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Phosphorus Uptake of Common Wheat (*Triticum aestivum* L) Cultivars under Increasing Levels of Exchangeable Aluminum in Stagnic Podzoluvivsols

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Abstract

The genetically acidic, as well as the secondarily acidic soils in Bulgaria require our high awareness on wheat tolerance to increasing levels of exchangeable aluminum in soil. Under conditions of a vegetation experiment, the peculiarities of phosphorus uptake were investigated in 20 winter cereal genotypes: 18 *T. aestivum* L. cultivars, one *T. durum* Desf. Variety and the rye-wheat hybrid Triticale. The latter was used as a standard. The experiment was carried out against two backgrounds of soil fertilization: 1 – check variant with regard to the levels of exchangeable Al3+ ; 2 – mineral fertilization at N:P:K=1:1:1 from norms of 200 mg N, P2O5 and K2O/1000 g soil. The experiment was carried out on light grey forest soil (Stagnic Podzoluvicsols-FAO, 2002) with content of exchangeable Al3+ 0.5 meq/100 g soil (Ao). Furthermore, increasing levels of toxicity were created by addition of 2.5 meq Al3+/100 g (A1) and 5.0 meq Al3+ /100 g (A2). The independently applied increasing levels of exchangeable aluminum lead to lower amounts of phosphorus uptake in the organs of over ground bio mass and the roots of the tested cereals. Lowest amounts of phosphorus uptake were determined in the variants with additional introduction of 5.0 meq Al3+/100 g. At the end of the growing season, the phosphorus uptake in the total bio mass after additional introduction of 2.5 meq Al3+/100 g (A1) was 73.0 % from the phosphorus uptake in the check variant. The amount of P uptake in the roots decreased with 41.0 % and the uptake in grain yield – with 28.5 %. The balanced introduction of nitrogen, phosphorus and potassium in soil had a positive effect on P uptake in the tested cereals. The phosphorus uptake with the over ground bio mass increased at the end of the growing season with 82.8 % after treatment of the check variant, and with 40.4 % after treatment of the variants with introduction of 2.5 meq Al3+/100 g. The positive role of balanced mineral fertilization on phosphorus uptake in grain was very well expressed. The increase in the check variant was with 68.1 %, and in the variants with introduction of 2.5 meq Al3+/100 g – with 31.3%. A similar tendency was also observed for P uptake in the roots. The variation of phosphorus uptake on the level of the genotype was strongly expressed at all levels of exchangeable aluminum content in soil applied independently and in combination with balanced mineral fertilization. Triticale Vihren and cultivar Karat had higher phosphorus uptake in grain in comparison to the rest of the cultivars. The addition of high concentration of exchangeable aluminum in soil (5.0 meq Al3+/100 g) not only caused strong disturbance of phosphorus uptake in the tested winter cereals but also to perishing of common wheat varieties Pryaspa, Trakiya, Sadovo 1 and Kristal.

Key words: aluminum toxicity, wheat, mineral fertilization, phosphorus uptake, Stagnic Podzoluvicsols

Introduction

The presence of aluminum (Al) toxicity and deficiency of phosphorus (P) are the main factors which limit the accumulation of bio mass and the uptake of nutrients in the plants grown on acidic soils.

The availability of exchangeable aluminum in the soils with acid reaction is the reason for the toxic effects leading to decrease of yield and quality of the production, and often to compromising of the crop (Alva et al., 1986; Wringht, 1989). The study of the growth, development and nutrition characteristics of the various wheat genotypes under conditions of acid reaction is of particularly important scientific and applied significance. According to Brar and Giddens (1968), and Haynes (1986), Al3+ toxicity in the acidic soils is the main stress factor for the growth and the ion transport to roots. In the investigations of Klimashevskiy and Chernisheva (1980), the dominant role of the genotype specificity of the resistance of the plants to ion toxicity belongs to the roots.

In their review Samac and Tesfaye (2003) have pointed out that aluminum toxicity, besides suppressing elongation and division of the root cells, also stops their growth, accompanied with heavily impeded uptake of nutrients.

The aim of this investigation was to find out what is the effect of the increasing levels of exchangeable aluminum in soil on the phosphorus uptake in some organs of winter cereals.

Materials and Methods

Under conditions of a vegetation experiment, the tolerance of 18 *Tr. aestivum* L. genotypes, 1 representative of *Tr. durum* Desf. Cultivar Saturn 1) and 1 representative of the rye-wheat hybrid Triticale (cultivar Vihren), used as a standard crop, was investigated. The tested materials are representatives of Bulgarian breeding. The experiment was carried out on light grey forest soil (Stagnic Podzoluvicsols - FAO, 2006) with content of exchangeable aluminum 0.5 meq/100 g soil and pH KCl – 4.8 (A0). Additionally, 2.5 (A1) and 5.0 (A2) meq Al3+/100 g soil were introduced, under conditions without and with fertilization (т) with N200P200K200 mg/1000 g soil (A0+т; A1+т; A2+т), respectively.

The dry matter by organs was determined at the end of the growing season of the plants. They were prepared for phosphorus content determining after wet burning according to Kjeldahl, and for colorimetric determining according to the yellow molybdenum-vanadate reaction.

The statistical analysis of the obtained results was done with the software SPSS 13.0.

Results

Based on the dispersion analysis, it was found out that the independent and combined action of the factors level of exchangeable aluminum and cultivar, depending on the nutrition regime, influenced the accumulation of nitrogen in some organs of the tested winter cereals (Table 1). It is evident that the independent effect of the above factors both in the check variants (A0, A1 и A2) and in the variants with balanced mineral fertilization (A0+f, A1+f и A2+f) had effect on phosphorus uptake in the investigated organs with statistical significance at the maximum level.

Table1. Dispersion analysis on the effect of the investigated factors on the P uptake by organs

Source	Dependent Variable	df	Check variants			Fertilizer variants		
			MS	F	Sig.	MS	F	Sig.
Al level (1)	Leaves	2	14,480	499,323	,000	654,270	1390,812	,000
	Stems	2	69,849	313,134	,000	96,390	812,906	,000
	Grain	2	14362,821	1474,766	,000	41252,565	827,230	,000
	Glumes	2	7,084	134,667	,000	136,722	469,578	,000
	Roots	2	72,849	132,940	,000	118,712	142,444	,000
	Spikes	2	15001,823	1513,341	,000	46138,534	949,995	,000
	V.mass	2	216,850	580,456	,000	2215,911	1377,169	,000
	Over ground mass	2	18096,042	1470,848	,000	62575,594	1220,159	,000
	T.mass	2	20409,058	1302,532	,000	68145,293	1338,584	,000
Genotypes (2)	Leaves	19	,725	24,986	,000	21,993	46,752	,000
	Stems	19	11,356	50,909	,000	3,043	25,665	,000
	Grain	19	65,956	6,772	,000	360,236	7,224	,000
	Glumes	19	3,044	57,865	,000	5,084	17,460	,000
	Roots	19	1,967	3,590	,000	2,886	3,463	,000
	Spikes	19	81,749	8,247	,000	404,015	8,319	,000
	V.mass	19	12,427	33,263	,000	51,460	31,982	,000
	Over ground mass	19	108,665	8,832	,000	539,337	10,517	,000
	T.mass	19	117,688	7,511	,000	581,485	11,422	,000
1 x 2	Leaves	38	,286	9,872	,000	11,080	23,554	,000
	Stems	38	10,897	48,851	,000	1,944	16,398	,000
	Grain	38	46,032	4,727	,000	150,383	3,016	,000
	Glumes	38	2,209	41,990	,000	3,621	12,436	,000
	Roots	38	1,089	1,988	,008	1,935	2,322	,002
	Spikes	38	46,908	4,732	,000	144,910	2,984	,000
	V.mass	38	12,956	34,681	,000	27,666	17,194	,000
	Over ground mass	38	65,780	5,347	,000	163,604	3,190	,000
	T.mass	38	69,691	4,448	,000	177,411	3,485	,000

The interaction of the two factors influenced the phosphorus uptake in the over ground bio mass and grain also to the maximum level of significance.

The depression in the phosphorus uptake by organs of the vegetation mass as a result from the addition of 5 meq Al/100 g soil (A2) was highest (Table 2). The Waller-Duncan test revealed clear and significant differences in the amount of phosphorus uptake in leaves, stems and the non-grain part of spike in the check variants A0, A1 and A2, separating them in different groups. Highest amount of phosphorus uptake, regardless of the increasing levels of exchangeable aluminum in soil, was found in stems, followed by leaves and the non-grain part of spikes. With the higher levels of added exchangeable aluminum in soil in the check variants, phosphorus uptake decreased. In the leaves, the phosphorus uptake at maturity stage in the variants with addition of 2.5 meq Al3+/100 g (A1) was 82.41%, with addition of 5.0 meq Al3+/100 g (A2) it was 39.67% from the amounts taken up from soil in its natural condition (A0). In stems, the uptake in both variants of added exchangeable aluminum significantly decreased and was 24.49 % from the uptake in A0. Decrease in amounts of phosphorus uptake was also found in the non-grain part of spike, but these amounts were considerably less expressed after the addition of 5.0 meq Al3+/100 g (A2) in comparison to the amounts of uptake in the rest of the organs of the vegetative mass. Averaged for the tested cultivars, the amount of uptake in the non-economic part of yield at addition of 2.5 meq Al3+/100 g (A1) was 82.67% from the amount of uptake at the natural condition of soil, and with the increase of the addition to 5.0 meq Al3+/100 g (A2) – 34.16%.

The balanced mineral fertilization definitely had a positive role for increasing the phosphorus uptake in the organs forming the vegetation mass of plants. The results obtained showed that the balanced introduction of the main macro elements increased P uptake in the vegetation mass, averaged for the tested levels of exchangeable Al3+ in soil, with 116.73 %. The positive effect of mineral fertilization was highest at P uptake in leaves and significantly weaker in stems.

Table2. Phosphorus uptake in vegetation mass organs according to aluminum in soil (mg/pot) Waller-Duncan=40

Check variants		Fertilizer variants (+ $N_{200}P_{200}K_{200}$)	
Variants-Al	Value/Group	Variants-Al	Value/Group
vegetation mass			
+ 5,0 meq Al^{3+}/100 g	2,331 a	+ 5,0 meq Al^{3+}/100 g	4,177 a
+ 2,5 meq Al^{3+}/100 g	5,640 b	+ 2,5 meq Al^{3+}/100 g	10,829 b
+ 0,5 meq Al^{3+}/100 g	6,823 c	+ 0,5 meq Al^{3+}/100 g	19,036 c
Leaves			
+ 5,0 meq Al^{3+}/100 g	,769 a	+ 5,0 meq Al^{3+}/100 g	1,518 a
+ 2,5 meq Al^{3+}/100 g	1,598 b	+ 2,5 meq Al^{3+}/100 g	4,961 b
+ 0,5 meq Al^{3+}/100 g	1,939 c	+ 0,5 meq Al^{3+}/100 g	9,579 c
Stems			
+ 5,0 meq Al^{3+}/100 g	,805 a	+ 5,0 meq Al^{3+}/100 g	1,513 a
+ 2,5 meq Al^{3+}/100 g	2,834 b	+ 2,5 meq Al^{3+}/100 g	2,992 b
+ 0,5 meq Al^{3+}/100 g	3,286 c	+ 0,5 meq Al^{3+}/100 g	4,617 c
Glumes			
+ 5,0 meq Al^{3+}/100 g	,757 a	+ 5,0 meq Al^{3+}/100 g	1,145 a
+ 2,5 meq Al^{3+}/100 g	1,209 b	+ 2,5 meq Al^{3+}/100 g	2,877 b
+ 0,5 meq Al^{3+}/100 g	1,598 c	+ 0,5 meq Al^{3+}/100 g	4,841 c

At the end of the growing season the roots of wheat had highest amount of P in the variant with natural content of exchangeable aluminum (A0), and the modeled increasing amounts of toxic aluminum in soil sharply decreased the uptake of phosphorus (Table 3). In the last of the check variants - A2, with addition of 5.0 meq Al/100 g soil, the roots of the winter cereals took up averagely 2.93 times less phosphorus in comparison to the check (A0).

The role of balanced mineral fertilization for phosphorus uptake of plants under natural condition of the light grey forest soil and the additionally introduced amounts of exchangeable aluminum was strongly expressed in a positive direction. At harvesting, the root mass of the fertilized plants had averagely 36.40 % more phosphorus uptake in comparison to the checks. This tendency was confirmed in grain, the mean increase of the phosphorus uptake in the grain of fertilized plants being with 49.09 % more in comparison to the check variants.

Ultimately, the over ground mass and the total formed bio mass, together with the roots, had respectively 59.46 % and 57.99 % more P taken up as a result from mineral fertilization in comparison to the control plants. The results showed that with the higher levels of toxic aluminum in soil, the positive role of the applied mineral fertilization on the P uptake of plants increased. The discussed peculiarities in the P uptake by organs were very well differentiated by the Waller-Duncan test as well.

The addition of 5.0 meq Al3+/100 g soil not only caused strong disturbance of phosphorus uptake in the tested winter cereals but also the perishing of the common wheat cultivars Pryaspa, Trakiya, Sadovo 1 and Kristal.

The factor cultivar also contributed to a change in the spectrum of effect of the different levels of exchangeable aluminum in soil on the uptake of this essential nutrient (Figure 1). The amount of P uptake in the over ground bio mass of the check variants varied from 25.061 mg P2O5/pot (cultivar Aglika) to 40.800 mg P2O5/pot (cultivar Vihren). Based on the amount of P uptake, the Waller-Duncan test distributed the cultivars into 11 groups. Most of the tested winter cereals demonstrated similarity in the phosphorus uptake.

Table 3. Phosphorus uptake in roots, grain, over ground mass and total mass according to aluminum in soil (mg/pot) Waller-Duncan=40

Check variants		Fertilizer variants (+ $N_{200}P_{200}K_{200}$)	
Variants-Al	Value/Group	Variants-Al	Value/Group
Roots			
+ 5,0 meq Al^{3+}/100 g	,775 a	+ 5,0 meq Al^{3+}/100 g	1,115 a
+ 2,5 meq Al^{3+}/100 g	2,050 b	+ 2,5 meq Al^{3+}/100 g	2,748 b
+ 0,5 meq Al^{3+}/100 g	3,473 c	+ 0,5 meq Al^{3+}/100 g	4,559 c
Grain			
+ 5,0 meq Al^{3+}/100 g	7,546 a	+ 5,0 meq Al^{3+}/100 g	11,158 a
+ 2,5 meq Al^{3+}/100 g	32,072 b	+ 2,5 meq Al^{3+}/100 g	42,101 b
+ 0,5 meq Al^{3+}/100 g	44,830 c	+ 0,5 meq Al^{3+}/100 g	75,372 c
Over Ground Mass			
+ 5,0 meq Al^{3+}/100 g	9,877 a	+ 5,0 meq Al^{3+}/100 g	15,335 a
+ 2,5 meq Al^{3+}/100 g	37,712 b	+ 2,5 meq Al^{3+}/100 g	52,930 b
+ 0,5 meq Al^{3+}/100 g	51,653 c	+ 0,5 meq Al^{3+}/100 g	94,408 c
Total mass (Over Ground mass+ Roots)			
+ 5,0 meq Al^{3+}/100 g	10,652 a	+ 5,0 meq Al^{3+}/100 g	16,450 a
+ 2,5 meq Al^{3+}/100 g	39,762 b	+ 2,5 meq Al^{3+}/100 g	55,677 b
+ 0,5 meq Al^{3+}/100 g	55,126 c	+ 0,5 meq Al^{3+}/100 g	98,966 c

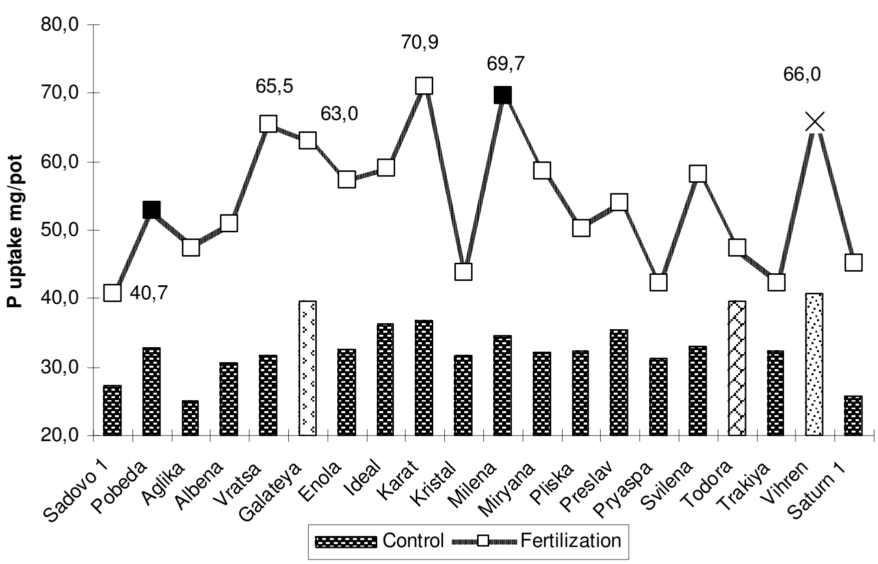

Figure1. Phosphorus uptake in over ground mass, mg P_2O_5/pot

Averaged for the variants of the tested toxic aluminum levels in combination with mineral fertilization, the phosphorus uptake varied from 40.690 mg P2O5/pot in cultivar Sadovo 1 to 70.927 mg P2O5/pot in cultivar Karat.

The balanced mineral fertilization contributed to the uptake of more P in the over ground mass and deepened the genotypic differentiation. The variation of the values of P uptake was from 40.690 mg P2O5/pot (Sadovo 1) to 70.927 mg P2O5/pot (Karat). These two cultivars occupied opposite positions with regard to their response to the indicated growing conditions.

The increasing levels of exchangeable aluminum in soil were at the basis of a distinct genotypic differentiation in the amount of P uptake in the grain of the tested winter cereals (Table 4). Under the conditions of this experiment, the grain of cultivars Aglika, Sadovo 1 and Saturn 1 had the lowest amounts of phosphorus uptake, averaged for the check variants A0, A1 and A2. Phosphorus uptake in the grain of cultivars Albena, Vratsa and Preslav also decreased. In a large number of cultivars, a well expressed similarity was found toward increasing of the amounts of P uptake. Under conditions of increasing chemical stress in soil, the triticale cultivar Vihren had maximum mean amounts of phosphorus uptake in grain.

Mineral fertilization significantly increased the ability of all winter cereals cultivars to take up P in grain. The mean increase of phosphorus uptake in grain was with 52.32 %. According to the Waller-Duncan test, the differentiation between the cultivars was slightly less expressed. A rearrangement of positions was found in comparison to the check variants. The positive effect of mineral fertilization was lowest in cultivars Todora, Trakiya and Pryaspa, in which the increase of the phosphorus uptake in grain was with 16.23 %, 25.38 % and 25.60 %, respectively Cultivars Karat, Vihren and Vratsa had highest amounts of phosphorus uptake in grain under balanced fertilization. The mineral fertilization contributed to the highest increase of phosphorus content in grain according to the check variants in cultivars Vratsa – with 92.13 %, Milena – with 82.15 % and Karat – with 79.68 %.

The amounts of phosphorus uptake in roots were at the basis of the significantly less expressed differentiation between the cultivars in comparison to the differentiation determined for grain (Table 5).

In the check variants with increasing levels of toxic aluminum in soil, cultivar Vratsa had lowest P uptake in roots. Under the same conditions, cultivar Preslav exceeded it 4.4 times by P uptake in the root mass. Regardless of this fact, the greater part of the cultivars demonstrated strongly expressed similarity and sameness in the amounts of P uptake in roots.

Table4. Phosphorus uptake in grain according to genotype and fertilization (mg P_2O_5/pot)

Genotypes	Check variants	Fertilizer variants – + $N_{200}P_{200}K_{200}$
	Value/Group	
Sadovo 1	23,853 ab	32,836 a
Pobeda	27,889 cde	36,766 ab
Aglika	21,516 a	36,812 ab
Albena	27,067 bc	42,142 bcd
Vratsa	26,956 bc	51,791 ef
Galateya	34,124 g	47,868 def
Enola	28,286 cdef	47,043 cde
Ideal	31,614 fg	48,437 def
Karat	30,972 defg	55,652 f
Kristral	27,914 cde	36,207 ab
Milena	29,458 cdef	53,658 ef
Miryana	27,997 cde	49,696 def
Pliska	27,788 cde	39,692 abc
Preslav	27,321 bc	39,374 abc
Pryaspa	27,740 cd	34,842 ab
Svilena	28,444 cdef	47,105 cde
Todora	31,213 efg	36,280 ab
Trakiya	27,608 cd	34,615 ab
Vihren	33,734 g	53,971 ef
Saturn 1	21,493 a	32,755 a

Table 5. Phosphorus uptake in roots according to genotype and fertilization (mg P_2O_5/pot)

Genotypes	Check variants	Fertilizer variants – + $N_{200}P_{200}K_{200}$
	Value/Group	
Sadovo 1	1,752 abc	1,814 a
Pobeda	2,176 bc	1,886 a
Aglika	2,301 bc	1,920 ab
Albena	1,695 ab	1,979 ab
Vratsa	0,901 a	2,027 ab
Galateya	2,183 bc	2,462 abc
Enola	2,014 bc	2,664 abcd
Ideal	2,257 bc	2,692 abcd
Karat	2,261 bc	2,851 abcd
Kristral	1,734 abc	2,875 abcd
Milena	2,014 bc	2,876 abcd
Miryana	2,341 bc	2,887 abcd
Pliska	2,311 bc	2,909 abcd
Preslav	3,916 d	3,036 bcd
Pryaspa	1,477 ab	3,160 cd
Svilena	1,961 bc	3,212 cd
Todora	1,919 bc	3,221 cd
Trakiya	1,804 abc	3,362 cd
Vihren	2,602 c	3,609 de
Saturn 1	2,369 bc	4,698 e

The mineral fertilization increased the residue amounts of P uptake in roots with a mean of 38.85 % and slightly increased the differentiation between the different winter cereal cultivars.

Cultivars Sadovo 1 and Pobeda were characterized with the lowest amount of P uptake in roots. A big group of cultivars shared similarities with them, but also differed from them with the greater amount of P uptake in roots. Highest accumulated amount of phosphorus in roots had durum wheat cultivar Saturn 1, followed by triticale Vihren.

The increasing levels of exchangeable aluminum in soil influence the mechanisms of uptake of nutrients and their redistribution in the plants during the individual developmental stages. Although wheat and triticale are considered comparatively tolerant to acidic soil reaction among all winter cereals, their response with regard to phosphorus uptake under increasing levels of exchangeable Al^{3+} in soil varies within a wide range (Taylor и Foy, 1985a, 1985b). The results from our investigation confirmed this opinion completely.

The availability of exchangeable Al in soil had strong effect on the amount of P uptake in plants at the end of their vegetation cycle. Averaged for the check variants (A0, A1 and A2), the exchangeable aluminum in soil controlled 90.54 % of P uptake in grain, 64.91 % of P uptake in roots and 89.31 % of the uptake in the total formed bio mass of the tested cereals (Figure 2).

The role of the genotype as a factor of P uptake in grain and total bio mass was about 4 %, while in the roots, which are the first to meet the stress levels of toxic aluminum in soil, the strength of effect reached 16.65 %. The strength of effect of the interaction of the two factors with regard to phosphorus uptake in roots was also most strongly expressed.

In the variants with mineral fertilization the indicated tendencies remained the same, but the strength of the independent effect of the factor levels of exchangeable aluminum in soil decreased while the strength of the factor genotype became greater. This peculiarity was valid for phosphorus uptake in the total formed biomass and in grain, while in the roots the strength of its effect remained the same, the strength of the factor genotype decreased at the expense of the higher effect of the interaction between the two factors. The response of the roots to the added stress in soil influenced not only its development but also the uptake of nutrients and their further metabolism. Kochian (1995) reported that in acid soils the exchangeable aluminum caused chronic drought and stress due to nutrition insufficiency. The higher effect of this factor on P uptake in plants was very strong and regardless of the fact that mineral fertilization had positive influence, the level of availability of exchangeable aluminum in soil was decisive for the uptake of phosphorus.

Averaged for the check and fertilizer variants, a great part of the tested cultivars had higher content of available phosphorus in leaves, stems and the non-grain part of spikes in comparison to triticale Vihren (Table 6). The strongly expressed genotype specificity in phosphorus uptake to the discussed organs lead not only to the maintenance of this specificity but also to its deepening with the sum of accumulated phosphorus uptake in the vegetation mass.

Averaged for the check variants, only in cultivars Preslav and Todora there was more phosphorus uptake in the vegetation mass in comparison to triticale cultivar Vihren accepted as a standard crop (Figure 3). Mineral fertilization lead to a wider set of common wheat cultivars (Pobeda, Milena, Karat, Galateya and Preslav) exceeding cultivar Vihren, as well as the durum wheat representative Saturn 1, by P uptake.

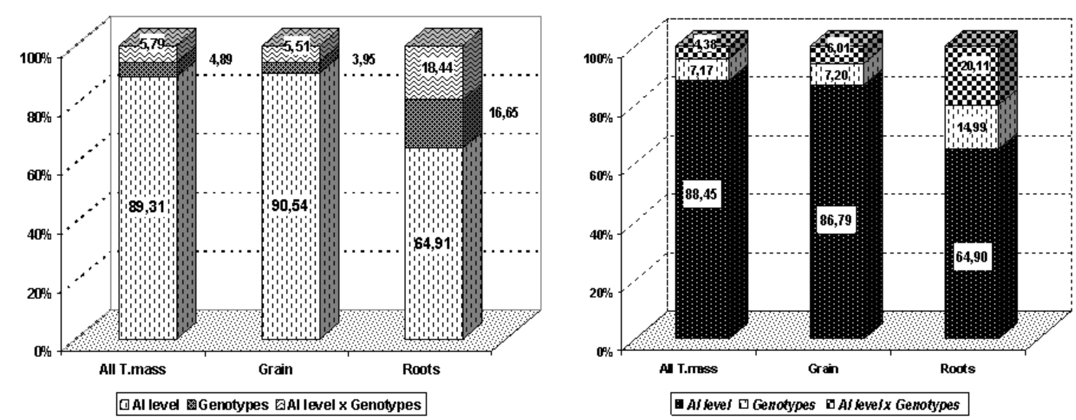

Figure2. Strenght of factors effect, %

Table 6. Phosphorus uptake in the organs of wheat genotypes (mg/pot)

Genotypes	Check variants			Fertilizer variants (+ $N_{200}P_{200}K_{200}$)		
	Leaves	Stems	Non-grain part of spike	Leaves	Stems	Non-grain part of spike
Sadovo 1	0,824 a	1,836 cde	0,787 abc	3,340 a	2,525 cd	1,991 ab
Pobeda	1,736 h	2,164 def	0,931 cdef	8,173 hij	4,086 i	3,929 h
Aglika	1,194 cd	1,274 ab	1,078 efgh	4,875 de	2,417 cd	3,148 efg
Albena	1,267 cdef	1,597 bc	0,647 a	4,529 cd	2,617 cd	1,543 a
Vratsa	1,740 h	1,852 cde	1,147 fgh	5,677 fg	3,300 fg	4,699 i
Galateya	1,480 g	2,280 efg	1,653 i	5,976 g	3,876 i	5,285 j
Enola	1,336 defg	1,887 cde	1,051 defg	4,055 bc	3,127 fg	3,002 def
Ideal	1,445 g	2,553 fg	0,757 abc	4,162 bc	3,781 hi	2,622 cde
Karat	1,781 h	2,657 g	1,296 h	7,845 hi	4,049 i	3,381 fgh
Kristral	1,009 b	1,967 cde	0,888 bcde	2,972 a	2,708 de	1,966 ab
Milena	2,036 i	2,128 def	0,913 cdef	8,611 j	3,963 i	3,427 fgh
Miryana	1,12 bc	1,972 cde	1,034 defg	3,033 a	3,451 gh	2,344 bc
Pliska	1,362 defg	2,008 cde	1,304 h	5,414 def	2,529 cd	2,525 bcd
Preslav	1,418 fg	5,810 h	0,947 cdef	8,518 ij	3,074 f	2,916 def
Pryaspa	1,220 cde	1,641 bc	0,652 ab	3,529 ab	1,931 ab	2,034 ab
Svilena	1,509 g	1,871 cde	1,216 gh	4,988 def	3,472 gh	2,517 bcd
Todora	1,010 bc	6,483 i	0,833 abcd	5,288 def	3,009 ef	2,711 cde
Trakiya	1,374 efg	1,689 bcd	1,627 i	2,894 a	2,271 bc	2,533 bcd
Vihren	1,482 g	1,607 bc	3,977 j	5,431 def	2,987 ef	3,576 gh
Saturn 1	2,274 j	0,886 a	1,025 defg	7,744 h	1,638 a	2,941 def

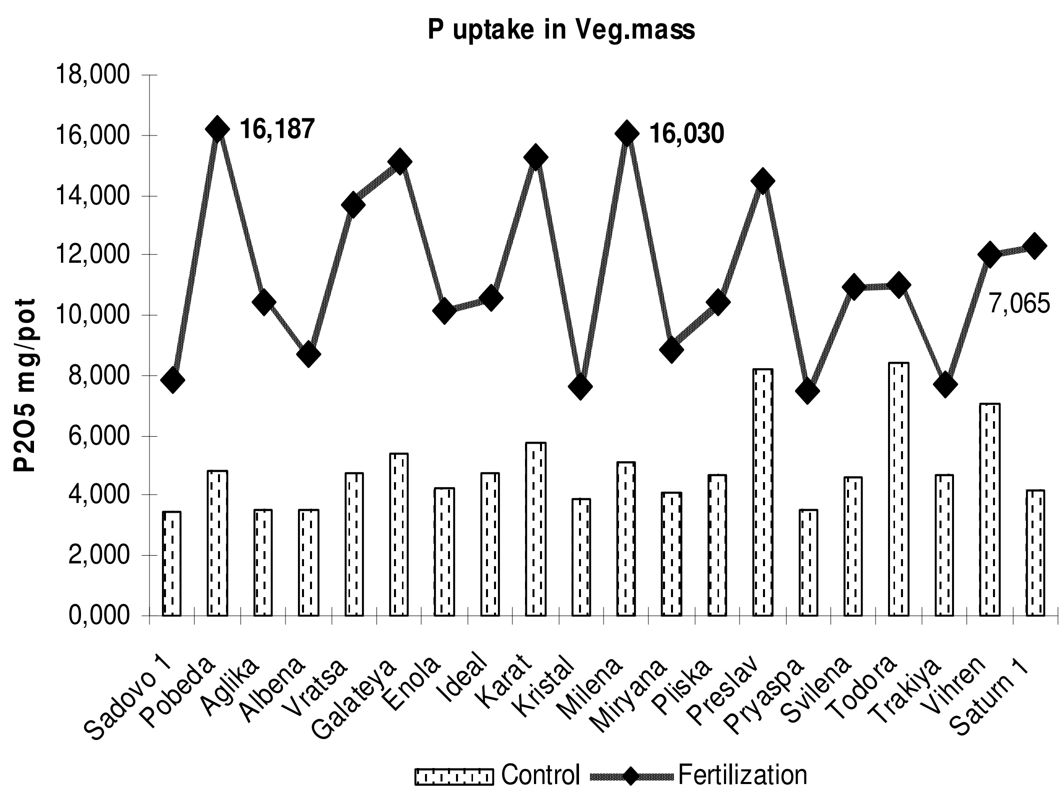

Figure 3. Phosphorus uptake in vegetation mass (leaves+stems+non-grain part of spike), mg P_2O_5/pot

The balanced mineral fertilization had a well expressed buffer activity against the negative effect of the increasing toxic aluminum levels in soil, which in this case played a key role for P uptake of plants. Besides the fact that it increased phosphorus uptake in all tested genotypes, higher phosphorus uptake was found in comparison to triticale Vihren in two of the common wheat cultivars (Karat and Milena).

Mineral fertilization played another well expressed role: it increased the role of the factor cultivar for P uptake in plants with a mean of 46.55 % in comparison to the uptake of the check variants.

The correlation of the amount of P uptake by organs and in the over ground bio mass in the check variants was clearly expressed at level 0.01 (Table 7). The highest correlation was found between P uptake in grain and in the over ground bio mass (r=0.991**). The correlation of P in grain and in roots was very well expressed (r=0.746**). Among all organs of the vegetation mass, the correlation between phosphorus in grain and in stems had a lower value, although significant at a high level. Mineral fertilization strongly enhanced the dependence between the phosphorus uptake in grain with that in stems and maintained high correlations with the other organs (Table 8).

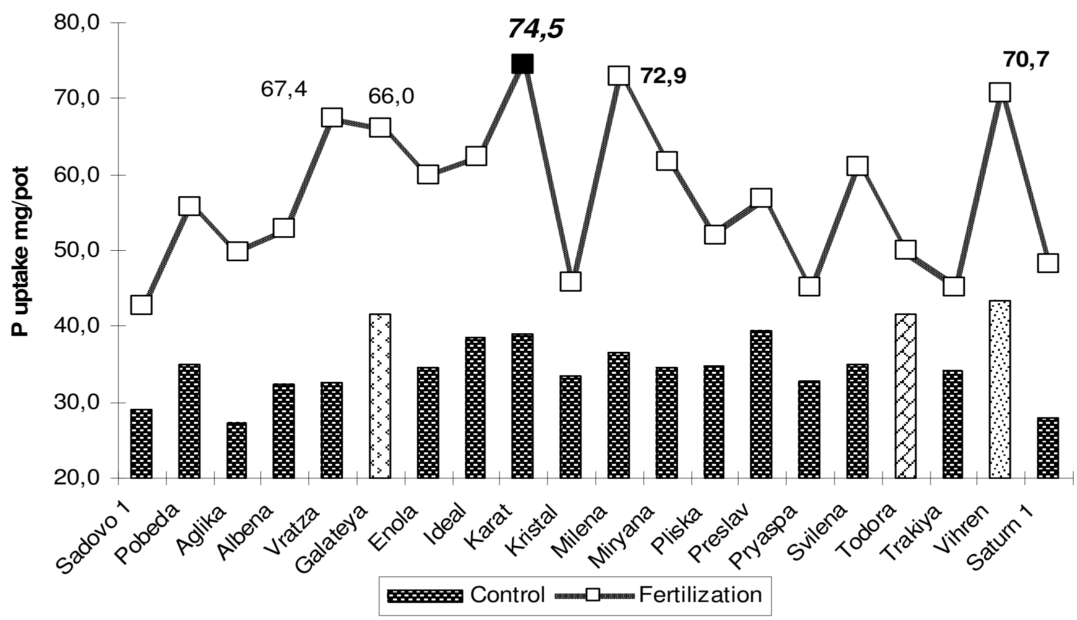

Figure 4. Phosphorus uptake in all total mass (over ground mass+roots), mg P_2O_5/pot

Table 7. Pearson Correlations between P uptake by organs in the check variants

Organs	Leaves	Stems	Grain	Non-grain part of spike	Roots	Spikes	V.mass	Over ground mass
Stems	,226*							
Grain	,724**	,457**						
Over ground mass	,285**	,056	,323**					
Roots	,606**	,361**	,746**	,300**				
Spikes	,726**	,450**	,998**	,383**	,748**			
V. mass	,504**	,882**	,646**	,474**	,534**	,663**		
Over ground mass	,724**	,553**	,992**	,365**	,748**	,993**	,739**	
Total mass	,728**	,548**	,991**	,366**	,780**	,992**	,737**	,999**

* Correlation is significant at 0.05 level (2-tailed).
** Correlation is significant at 0.01 level (2-tailed)

Table 8. Pearson Correlations between P uptake by organs in the fertilizer variants

Organs	Stems	Grain	Non-grain part of spike	Roots	Spikes	V. mass	Over ground mass	Total mass
Leaves	,751**	,719**	,749**	,687**	,736**	,957**	,796**	,799**
Stems		,814**	,778**	,674**	,828**	,877**	,857**	,857**
Grain			,682**	,755**	,999**	,790**	,991**	,990**
Over ground mass				,615**	,719**	,889**	,751**	,752**
Roots					,761**	,721**	,775**	,795**
Spikes						,814**	,995**	,994**
V. mass							,863**	,866**
Over ground mass								,999**

* Correlation is significant at 0.05 level (2-tailed).
** Correlation is significant at 0.01 level (2-tailed)

The amount of phosphorus uptake in the total formed bio mass, including also the roots, gave the final outlook of phosphorus uptake and redistribution in the individual variants of the experiment and the response of the cultivars (Figure 4). Averaged for the check variants, none of the tested genotypes exceeded triticale Vihren by the sum of phosphorus uptake. Cultivars Todora and Galateya were to a maximum degree close to it. The strongest depression in phosphorus uptake under increasing levels of toxic aluminum in soil was found in cultivar Aglika.

The balanced mineral fertilization had a well expressed buffer activity against the negative effect of the increasing toxic aluminum levels in soil, which in this case played a key role for P uptake of plants. Besides the fact that it increased phosphorus uptake in all tested genotypes, higher phosphorus uptake was found in comparison to triticale Vihren in two of the common wheat cultivars (Karat and Milena).

Mineral fertilization played another well expressed role: it increased the role of the factor cultivar for P uptake in plants with a mean of 46.55 % in comparison to the uptake of the check variants.

The correlation of the amount of P uptake by organs and in the over ground bio mass in the check variants was clearly expressed at level 0.01 (Table 7). The highest correlation was found between P uptake in grain and in the over ground bio mass (r=0.991**). The correlation of P in grain and in roots was very well expressed (r=0.746**). Among all organs of the vegetation mass, the correlation between phosphorus in grain and in stems had a lower value, although significant at a high level. Mineral fertilization strongly enhanced the dependence between the phosphorus uptake in grain with that in stems and maintained high correlations with the other organs (Table 8).

Conclusions

In the genetically acid soils, level of exchangeable aluminum in soil was the factor determining the effect on the phosphorus uptake in grain (90.5 %), in the over ground bio mass of plants (89.3 %) and in their roots (64.9 %).

The balanced mineral fertilization to a considerable degree decreased the negative effect of the levels of exchangeable aluminum in soil on the phosphorus uptake of plants. It also enhanced the positive role of the factor cultivar, especially in the phosphorus uptake of the above ground bio mass and grain. The increase of the amount of phosphorus uptake in the total bio mass was with averagely 62.6%, in grain – with 52.3%, and in roots – with 38.9% according to the untreated variants.

The levels of exchangeable aluminum in soil and the applied balanced mineral fertilization caused significant deepening of the genotypic differentiation between the cultivars with regard to the amounts of phosphorus uptake in the over ground bio mass, grain and roots.

Averaged for the increasing levels of toxic 3+Al in soil, cultivar Galateya was to a maximum degree close to triticale Vihren by amount of phosphorus uptake in total bio mass, and exceeded it by amount of phosphorus uptake in grain, as well as all other investigated genotypes.

Averaged for the variants with mineral fertilization, highest amounts of phosphorus uptake in the total bio mass and grain exceeding the amounts of uptake of triticale Vihren were found in cultivar Karat. Highest positive response in phosphorus uptake as a result from mineral fertilization was determined in cultivar Vratsa.

At the end of the growing season the roots of triticale Vihren had highest amounts of phosphorus uptake and none of the tested genotypes exceeded it under balanced fertilization.

The correlations of phosphorus uptake in grain with the uptake in the rest of the organs were positive and very well expressed. Averaged for the increasing levels of exchangeable aluminum in soil, the correlations with phosphorus uptake in stems and glumes were highest. The balanced introduction of main macro elements caused their approximately double increase.

The correlations of phosphorus uptake in grain with the uptake in roots remained at a constant level regardless of mineral fertilization.

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