Phosphorus availability in hydromorphic soils of Eastern Croatia

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ABSTRACT

The phosphorus (P) availability was tested on hydromorphic soils located in the Sava valley. 480 soil profiles covering the area of 31 227 ha was analysed in our study. The plant available P was determined by the Ammonium-Lactate method. The P availability in the surface layer (0–30 cm) is very low (up to 5 mg P_2O_5/100 g of soil) in about 30% of the tested agricultural land (9 440 ha), next 32% (9 897 ha) is in the range of a low P availability (from 5.1 to 10 mg), while only 17% (5 445 ha) has a good or very good P availability (above 20 mg). Especially high frequency of low P availability was found in vertic gley, amphygley and hypogley soils (total 8 680 ha or 28% of tested agricultural land).

Keywords: phosphorus availability; soil test; hydromorphic soil; Eastern Croatia; ameliorative fertilization; field experiments

The growth retardation of maize at the early growth stage was found, which is in close connection with different types of nutritional unbalances under the influence of phosphorus (P), potassium (K) and zinc (Zn) deficiency (Kovačević et al. 1988). The P deficiency was found mainly in hydromorphic soils. The P deficiency in hydromorphic soils is in connection with their more acid reaction, relatively heavier texture and more intensive P fixation capacity (Vukadinović et al. 1988, Voplakal 1994, Efimov et al. 2001, Mengel and Kirkby 2001). Routine soil test data (pH, humus contents, plant available P and K according the AL-method) as a source information for the adequate fertilization are available in about one fourth of total agricultural soils (160 000 ha) in Eastern Croatia (approximately 50% of soils at former state farms and only 4% of soils at small farms). For this reason the fertilization practice is based mainly on general needs of individual field crops instead of on a nutritional status in the soil (Kovačević and Bašić 1997). The development studies are the source of additional information concerning the nutritional status of agricultural soils in the region. The intention of this study is the testing of available P status in hydromorphic soils of the eastern part of Sava lowland area based on data from studies made for demands of hydromelioration projects.

MATERIAL AND METHODS

Description of the area

Part of agricultural land of three former state farms in the area of the eastern part of Sava valley (Croatian: Posavina) in Croatia (PPK Zupanja, Zupanja, AK Jasinje Slavonski Brod and PPK Nova Gradiska, Nova Gradiska) is covered in this study.

In the period from 1978 to 1989 this area was drained (total 31 227 ha or 19.2% of agricultural soil of the region – the municipalities Zupanja, Slavonski Brod and Nova Gradiska). It is a narrow belt in the west-eastern direction, approximately 150 km long and between 5 and 10 km wide. The western and eastern borders are defined by the rivers Slobostina and Josava, respectively. The river Sava defines the area from the south and Psunj, Pozeska gora and the Dilj Mountains from the north.

Geological and pedological characteristics

The relief of this area is a typical lowland with the altitude between 80 and 100 m above sea level. The lithological ground is mainly sediment of pleistocen-holocen age (Vidacek et al. 2001). There are three ways of dampening the soils as follows: by surface water, underground water and by their combination (Škorić et al. 1985). Dominant soil types are different types and subtypes of hydromorphic soils (Kovačević 1997). Some improvement of soils was made by hydromelioration in the period from 1978 to 1989 (Petošić 1994a, b, 1998, Marušić 2001). However, after the regulation of water-air relations in the soils, some chemical properties including nutritional unbalances became limiting factors of field crop yields.

Climatic characteristics

Eastern Croatia, including the Sava valley, has a moderate continental climate characterized by low horizontal changes of temperature and a specific distribution of rainfall (more rainfall in the warmer part of the year, from April to September). The mean amplitude of temperatures (differences between mean monthly air-temperatures in the coldest January and the warmest July) in the lowland area of the region is about 22°C (Šegota 1975). For example, for the period 1931–1960 (the data of Slavonski Brod Weather Bureau) the mean rainfall was 785 mm (53% in the 6-month period from April to September) and the mean air-temperature was 11.2°C (January –0.7°C and July 22.8°C).

Collection of the data and their analyses

We analysed the total of 480 soil profiles covering an area of 31 227 ha. Depending on the surface uniformity, each profile covers approximately 65 ha or a range between 49 and 82 ha. Soil samples were taken from the depth 0–30 cm and 31–65 cm, respectively, in the profile. Soil sampling and chemical analysis were made in the period before 1990. Yield data for wheat and maize were received from the former state farms Zupanja, Jasinje and Nova Gradiska. Plant available P was determined by the Ammonium-Lactate method (Egner et al. 1960). Statistical analyses of soil data (Table 4, Figures 1–7) were obtained by the Bonferroni's test and Pearson's Correlation Coefficients (Mead et al. 1996).

The field experiments with liming and ameliorative P fertilization

In the last 20-year period the field trials with ameliorative treatments were conducted on different soil types of eastern Croatia and northern Bosnia. These experiments were conducted in four replicates. Some experiments included either liming or ameliorative P fertilization.

The liming experiment with increased rates of calcite (about 50% CaO) up to 32 t/ha was conducted in duplicate for the maize-wheat rotation in spring 1986 on a pseudogley soil near Brcko in the Bosnian part of the Sava valley

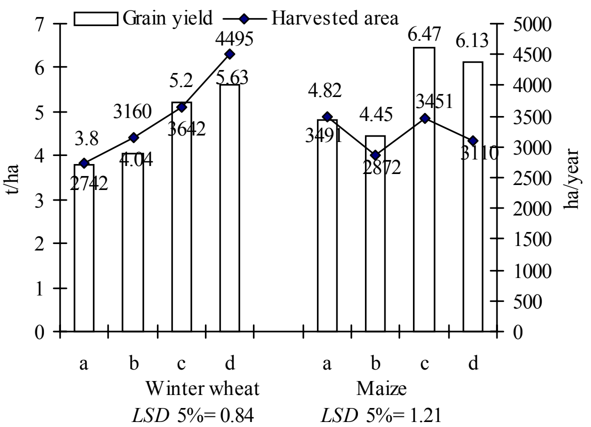

Figure 1. Wheat and maize harvested area (ha/year) and grain yields (t/ha) on the fields of the state farm Jasinje Slavonski Brod for four 5-year periods from 1971–1975 (a) to 1986–1990 (d)

(Kovačević et al. 1992a, b). Maize and wheat yields, nutritional status of maize (ear-leaf at silking) and wheat (flag-leaf at heading stage) were shown in Figures 2 and 3.

The field experiment with increased rates of the P fertilization up to 2 550 kg P_2O_5/ha (as MAP: monoammonium phosphate 12% N + 52% P_2O_5) and the K fertilization up to 2 550 kg K_2O/ha (as muriate of potash) was conducted in the spring 1990 on hydromorphic soil near Nova Gradiska. The experiment was duplicated and maize and soybean were grown in the first experimental year and some results were shown in Figures 4 and 5. The yield and P status in maize as affected by P fertilization up to 875 kg P_2O_5/ha were shown in Figure 6. Response of three maize hybrids to the application of 1 500 kg P_2O_5/ha is shown in Figure 7.

RESULTS AND DISCUSSION

Wheat and maize yield status

Wheat and maize are the most frequent field crops on arable soils in the tested area of three former state farms. For example, in the period 1976–1990 the harvested areas were 11 308 ha/year (wheat) and 8 853 ha/year (maize). The shares of wheat and maize harvested areas in total arable soils of the farms were 25.1 and 19.7%, respectively. Their grain yields (5.10 and 6.13 t/ha for wheat and maize, respectively) were considerably lower in comparison with the genetic potential and the degree of climate favourableness. The total area covered by wheat and maize on arable soils of three former state farms in the tested period was 20 161 ha/year or close to two thirds of the area covered by these pedological investigations. The yield of the most arable crops of this area has increased during this period, mainly because of hydromelioration. Total 161 530 ha of arable soils in Croatia is covered by drainage, as many as 53 619 ha were drained in the narrow lowland part of the Sava valley (Petošić et al. 2001). For example, the wheat yields for four 5-year periods on the field of AK Jasinje were about 50% higher for the 1986–1990 period in comparison with the period of 1971–1975 (Figure 1). In general, lower yields of wheat in eastern Croatia are in connection with excess of water (Table 1), especially in the autumn/winter period (Mušac and Kovačević 1984, Kovačević and Josipović 1995). Yield increases of wheat could be explained by the hydromelioration because of improved water-air relations in the soil and diminished negative influences of wet growing seasons on the yield.

However, the maize yield increases at AK Jasinje for the same period of time were somewhat lower in comparison with wheat (Figure 1). In general, variations of the maize yield in eastern Croatia are higher in comparison with the wheat yield. Also, under our environmental conditions, as well as in the U.S. Maize Belt, low yields of maize are in connection with the shortage of rainfall and higher air-temperatures during July and August (Shaw 1988, Kovačević and Josipović 1998). For this reason, the higher rainfall in comparison with the long-term mean,

Table 1. Influences of weather conditions on wheat and maize yields on the state farm AK Jasinje Slavonski Brod

	Less favourable growing seasons				More favourable growing seasons				Long-term values	
	Response of wheat to weather conditions									
	1979/1980		1980/1981		1982/1983		1983/1984		1971–1990	
	Wheat yields (t/ha) on AK Jasinje (in the bracket harvested area in ha)									
	3.63 (2 950)		4.44 (3 070)		5.61 (3 743)		6.03 (3 943)		4.60 (3 703)	
Months	rainfall (mm) and mean air-temperatures (°C)									
	mm	°C	mm	°C	mm	°C	mm	°C	mm	°C
October–June	696	7.2	663	7.1	469	9.0	504	6.8	509	7.7
	Response of maize to weather conditions									
	1987		1988		1986		1989		1971–1990	
	Maize yields (t/ha) on AK Jasinje (in bracket harvested area in ha)									
	5.42 (3 173)		4.35 (2 963)		7.72 (3 525)		7.02 (2 781)		5.42 (3 231)	
Months	rainfall (mm) and mean air-temperatures (°C)									
	mm	°C	mm	°C	mm	°C	mm	°C	mm	°C
January–March	184		198		205		63		129	2.5
April–September	302	17.9	299	17.9	402	17.4	584	17.1	426	16.9
July + August	86	21.4	97	22.4	189	20.1	149	20.5	158	20.0

especially for summer months, is more favourable for the maize growth and yield under dry- farming system (Table 1). The differentiation of more and less favourable growing seasons was made based on mean grain yields of wheat and maize (Table 1).

Plant available phosphorus status on hydromorphic soils

Amphygley and hypogley are the most common soil types of the region because they cover 21 274 ha or 68% of the tested area. In general, based on mean values, the most favourable P status was found in semiglay alluvial soils, while in vertic gley and amphygley they were considerably lower. Also, the P status in the deeper soil layer was 60% lower than in 0–30 cm soil depth (Table 2).

Concerning the degree of P availability in the surface layer, about 30% of tested agricultural land (9 440 ha) is too little supplied with plant available P (until 5 mg P_2O_5/100 g of soil), the next 32% (9 897 ha) is in the range of low P availability (from 5.1 to 10.0 5 mg P_2O_5/100 g of soil), 20% (6 445 ha) is in the moderate range, while only 17% (5 445 ha) is in the ranges of good or very good P supply (Table 3). Especially high frequency of very low P availability (until 5.0 mg P_2O_5/100 g) is found in vertic gley, amphygley and hypogley soils, because total 8 680 ha (or 28% of tested agricultural land) of these soils are poor in P. The most favourable P status was found in semiglay alluvial soils (only 5% or 116 ha is very low in P), but only about 7% of tested area is covered by this soil type (Table 3). The consumption of mineral fertilizers in Croatia is low compared to the European average. According to internal data of Petrokemija Fertilizer Factory Kutina (Stojić, personal communication) it was 105 kg (status 2002) and 138 kg (status 2000) of active ingredients (N + P_2O_5 + K_2O = 63 + 35 + 40 kg/ha, status 2000) on a hectare of cropped area.

The fertilization on the state farms was considerably higher in comparison with the state mean. For example, the mean fertilization (active ingredients) of wheat on three state farms (Zupanja, Jasinje and Nova Gradiska) for 1982/1983 (Mušac and Kovačević 1984) was 387 kg/ha (92 kg P_2O_5/ha, 11 511 ha, mean yield 5.56 t/ha). Analogous data for the period ten-year later (Kovačević and Grgić 1993) were 328 kg/ha (89 kg P_2O_5/ha, 7 057 ha, mean yield 5.44 t/ha). However, this level of fertilization is sufficient only for the maintenance of the soil P status. For this reason, we presume that results of the soil test (Tables 2 and 3) are applicable for the current fertilization practice. Also, our opinion is that higher fertilization could be the next step for a yield increase of field crops on arable soils in the Sava valley.

Based on our experiences and results of soil tests, we could recommend different degrees of ameliorative P fertilization for soils with very low and low P supply. For example, application of 1 000 kg P_2O_5/ha for soils with very low P supply (until 5 mg P_2O_5/100 g in the surface layer: about 30% of the tested area) and 500 kg P_2O_5/ha for soil with low P supply in the range between 5.1 and 10.0 mg P_2O_5/100 g (about 32% of the tested area) by MAP application before ploughing. In the next several years the ordinary P fertilization in levels between 100 and 150 kg P_2O_5/ha will be necessary for the maintenance of the improved P status in these soils. For the remaining 38% of the tested area, the maintenance of plant available P on the levels that were found by soil tests is possible by an ordinary fertilization practice.

Table 2. Properties of soil types – means of tested (*n*) profiles for two depths

Soil type	*n*	Area (ha)	Percent humus	Percent clay	Percent silt	pH 1N KCl	P_2O_5 mg/100 g (AL-method)
			Soil depth 0–30 cm				
Amphygley	142	11 724	2.9B	45.7B	46.1C	5.7BC	8.4B
Hypogley	165	9 550	2.7BC	39.3C	53.9B	6.0A	9.9B
Vertic gley	84	4 160	4.1A	60.2A	35.8D	6.0AB	8.0B
Semigley alluvial	40	2 315	1.9D	34.3D	61.4A	5.6C	14.6A
Pseudogley-gley	26	2 147	2.1CD	30.5D	57.4AB	5.5BC	9.5B
Alluvial soil	23	1 331	2.8BC	28.7D	57.4AB	6.1AB	10.5AB
Total	480	31 227					
Mean			2.8	39.8	52.0	5.8	10.1
			Soil depth 30.1–65 cm				
Amphygley	142	11 724	1.50	45.3	46.3	6.1	3.3
Hypogley	165	9 550	1.50	39.9	53.8	6.3	4.8
Vertic gley	84	4 160	2.07	62.6	33.9	6.4	2.1
Semigley alluvial	40	2 315	0.98	36.9	59.2	5.9	7.0
Pseudogley-gley	26	2 147	1.39	34.4	54.0	5.8	4.4
Alluvial soil	23	1 331	1.44	30.0	54.4	6.5	2.8
Total	480	31 227					4.1
Mean			1.48	41.6	50.3	6.2	
			Statistical analyses of variance (0–30 cm soil depth)				
Source of variability		*df*			*F*		
Total		478	humus	clay	silt	pH	P_2O_5
Soil type		5	35.2**	111.2**	98.3**	5.2**	6.2**
Error		473					

Growth retardation as affected by P deficiency and response of field crops to liming and ameliorative P fertilization

The growth retardation at early growth stage and chlorosis typical for P deficiency have been found in maize plants grown on some soils in the wider part of both sides of Sava valley and in Croatia and Bosnia, respectively. As chlorotic and normal plants grown on the same plots, comparative analyses of chemical composition of aerial part of maize were conducted (Kovačević et al. 1988, 1992a, Kovačević and Vukadinović 1992). Table 4 shows typical examples of these nutritional disorders. The dry matter yield and the P concentration of chlorotic plants

Table 3. Ranges of phosphorus availability (AL-method) in surface soil layer of individual soil types (*n* = total number of soil profiles)

Soil type	*n* (480)	Range of available P (mg P_2O_5 100/g of soil) > 5.0	5.1–10.0	10.1–15.0	15.1–20.0	20.1–25.0	< 25	Area ha (100%)
		Soil depth 0–30 cm: percent of individual range						
Amphygley	142	35.2	32.4	18.4	9.1	3.5	1.4	11 724
Hypogley	165	28.5	31.5	20.6	10.3	6.6	2.5	9 550
Vertic gley	84	44.0	22.6	15.5	10.7	1.2	6.0	4 160
Semigley alluvial	40	5.0	25.0	40.0	12.5	7.5	10.0	2 315
Pseudogley-gley	26	19.2	46.2	19.2	11.5	0	3.9	2 147
Alluvial soil	23	17.4	43.5	26.1	8.7	0	4.3	1 331
Total (ha)		9 440	9 897	6 445	3 157	1 271	1 017	31 227
Frequency (%)		30.2	31.7	20.6	10.1	4.1	3.3	100

Table 4. Properties of maize at 6–9 leaves stage (June 1986) on P-deficient soils in eastern Croatia (Valpovo) and northern Bosnia (Brcko and Nova Topola)

Plant status	Locality	Aerial part of maize: dry matter yield (g/plant), plant height (cm), P, Fe and Al status (mg/kg on dry matter basis)				
		g/plant dry matter yield	cm height	mg/kg P	mg/kg Al	mg/kg Fe
Influences of the plant status (factor A)						
Chlorotic		2.07	25.9	0.31	2 038	2 108
Normal		15.78	65.2	0.47	394	390
LSD A 5%		2.37	2.8	0.14	609	422
LSD A 1%		4.34	5.2	0.26	1 117	774
Influences of the locality (factor B)						
	Valpovo	10.11	47.4	0.38	321	982
	Brcko	5.85	38.1	0.41	1 185	675
	N. Topola	10.81	51.1	0.38	2 142	1 940
LSD B 5%		2.30	4.8	n.s.	700	716
LSD B 1%		3.22	6.7		981	1 003
Interactions AB						
Chlorotic	Valpovo	1.80	24.0	0.25	388	1 565
	Brcko	1.61	23.5	0.37	1 910	990
	N. Topola	2.78	30.3	0.29	3 816	3 470
Normal	Valpovo	18.43	70.8	0.51	253	400
	Brcko	10.08	52.8	0.44	459	360
	N. Topola	18.84	72.0	0.46	470	410
LSD AB 5%		3.50	6.2	0.17	n.s.	919
LSD AB 1%		5.44	9.0	0.28		1 349
Mean of 24 samples		8.92	45.5	0.39	1 216	1 199

were very significantly lower in these preliminary investigations, while the Al and Fe concentration were higher in comparison with the non-chlorotic plants.

A liming of acid soils and an increased P fertilization could improve the yield and the nutritional status of field crops. With this aim we conducted field experiments in the Brcko area (Kovačević et al. 1992a, b). As affected by liming the yield of wheat was significantly increased by 0.3 t/ha or 5% only, while the yield of maize was similar to the control, although of an improved P status in plants

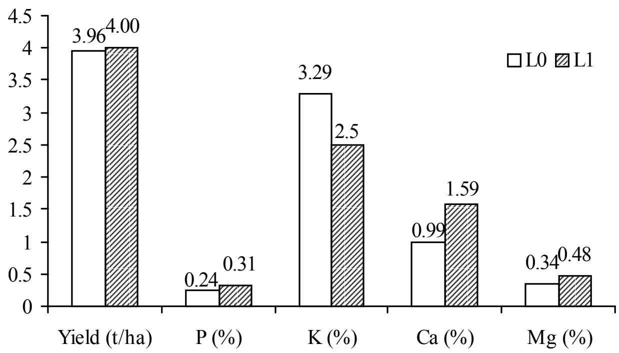

Figure 2. Influences of liming (L0 = control, L1 = 32 t/ha calcite in autumn 1986) on maize status near Brcko, northern Bosnia 1988: grain yield (t/ha) and concentrations of P, K, Ca and Mg in ear-leaf at silking (% on dry matter basis); *LSD* 5% values = n.s. (yields), 0.04 (P), 0.12 (K), 0.12 (Ca) and 0.07 (Mg); n.s. = non-significant differences

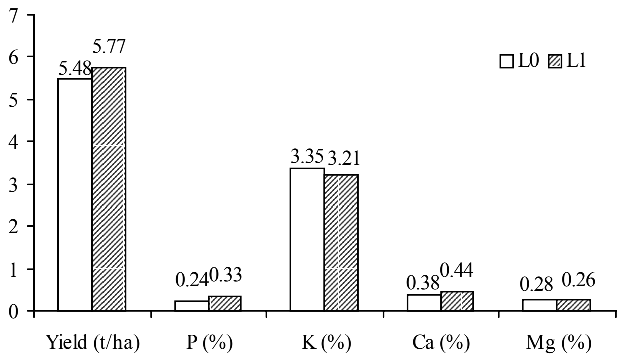

Figure 3. Influences of liming (L0 = control, L1 = 32 t/ha calcite in autumn 1986) on wheat status near Brcko, northern Bosnia 1988: grain yield (t/ha) and concentrations of P, K, Ca and Mg in flag-leaf at heading (% on dry matter basis); *LSD* 5% values = 0.21 t (yield), 0.05 (P), n.s. (K, Ca and Mg)

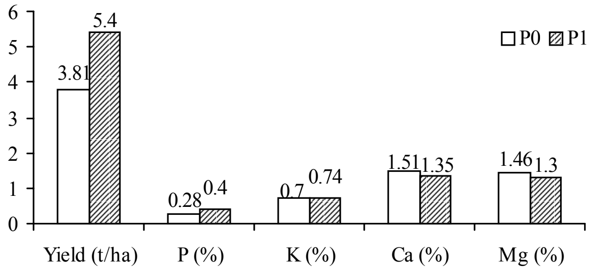

Figure 4. Influences of ameliorative P fertilization (P0 = control, P1 = 1 350 kg P_2O_5/ha) on maize properties (Nova Gradiska hydromorphic soil, 1990): grain yield (t/ha) and concentrations of P, K, Ca and Mg in ear-leaf at silking (% on dry matter basis); *LSD* 5% values = 0.57 (yield), 0.02 (P), 0.13 (Ca), n.s. (K and Mg)

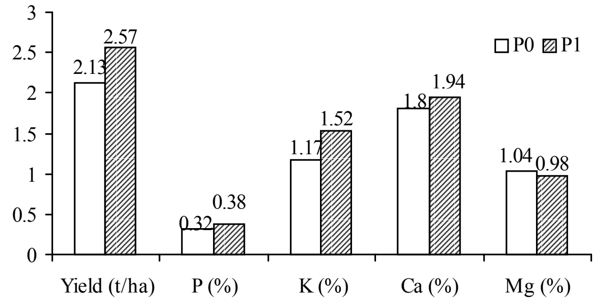

Figure 5. Influences of ameliorative P fertilization (P0 = control, P1 = 1 350 kg P_2O_5/ha) on soybean properties (Nova Gradiska hydromorphic soil, 1990): grain yield (t/ha) and concentrations of P, K, Ca and Mg in the uppermost full-developed 3-leaves at flowering (% on dry matter basis); *LSD* 5% values = 0.49 (yield), 0.02 (P), 0.13 (K), n.s. (Ca and Mg)

(ear-leaf of maize and flag-leaf of wheat). Also, the liming significantly increased the Ca and Mg concentration of maize leaves, while the K concentration decreased. In general, influences of liming on the nutritional status of wheat leaves were lower in comparison with maize (Figures 2 and 3).

The ameliorative P fertilization significantly increased the yield of maize (Figures 4, 6 and 7) and soybean (Figure 5).

The influence of the application of 1 350 kg P_2O_5/ha and the control on yields and nutritional status of leaves (the ear-leaf of maize at silking as well as the full-developed uppermost 3-leaves of soybean at flowering stage) on Nova Gradiska hydromorphic soil were shown in Figures 4 and 5. Unfortunately, these investigations were interrupted by the war in Croatia. The results of the first year of testing were elaborated by previous studies (Kovačević 1993, Kovačević et al. 1997). By application of 1 350 kg P_2O_5/ha yield increases were significant, for 42 and 21%, for maize and soybean, respectively. P concentrations in leaves have significantly increased up to 43% (maize) and 19% (soybean) in comparison with the control, while the influence of P fertilization on K, Ca and Mg status of the leaves was lower (Figures 4 and 5). Also, the highest P rate considerably influenced the K and Mg status, while the Ca status in the plant was similar in comparison to the control (Kovačević 1993, Kovačević et al. 1997).

In general, Croatia has favourable environmental conditions for seed-maize growing. However, the parents of maize hybrids are mainly less tolerant to different types of environmental stresses, including nutritional unbalances. Šimić (1999) conducted three field experiments with ameliorative rates of P and K fertilization in the Sava lowland area in the spring 1993 and tested responses of seven parents of maize hybrids for three growing seasons (ordinary fertilization of all treatments in the second and third year of testing). These investigations included an ameliorative P fertilization (as MAP) in the rate of 875 kg P_2O_5/ha on a hydromorphic soil near Nova Gradiska. The application of the ameliorative P rate of 875 kg P_2O_5/ha resulted in a grain yield increase of 42%. Also, as affected by applied P application, P concentrations (3-year means) of maize leaves have significantly increased from 0.27 to 0.40% P (Figure 6).

Banaj et al. (2002) conducted a field experiment with different rates of P and K fertilization for three maize hy-

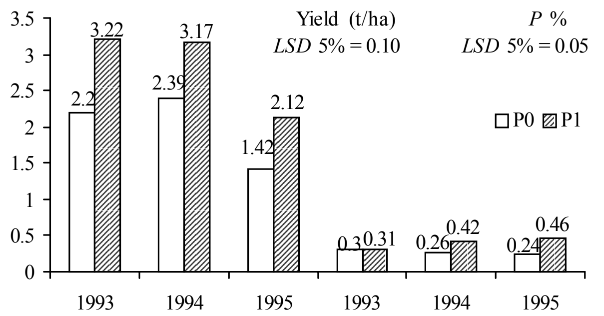

Figure 6. Response of maize to ameliorative P fertililization (P0 = control, P1 = 875 kg P_2O_5/ha in spring 1993): yield (t/ha) and P status (% on dry matter basis) in ear-leaf at silking (the growing seasons 1993, 1994 and 1995) – means of seven parents of maize hybrids

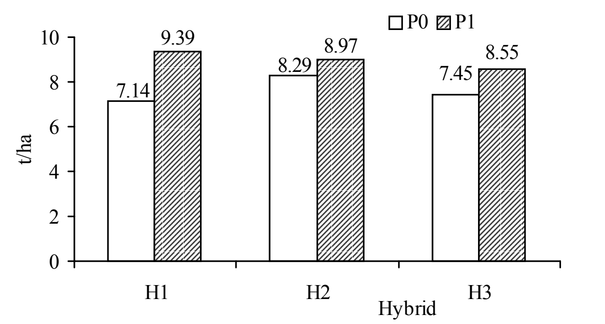

Figure 7. Response of maize hybrids (H1 = OsSK 444, H2 = OsSK 552, H3 = Bc 5982) to ameliorative P fertilization (P0 = control, P1 = 1 500 kg P_2O_5/ha in spring 2001): grain yield (t/ha) for the growing season 2001; *LSD* 5% values = 0.51 (mean) and 0.68 (H1–H3)

brids on a hydromorphic soil near Luzani, in the spring 2001. Influences of the highest P rate (1 500 kg P_2O_5/ha as MAP) on maize yield are shown in Figure 7. In maize the higher P application rate resulted in a yield increase of 18%. Also, the response of individual hybrids to the P fertilization was specific because a yield increase, depending on hybrid, was in the range between 8% (hybrid OsSK552) and 32% (hybrid OsSK444).

CONCLUSION

The low P availability (up to 10 mg P_2O_5 according to the AL-method) is a limiting factor for the yield formation of field crops on some hydromorphic soils in the eastern part of the Sava valley in Croatia. In our investigations we covered the area of 31 227 ha of agricultural soils, which is near 20% of the total agricultural soils in the region. Of the tested soils about 60% are low in available P and have the P demand of 1 000 kg P_2O_5/ha in the soils with the very low P availability and 500 P_2O_5/ha in the soils with the low P availability. It is recommended to apply the ameliorative fertilization step by step, depending on available funds.

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ABSTRAKT

Přijatelný fosfor v hydromorfních půdách východního Chorvatska

V hydromorfních půdách údolí Sávy byl stanoven obsah přijatelného fosforu laktátovou metodou. Ve studii bylo analyzováno 480 půdních vzorků z plochy 31 227 ha. Velmi nízký obsah přijatelného P v profilu 0–30 cm (pod 5 mg P_2O_5/100 g půdy) vykazovalo asi 30 % testované zemědělské půdy (9 440 ha), 32 % (9 897 ha) bylo v rozmezí nízkého obsahu (5,1–10 mg P_2O_5/100 g) a pouze 17 % (5 445 ha) mělo dobrý nebo velmi dobrý (nad 20 mg) obsah přijatelného P. Časté výskyty nízkého obsahu P byly zjištěny v gleji vertickém, pseudogleji glejovém a gleji modálním (celkem 8 680 ha, resp. 28 % testované zemědělské půdy).

Klíčová slova: přijatelný fosfor; půdní analýzy; hydromorfní půdy; východní Chorvatsko; meliorační hnojení; polní pokusy

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