	1438a	0.72a	1699c	2226g	569j	201g	3.80g	33c	24.5fg
Ghayta	15859b	1229c	0.47e	1532ef	2903b	758b	302b	5.50f	31.2c	30.6c
Konya	11297g	1248bc	0.51de	1167i	1797k	578h	275de	14.8a	30.3cd	28.9cd
Karatopak	12135f	1125d	0.52cde	1315h	2162h	571ij	164j	2.87h	19f	23.0g
Lazarka	16246ab	1119d	0.57bc	1850a	1845j	716c	340a	5.93f	42.5a	30.5c
Merilin	14441d	1229c	0.56bcd	1650cd	1655m	550l	282cd	12.0b	36.2b	29.2cd
Mihelca	13831e	1254bc	0.50de	1706c	2454f	511m	180i	3.70g	38.2b	24.6fg
Mirzabey	15909b	1199cd	0.40f	1513ef	2751d	663e	245e	9.15d	30.5cd	34.9b
Renan	15135c	1199cd	0.41f	1726bc	3184a	595g	270d	8.78d	36.7b	39.2a
Tiziana	14011de	1146d	0.51cde	1336gh	2835c	635f	191gh	7.08e	26.3e	29.4cd
Troubadur	16493a	1131d	0.51de	1652cd	2547e	635f	195g	7.02e	27.7de	25.7e
Average	14745	1227	0.51	1553	2231	624	235	7.556	32.3	28.3

CONCLUSIONS

Adequate amounts of P fertilization that increase biomass production in wheat cultivars can cause either accumulation or dilution effect of specific mineral nutrients in above ground parts of the wheat cultivars. The responses of varieties to uptake and translocate different elements could be related to cultivar/variety properties and the availabilities of the elements in the growth media.

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