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Department of Agricultural and Environmental Chemistry, University of Life Sciences
ul. Akademicka 15, 20-950 Lublin
e-mail: wiesław.bednarek@up.lublin.pl

WIESŁAW BEDNAREK, RENATA RESZKA

Phosphorus uptake by spring barley in dependence on the content of this element in soil

Pobranie fosforu przez jęczmień jary w zależności od występowania tego składnika w glebie

Summary. The purpose of our studies was to assess the dependence of yield, content and uptake of phosphorus by spring barley and the content of available forms as well as mineral fractions of this element in soil. The factors of the study were: liming, fertilization with two nitrogen forms at two levels and fertilization with phosphorus at two levels. Spring barley was harvested at its full maturity. The obtained results indicated that the yield of test plant depended on the content of phosphorus determined in $NaHCO_3$, easily soluble phosphates and calcium phosphates (positive correlation) as well as the amount of aluminum phosphates (negative correlation). The content of phosphorus in grain depended above all on the content of available phosphorus and P-Al, P-Fe, P-Ca fractions. The uptake of phosphorus by plant was depended on the content of this element determined by means of water, acid sodium carbonate and the amount of easily soluble phosphates and aluminum phosphates.

Key words: available phosphorus, mineral fractions, yield, uptake

INTRODUCTION

The optimal supply of phosphorus to plants conditions high and good quality yield. This component is taken up from soil solution by roots in the form of $H_2PO_4^-$ and HPO_4^{2-} ions. The availability of phosphorus to plants and its transformations are controlled by a combination of physical-chemical and biological processes of dissolution – precipitation, adsorption-desorption and mineralization-immobilization. The fertilizer phosphates introduced into the soil undergo solution in it and then they are very quickly precipitated from the soil solution or adsorbed on the molecules of the solid phase of the soil. In our climatic conditions the most of phosphorus is bound by iron (P-Fe) and aluminum (P-Al). The content of phosphate anions in the acid soil solution remains balanced with strengite, and in slightly acid soil – with variscite. In the conditions of neutral and alkaline reaction, the availability of phosphorus to plants is controlled by calcium phosphates. The products of fertilizer phosphorus transformations are characterized by differentiated solubility, and thus, variable availability for plants. The predominant significance in the formation of the phosphorus status in soils and their ability to supply this nutrient to plants is that of the reaction and mineral fertilization [Kęsik and Pietrasz-Kęsik 1981, Sims and Ellis 1983, Bosch and Amberger 1986, Bednarek 1987, 1992, Bednarek and Lipiński 1994].

The purpose of these studies was to determine the relationship between the yield, content and uptake of phosphorus by spring barley and the content of available forms and mineral fractions of this element in the soil.

MATERIAL AND METHODS

The basis of the presented paper was a two-year pot experiment. It was set up on the soil material with the grain composition of light loamy sand. The soil was characterized with very acidic reaction (pH = 4.00) and low abundance with available phosphorus (26 mg P kg^{-1}). The scheme of the experiment comprised 9 combinations in 4 replications on limed and non-limed soil. The experimental factors were: liming, fertilization with two forms of nitrogen: ammonium or nitrate, two levels of fertilization with nitrogen: N1 – 0.1 g N kg^{-1}, N2 – 0.2 g N kg^{-1} and fertilization with phosphorus in two doses: P1 – 0.06 g P kg^{-1}, P2 – 0.12 g P kg^{-1}. The above-mentioned experimental factors were applied against the background of control object. $CaCO_3$ was applied once, before establishing the experiment, in the amount equivalent to 1 Hh. Fertilization with nitrogen, phosphorus, potassium and magnesium was applied in each year of the study before sowing the plants. Phosphorus was added in the form of triple, granulated superphosphate (20.1% P), nitrogen in the form of ammonium sulphate (20% N) or calcium nitrate (15.5% N). In the vegetation period permanent soil moisture was maintained on the level of 60% field water capacity. The test plant was spring barley Bryl cultivar, which was harvested at its full maturity. After the harvest yields of grain, straw and mass of roots were determined. In the soil material we determined the content of available phosphorus (in distilled water, 0.01 mol dm^{-3} $CaCl_2$, lactate buffer with pH 3.55 (the Egner-Riehmn method) and in acid sodium carbonate (the Olsen method). The mineral fractions of phosphorus were determined according to Chang and Jackson method with modifications according to Askinazi, Ginzburg and Lebiedewa (easily soluble phosphates – easily soluble P; aluminium phosphates – P-Al; iron phosphates – P-Fe and calcium phosphates – P-Ca). The plant material was mineralized in concentrated sulphuric acid (VI) with an addition of perhydrol. In mineralizates we determined the content of phosphorus by means of the vanadium-molybdate method. The measurements were performed with the use of photocolorimeter Cecil 2011. The uptake of phosphorus by plants was calculated in reference to yield and content of this element.

The dependences between the content of available forms and mineral fractions of phosphorus and the selected features of a plant were determined with the use of regression analysis method. The numerical force of the array was 32 – for particular factors of the experiment and 64 – for the experiment. The tables show only a significant correlation (rxy) and regression coefficients (byx).

RESULTS AND DISCUSSION

The grain yield of spring barley grown on acid soil was not significantly dependent on the content of available forms of phosphorus, whereas on the limed soil a positive correlation with phosphorus extracted by H_2O was found (tab. 1). Irrespective of the form of nitrogen applied, we observed a positive relationship with the concentration of $NaHCO_3$ extracted P. Moreover, in combinations with calcium nitrate the grain yield was positively formed by phosphorus determined according to Egner-Riehm and in water. Irrespective of liming and fertilization with nitrogen, a significant positive relationship with calcium phosphate fractions was revealed (tab. 2), which can be explained by the fact that spring barley is a plant sensitive to soil acidification. Besides, phosphorus and calcium are components of phytine. Both in the objects fertilized with $(NH_4)_2SO_4$, and with $Ca(NO_3)_2$ an advantageous effect of easily soluble P fraction was observed.

The relationship between straw yield and the content of available forms of phosphorus was similar to that of grain yield, though slightly lower values of correlation coefficients were observed (tab. 1). The straw yield was to the greatest extent dependent on the soil content of calcium phosphates (positive correlation) (tab. 2). Besides, on the acid soil a significant effect of aluminum phosphates was revealed (negative correlation). Both in the objects fertilized with calcium nitrate, as well as with ammonium sulphate, a positive relationship was found with the number of easily soluble phosphate fractions.

The root mass of the tested plant revealed a significant, positive correlation with phosphorus content determined in accordance with Olsen method (objects fertilized with $(NH_4)_2SO_4$ and $Ca(NO_3)_2$), as well as the content of P extracted by lactate buffer and water (combinations with calcium nitrate). In limed soil we found a negative correlation with the amount of the component extracted by sodium bicarbonate (tab. 1). In most of the combinations we observed a distinctly positive effect of P-Ca fraction (tab. 2). Besides, irrespective of the kind of nitrogen fertilizer, the root mass increased with the increase of the easily soluble phosphate fraction content. In the conditions of soil alkalization it was also positively correlated with the amount of P-Fe fractions.

The total yield of spring barley grown on acid soil was not significantly dependent on the content of analyzed, available forms of phosphorus (tab. 1), whereas the yield of plants harvested from limed soil revealed a positive correlation with the concentration of P in H_2O, which was most probably caused by the fact that phosphorus, which is the most available to plants, is extracted by water. Similarly, Bednarek [1991] observed significant and positive correlations of the plant yield with the amount of phosphorus extracted by water. In this experiment, both in the objects fertilized with ammonium sulphate, and with calcium nitrate, we found significant, positive correlations with phosphorus extracted by $NaHCO_3$. Besides, in the combinations with the saltpeter form of the fertilizer we observed the beneficial effect of the component determined in accordance with the Egner-Riehm method and in water. Irrespective of liming and the used form of nitrogen, the plant yield was significantly positively related to the content of calcium phosphate fractions (tab. 2). Both in the soil fertilized with $(NH_4)_2SO_4$, and with $Ca(NO_3)_2$ the increased concentration of easily soluble P and P-Ca fractions enhanced the increase of yield. Besides, on acid soil we found a significant correlation with P-Al (negative correlation), and on that fertilized with calcium nitrate – with P-Fe and the sum of fractions (positive correlation).

Table 1. Relations between yield of spring barley and the content of movable forms of phosphorus in soil (correlation and regression coefficients)
Tabela 1. Zależności między plonem jęczmienia jarego a zawartością ruchomych form fosforu w glebie (współczynniki korelacji i regresji)

Specification Wyszczególnienie	P available przyswajalny	Grain Ziarno		Straw Słoma		Roots Korzenie		Total plant Cała roślina	
		rxy	byx	rxy	byx	rxy	byx	rxy	byx
Acid soil Gleba kwaśna	P E-R	-	-	-	-	-	-	-	-
	P H_2O	-	-	-	-	-	-	-	-
	P $CaCl_2$	-	-	-	-	-	-	-	-
	P $NaHCO_3$	-	-	-	-	-	-	-	-
Limed soil Gleba wapniowa	P E-R	-	-	-	-	-	-	-	-
	P H_2O	0.364	0.527	0.400	0.596	-	-	0.411	1.183
	P $CaCl_2$	-	-	-	-	-	-	-	-
	P $NaHCO_3$	-	-	-		-0.357	-0.006	-	-
P1	P E-R	-	-	-	-	-	-	-	-
	P H_2O	0.501	3.743	0.467	3.451	0.494	0.232	0.484	7.411
	P $CaCl_2$	-	-	-	-	-	-	-	-
	P $NaHCO_3$	0.376	0.519	-	-	-	-	-	-
P2	P E-R	-	-	-	-	-	-	-	-
	P H_2O	-	-	-	-	-	-	-	-
	P $CaCl_2$	-	-	-	-	-	-	-	-
	P $NaHCO_3$	0.415	0.392	0.398	0.332	0.496	0.029	0.409	0.754
N1	P E-R	-	-	-	-	-	-	-	-
	P H_2O	-	-	-	-	-	-	-	-
	P $CaCl_2$	-	-	-	-	-	-	-	-
	P $NaHCO_3$	0.416	0.345	0.384	0.309	0.436	0.025	0.403	0.683
N2	P E-R	-	-	-	-	-	-	-	-
	P H_2O	-	-	-	-	-	-	-	-
	P $CaCl_2$	-	-	-	-	-	-	-	-
	P $NaHCO_3$	-	-	-	-	-	-	-	-
Ammonium sulphate Siarczan amonowy	P E-R	-	-	-	-	-	-	-	-
	P H_2O	-	-	-	-	-	-	-	-
	P $CaCl_2$	-	-	-	-	-	-	-	-
	P $NaHCO_3$	0.446	0.448	0.436	0.410	0.394	0.025	0.438	0.882
Calcium nitrate Saletra wapniowa	P E-R	0.667	0.250	0.598	0.188	0.630	0.016	0.650	0.456
	P H_2O	0.578	1.731	0.537	1.348	0.590	0.116	0.573	3.210
	P $CaCl_2$	-	-	-	-	-	-	-	-
	P $NaHCO_3$	0.623	0.282	0.481	0.182	0.594	0.018	0.572	0.484
Together Razem	P E-R	-	-	-	-	-	-	-	-
	P H_2O	-	-	-	-	-	-	-	-
	P $CaCl_2$	-	-	-	-	-	-	-	-
	P $NaHCO_3$	0.345	0.306	0.287	0.240	0.335	0.018	0.318	0.565

Table 2. Relations between yield of spring barley and the content of movable forms of phosphorus in soil (correlation and regression coefficients)
Tabela 2. Zależności między plonem jęczmienia jarego a zawartością ruchomych form fosforu w glebie (współczynniki korelacji i regresji)

Specification Wyszczególnienie	P fractions frakcje P	Grain Ziarno		Straw Słoma		Roots Korzenie		Total plant Cała roślina	
		rxy	byx	rxy	byx	rxy	byx	rxy	byx
Acid soil Gleba kwaśna	P easily sol.	-	-	-	-	-	-	-	-
	P-Al	-	-	-0.377	-0.205	-	-	-0.360	-0.402
	P-Fe	-	-	-	-	-	-	-	-
	P-Ca	0.922	2.258	0.923	2.276	0.872	0.132	0.926	4.692
	Sum fr.	-	-	-	-	-	-	-	-
Limed soil Gleba wapniowa	P easily sol.	-	-	-	-	-	-	-	-
	P-Al	-	-	-	-	-	-	-	-
	P-Fe	-	-	-	-	0.362	0.003	-	-
	P-Ca	0.653	0.427	0.436	0.294	-	-	0.562	0.730
	Sum fr.	-	-	-	-	-	-	-	-
P1	P easily sol.	0.640	2.205	0.586	1.994	0.598	0.130	0.614	4.333
	P-Al	-0.532	-0.727	-0.607	-0.820	-0.525	-0.045	-0.571	-1.600
	P-Fe	-	-	-	-	-	-	-	-
	P-Ca	0.917	1.987	0.903	1.933	0.889	0.121	0.913	4.052
	Sum fr.	-	-	-	-	-	-		
P 2	P easily sol.	0.548	1.176	0.549	1.042	0.558	0.073	0.552	2.307
	P-Al	-0.701	-0.674	-0.701	-0.596	-0.625	-0.037	-0.702	-1.315
	P-Fe	-	-	-	-	-	-	-	-
	P-Ca	0.924	1.652	0.919	1.453	0.861	0.094	0.923	3.218
	Sum fr.	-	-	-	-	-	-	-	-
N1	P-łr.	0.513	0.961	0.477	0.867	0.457	0.058	0.497	1.904
	P-Al	-0.409	-0.281	-0.394	-0.263	-0.402	-0.019	-0.401	-0.563
	P-Fe	-	-	-	-	-	-	-	-
	P-Ca	0.920	1.753	0.899	1.663	0.851	0.111	0.911	3.546
	Sum fr.	-	-	-	-	-	-	-	-
N2	P easily sol.	0.519	1.266	0.473	1.055	0.455	0.063	0.496	2.384
	P-Al	-	-	-0.384	-0.257	-	-	-	-
	P-Fe	-	-	-	-	-	-	-	-
	P-Ca	0.901	1.746	0.880	1.560	0.866	0.096	0.894	3.414
	Sum fr.	-	-	-	-	-	-	-	-
Ammonium sulphate Siarczan amonowy	P easily sol.	0.446	1.374	0.456	1.317	0.423	0.084	0.450	2.783
	P-Al	-	-	-	-	-0.379	-0.020	-	-
	P-Fe	-	-	-	-	-	-	-	-
	P-Ca	0.926	2.161	0.915	2.000	0.913	0.137	0.923	4.318
	Sum fr.	-	-	-	-	-	-	-	-
Calcium nitrate Saletra wapniowa	P easily sol.	0.754	0.694	0.650	0.502	0.624	0.038	0.720	1.241
	P-Al	-	-	-	-	-	-	-	-
	P-Fe	0.373	0.084	-	-	0.527	0.008	0.377	0.159
	P-Ca	0.854	1.127	0.772	0.853	0.661	0.057	0.828	2.045
	Sum fr.	0.467	0.064	0.382	0.044	0.501	0.005	0.442	0.113
Together Razem	P easily sol.	0.497	1.059	0.457	0.914	0.335	0.018	0.479	2.043
	P-Al	-0.349	-0.250	-0.388	-0.260	-0.361	-0.160	-0.370	-0.529
	P-Fe	-	-	-	-	-	-	-	-
	P-Ca	0.909	1.751	0.888	1.606	0.853	0.102	0.901	3.474
	Sum fr.	-	-	-	-	-	-	-	-

Table 3. Relations between content of phosphorus in spring barley and the occurrence of movable forms of this element in soil (correlation and regression coefficients)
Tabela 3. Zależności między zawartością fosforu w jęczmieniu jarym a występowaniem ruchomych form tego pierwiastka w glebie (współczynniki korelacji i regresji)

Specification Wyszczególnienie	P available P przyswajalny	Grain Ziarno		Straw Słoma		Roots Korzenie	
		rxy	byx	rxy	byx	rxy	byx
Acid soil Gleba kwaśna	P E-R	0.838	0.016	0.721	0.021	0.579	0.009
	P H_2O	0.698	0.074	0.578	0.096	0.457	0.038
	P $CaCl_2$	0.804	0.866	0.663	1.116	0.533	0.449
	P $NaHCO_3$	0.749	0.016	0.603	0.020	0.467	0.008
Limed soil Gleba wapniowa	P E-R	0.410	0.008	0.402	0.005	-	-
	P H_2O	-	-	0.364	0.039	-0.406	-0.031
	P $CaCl_2$	0.710	0.944	0.571	0.489	-	-
	P $NaHCO_3$	0.776	0.020	0.605	0.010	-	-
P1	P E-R	-	-	0.358	0.010	-	-
	P H_2O	-	-	-	-	-	-
	P $CaCl_2$	-	-	-	-	-	-
	P $NaHCO_3$	-	-	-	-	-	-
P2	P E-R	-	-	-	-	-	-
	P H_2O	-	-	-	-	-	-
	P $CaCl_2$	0.576	0.804	0.489	1.232	-	-
	P $NaHCO_3$	-	-	-	-	-	-
N1	P E-R	0.581	0.010	0.420	0.009	-	-
	P H_2O	0.479	0.061	0.350	0.059	-	-
	P $CaCl_2$	0.779	0.833	0.606	0.858	-	-
	P $NaHCO_3$	0.491	0.010	-	-	-	-
N2	P E-R	0.445	0.010	-	-	-	-
	P H_2O	-	-	-	-	-	-
	P $CaCl_2$	0.713	1.035	0.520	0.942	0.525	0.465
	P $NaHCO_3$	0.438	0.010	-	-	-	-
Ammonium sulphate Siarczan amonowy	P E-R	0.883	0.016	0.550	0.015	-	-
	P H_2O	0.715	0.071	0.459	0.070	-	-
	P $CaCl_2$	0.896	0.822	0.572	0.811	0.350	0.265
	P $NaHCO_3$	0.629	0.011	-	-	-	-
Calcium nitrate Saletra wapniowa	P E-R	0.373	0.005	0.372	0.005	-	-
	P H_2O	-	-	0.387	0.040	-	-
	P $CaCl_2$	0.798	0.901	0.755	0.794	-	-
	P $NaHCO_3$	-	-	-	-	-	-
Together Razem	P E-R	0.505	0.010	0.381	0.010	-	-
	P H_2O	0.395	0.052	0.325	0.054	-	-
	P $CaCl_2$	0.734	0.916	0.556	0.888	0.323	0.278
	P $NaHCO_3$	0.461	0.010	-	-	-	-

Table 4. Relations between content of phosphorus in spring barley and the occurrence of mineral fractions of this element in soil (correlation and regression coefficients)
Tabela 4. Zależności między zawartością fosforu w jęczmieniu jarym a występowaniem frakcji mineralnych tego pierwiastka w glebie (współczynniki korelacji i regresji)

Specification Wyszczególnienie	P fractions frakcje P	Grain Ziarno		Straw Słoma		Roots Korzenie	
		rxy	byx	rxy	byx	rxy	byx
Acid soil Gleba kwaśna	P easily sol.	0.799	0.067	0.664	0.086	0.559	0.036
	P-Al	0.941	0.013	0.857	0.018	0.752	0.008
	P-Fe	0.718	0.007	0.592	0.009	0.470	0.003
	P-Ca	-0.579	-0.036	-0.723	-0.071	-0.707	-0.035
	Sum fr.	0.831	0.005	0.696	0.006	0.573	0.003
Limed soil Gleba wapniowa	P easily sol.	-	-	-	-	-	-
	P-Al	0.843	0.018	0.770	0.011	-	-
	P-Fe	-	-	0.352	0.003	-0.381	-0.002
	P-Ca	-	-	-	-	-	-
	Sum fr.	0.504	0.004	0.470	0.002	-	-
P1	P easily sol.	-	-	-	-	-0.392	-0.018
	P-Al	0.842	0.020	0.805	0.024	0.538	0.010
	P-Fe	-	-	-	-	-	-
	P-Ca	-0.874	-0.034	-0.881	-0.041	-0.754	-0.022
	Sum fr.	-	-	-	-	-	-
P2	P easily sol.	-0.383	-0.015	-0.423	-0.030	-0.582	-0.021
	P-Al	0.770	0.013	0.842	0.026	0.588	0.010
	P-Fe	-	-	-	-	-	-
	P-Ca	-0.770	-0.025	-0.899	-0.052	-0.848	-0.026
	Sum fr.	-	-	-	-	-	-
N1	P easily sol.	-	-	-	-	-	-
	P-Al	0.915	0.015	0.892	0.019	0.511	0.006
	P-Fe	0.542	0.005	0.397	0.005	-	-
	P-Ca	-0.395	-0.018	-0.649	-0.038	-0.821	-0.029
	Sum fr.	0.665	0.004	0.502	0.004	-	-
N2	P easily sol.	-	-	-	-	-	-
	P-Al	0.864	0.015	0.743	0.016	0.701	0.008
	P-Fe	0.519	0.006	0.528	0.008	0.377	0.003
	P-Ca	-0.540	-0.025	-0.745	-0.043	-0.552	-0.016
	Sum fr.	0.584	0.004	0.487	0.004	0.414	0.002
Ammonium sulphate Siarczan amonowy	P easily sol.	0.607	0.032	-	-	-	-
	P-Al	0.940	0.013	0.812	0.018	0.587	0.007
	P-Fe	0.755	0.007	0.566	0.008	0.356	0.003
	P-Ca	-	-	-0.691	-0.042	-0.649	-0.021
	Sum fr.	0.865	0.005	0.571	0.005	-	-
Calcium nitrate Saletra wapniowa	P easily sol.	-	-	-	-	-	-
	P-Al	0.820	0.012	0.768	0.010	0.380	0.003
	P-Fe	0.460	0.004	0.520	0.004	-	-
	P-Ca	-	-	-	-	-	-
	Sum fr.	0.547	0.003	0.566	0.003	-	-
Together Razem	P easily sol.	-	-	-	-	-	-
	P-Al	0.886	0.015	0.809	0.018	0.604	0.007
	P-Fe	0.523	0.006	0.462	0.006	-	-
	P-Ca	-0.478	-0.022	-0.702	-0.041	-0.679	-0.021
	Sum fr.	0.615	0.004	0.491	0.004	-	-

Summing up, in the performed experiment the spring barley yield was positively correlated with the content of P in $NaHCO_3$, P-Ca, easily soluble P, and negatively correlated with P-Al. No significant correlations with P-Fe and the sum of fractions were revealed. The advantageous effect of increased amounts of easily soluble phosphates and calcium phosphates most probably resulted from the fact that easily soluble P fractions contain phosphorus compounds from which this component is the easiest available to the plants, while the content of P-Ca fractions increases with the increase of soil pH, and barley is a plant that is very sensitive to acidification and high concentration of movable aluminum. Tran Sen and Giroux [1987] also observed the positive correlation between the yield and P determined according to Olsen's method. Bednarek [1987, 1992] pointed to significant, positive correlations with the soil content of, first of all, phosphorus, determined in accordance with Egner-Riehm method, easily soluble phosphate fractions and aluminum. High coefficients of correlation between the content of phosphorus determined by means of the Egner-Riehm method, and the yield of plants are also indicated by the results of studies conducted by Adamus *et al*. [1981]. Bednarek and Lipiński [1994] found a positive correlation of grain yield with P-Al fraction, and of the vegetative parts – with easily soluble P and negative correlation with P-Fe. In Lipiński's [1997] studies the spring barley yield revealed the greatest positive connections with the content of phosphorus extracted with $CaCl_2$, H_2O and $NaHCO_3$, as well as with the amount of easily soluble phosphates and aluminum phosphates, while the experiment conducted by Chojnacki *et al*. [1981] indicates lack of dependence of corn yield upon the concentrations of available phosphorus.

The content of phosphorus in the grain of spring barley grown on acid soil and in the objects fertilized with ammonium sulphate was significantly positively correlated with the amounts of all the analyzed, available forms of P, while in the conditions of liming, as well as fertilizing with calcium nitrate, no significant correlations with the content of phosphorus extracted from soil by water were observed (tab. 3). Besides, in combinations with $Ca(NO_3)_2$ the concentration of P in grain did not reveal any significant correlation with phosphorus determined by means of Olsen's method. Analyzing the effect of particular phosphorus fractions, we can find that the content of P in the grain were to the greatest extent positively correlated with the amount of P-Al (tab. 4). The reason was, undoubtedly, a definitely lower grain yield of spring barley grown on acid soil with increased P-Al concentration. In the conditions of soil acidification we also found positive correlations with the fraction of easily soluble phosphates. Irrespective of the form of applied nitrogen, the increased amount of P-Fe enhanced the increase of phosphorus concentration, whereas the P-Ca fraction had no significant effect, or was negatively correlated (acid soil) with the discussed feature. Bednarek and Lipiński [1994] observed significant relationships with the P content in spring barley grain only with iron phosphates, and in vegetative parts with P-Fe and P-Al.

The concentration of phosphorus in the straw of spring barley grown on acid, as well as limed soil, was significantly and positively correlated with the amounts of all examined available forms of the component (tab. 3). Most probably, the reason for that was the fact that the content of this component in vegetative parts of the plants underwent greater changes under the influence of environmental factors, while the chemical composition of their generative parts mainly depends on genetic factors. Considering the form of nitrogen applied, we observed a positive correlation with the content of P extracted by calcium lactate, water and calcium chloride. Irrespective of liming and the form of nitrogen used, we revealed a significant, positive correlation with the number of aluminum phosphate, iron phosphate and the sum of fractions (tab. 4). Besides, in the acid soil, as well as in the combinations of ammonium sulphate, we found a significant, negative correlation with the amount of calcium phosphates. It was statistically proven that the content of phosphorus in the straw collected from non-limed soil was also influenced by the content of easily soluble P (positive correlation). Bednarek [1987], conducting studies with multiflorous darnel, found a strong correlation of P determined in accordance with Egner-Riehm method with easily soluble and aluminum phosphates. The influence of iron and calcium phosphates was smaller. In another experiment, the author [Bednarek 1992] in most cases did not observe any significant connections with the amount of the mineral forms of this component in the soil. Similarly, Chojnacki *et al*. [1981] demonstrated that the correlation between the content of phosphorus in plants and the content of available forms of this component only in a few cases had been statistically significant.

Table 5. Relations between uptake of phosphorus by spring barley and the occurrence of movable forms and mineral fractions of this element in soil (correlation and regression coefficients)
Tabela 5. Zależności między pobieraniem fosforu przez jęczmień jary a występowaniem ruchomych form i frakcji mineralnych tego pierwiastka w glebie (współczynniki korelacji i regresji)

Specification Wyszczególnienie		P E-R	P H_2O	P $CaCl_2$	P $NaHCO_3$	P-easily soluble	P-Al	P-Fe	P-Ca	Sum of fractions
Acid soil Gleba kwaśna	rxy	-	-	-	-	-	-	-	0.898	-
	byx	-	-	-	-	-	-	-	11.31	-
Limed soil Gleba wapniowa	rxy	0.723	0.699	0.756	0.740	0.526	0.912	0.615	-	0.769
	byx	0.680	5.597	48.59	0.931	1.328	0.936	0.350	-	0.265
P1	rxy	-	0.455	-	0.400	0.597	-0.475	-	0.846	-
	byx	-	15.80	-	2.567	9.559	-3.019	-	8.527	-
P2	rxy	-	-	-	0.422	0.518	-0.658	-	0.882	-
	byx	-	-	-	2.000	5.562	-3.160	-	7.891	-
N1	rxy	-	0.356	-	0.518	0.594	-	-	0.891	-
	byx	-	9.708	-	2.152	5.583	-	-	8.511	-
N2	rxy	-	-	-	0.373	0.529	-	-	0.853	-
	byx	-	-	-	1.695	6.260	-	-	8.004	-
Ammonium sulphate	rxy	-	-	-	0.512	0.533	-	-	0.939	-
Siarczan amonowy	byx	-	-	-	2.708	8.647	-	-	11.54	-
Calcium nitrate	rxy	0.882	0.771	0.540	0.787	0.852	0.511	0.650	0.724	0.768
Saletra wapniowa	byx	1.49	10.40	73.83	1.603	3.534	0.939	0.660	4.300	0.473
Together Razem	rxy	-	0.278	-	0.439	0.546	-	-	0.869	-
	byx	-	7.551	-	1.916	5.713	-	-	8.225	-

The content of phosphorus in the roots of the tested plant growing on acid soil was positively correlated with the concentrations of all the examined available forms of the component, whereas in the case of limed soil only a negative correlation with the content of P in H_2O was observed (tab. 3). In the combinations fertilized with ammonium sulphate, a positive correlation was found with the amount of component extracted with calcium chloride. From among the fractions of mineral phosphorus, the greatest, advantageous effect was that of the P-Al. fractions (tab. 4). In most objects, however, a negative correlation was found with the content of calcium phosphate fractions. The effects of easily soluble P and P-Fe fractions were multidirectional, depending on the analyzed experimental factor.

The phosphorus uptake by spring barley grown on limed soil, as well as by that fertilized with calcium nitrate, was significantly and positively correlated with the content of P extracted with calcium lactate, water, calcium chloride and sodium bicarbonate (tab. 5). However, in combinations with ammonium sulphate, a significant, positive correlation was only found with P determined according to Olsen's method. The absorption of the discussed component by plants harvested from acid soil was not significantly dependent on the analyzed available forms of phosphorus. The enumerated correlation coefficients indicate that the uptake of P was to the greatest extent positively correlated with the occurrence of calcium phosphates in the soil. With the exception of the objects on acid soil, the connections with fraction easily soluble P (positive correlation) were also demonstrated. Moreover, in soil alkalization conditions, positive correlations were found with P-Al, P-Fe and the sum of mineral phosphorus fractions. Tran Sen and Giroux [1987] as well as Sims and Ellis [1983] also indicate the strong connection between phosphorus uptake with the amount of the component extracted with sodium bicarbonate. Bednarek and Lipiński [1994] observed a positive correlation of the amount of phosphorus accumulated by the grain with the concentrations of iron phosphates, while in the case of vegetative parts with fractions easily soluble P and P-Al. Kęsik and Pietrasz-Kęsik [1981] demonstrate that plants take phosphorus mainly from easily soluble P and P-Al fractions. Similarly, Bednarek [1987, 1992] found significant positive correlations between P uptake and the soil content of easily soluble and aluminum phosphates as well as the available form of phosphorus, determined in accordance with Egner-Riehm method, whereas in another experiment the author [Bednarek 1991] demonstrated positive correlations of phosphorus uptake by plants with soil content of this component, determined in water, and fractions of easily soluble, iron and aluminum phosphates. Lipiński [1997] pointed out to the correlation of component uptake with the content of easily soluble phosphates and aluminum, as well as phosphorus extracted from soil by $CaCl_2$, H_2O and $NaHCO_3$. In the experiment conducted by Bosch and Amberger [1986] plants took the more phosphorus from the soil, the more phosphates connected with Al + Fe the soil contained, especially when pH had been previously evened to 6.5.

CONCLUSIONS

1. The spring barley yield revealed a positive correlation with the content of phosphorus extracted from soil with $NaHCO_3$, fractions of easily soluble phosphates and calcium phosphates, as well as a negative correlation with the content of aluminum phosphate fractions.

2. The content of phosphorus in the spring barley grain was positively correlated with all the analyzed available forms of the component, while the concentration of P in the straw did not depend on phosphorus determined according to the Olsen method. From among the mineral fractions, a significant, positive influence was exerted by P-Al and P-Fe fractions, while calcium phosphates limited the concentration of this element.

3. The phosphorus uptake by spring barley depended first of all upon the soil content of water and sodium bicarbonate-extracted P, as well as of easily soluble phosphate fractions and calcium phosphate fractions.

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Streszczenie. Celem badań było określenie zależności między plonem, zawartością i pobraniem fosforu przez jęczmień jary a zawartością ruchomych form i mineralnych frakcji tego pierwiastka w glebie. Czynnikami doświadczalnymi było wapnowanie, nawożenie dwoma formami azotu stosowane w dwóch dawkach oraz nawożenie fosforem na dwóch poziomach. Jęczmień jary zbierano w fazie dojrzałości pełnej. Otrzymane rezultaty badań wskazały, że plon rośliny testowej był uzależniony od zawartości fosforu oznaczonego w $NaHCO_3$, fosforanów łatwo rozpuszczalnych

i fosforanów wapnia (korelacja dodatnia) oraz ilości fosforanów glinu (korelacja ujemna). Zawartość fosforu w ziarnie była uzależniona głównie od zawartości fosforu przyswajalnego oraz frakcji P-Al, P-Fe i P-Ca. Pobranie fosforu przez roślinę było uzależnione od zawartości tego składnika oznaczonego w wodzie, wodorowęglanie sodu oraz ilości frakcji fosforanów łatwo rozpuszczalnych i fosforanów wapnia.

Słowa kluczowe: fosfor przyswajalny, mineralne frakcje, plon, pobranie