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Phosphorus and Potassium Availability in Hydromorphic Soils of the Sava Valley Area in Croatia

Dragutin PETOSIC[1], Vlado KOVACEVIC[2], Drazen KAUCIC[3]

[1]University of Zagreb, Faculty of Agriculture, Department of Soil Amelioration, Zagreb, Croatia
[2]University J. J. Strossmayer, Faculty of Agriculture, Field Crops Department, Osijek, Croatia
[3]Meteorological and Hydrological Service of Croatia, Zagreb
Corresponding author: E-mail: dpetosic@agr.hr

Abstract: This study covers a part of agricultural land of the eastern Sava Valley area. This is a narrow belt, longitude approximately 150 km and width from 5 to 10 km, extending in the west-east direction. Slobostina and Josava rivers make the border in the west and east, respectively. Unfavourable air-water relationships have always been limiting factors for field crop yields in Croatia. Considerable increases of main arable crop yields were achieved by applying hydroamelioration. However, retardation of maize, soybean and wheat growth and symptoms of phosphorus (P) and potassium (K) deficiency were observed on some soils. A total of 480 soil samples from an area of 31,227 ha were analysed for their P and K status (0-30 cm depth) by the Ammonium-Lactate method. About 30% of samples contained very little P (up to 5 mg P_2O_5 100 g^{-1} soil), 32% was within the range of low P availability (from 5.1 to 10 mg), while only 17% had good or very good P availability (above 20 mg). High frequency of low P availability was found especially in vertic gley, amphygley and hypogley soils (28% of tested agricultural land). Nearly one third of samples were poorly supplied with K (less than 10 mg K_2O/100 g soil, mainly in hypogley soils).The most favourable K status was recorded in semigley alluvial soils: only 7.7% of the area of this soil is moderately supplied with K and as much as 27.5% of the area is in the range of very high K availability (above 25 mg K_2O/100 g of soil).
To optimize P and K fertilization of this area, field experiments with increased rates of fertilizers were conducted. An excess of Mg and a very low K status occurred in maize and soybean plants grown on hypogley under the conditions of conventional fertilization. Ameliorative fertilization with K considerably increased grain yields of maize, depending on the trial close to four-fold, by 60% and by 87%, while soybean yields were increased by up to 55%. Under less favourable conditions in Luzani pseudogley (pH in 1n KCl: 4.82) maize yields were increased by 18% (P effects) and 22% (PK-effects) and decreased by 10% (K-effects), while the differences in yields on less acid Kobas pseudogley (pH in 1n KCl: 5.34) were in the range of statistical error.

Key words: phosphorus availability, potassium availability, AL-method, hydromorphic soils, Croatia

Introduction

Growth retardation at the early growth stage and chlorosis typical of phosphorus (P) deficiency (growth retardation accompanied with violet coloration of leaves and stem) were observed in maize plants grown on some mainly acid soils in the wider part of the Sava Valley, in Croatia and Bosnia. Cold weather and excessive soil moisture are the factors promoting these symptoms. Dry matter yield and P concentration in chlorotic plants were much lower than in normal plants (Petosic et al., 2003). Maize yields were considerably increased by ameliorative P fertilization and liming (Markovic et al., 2008; Komljenovic et al., 2010, 2013, 2015).

Nutritional disorders in maize due to potassium (K) deficiency (growth retardation, edge necrosis and chlorosis of leaves, and inclination to stalk lodging at maturity) were found on some clay soils of the Sava Valley. This is closely related to strong K-fixation (Vukadinovic et al., 1988) and excess of plant available magnesium (Mg) and calcium (Ca) in soil. Acute K deficiency in maize is closely related to K concentrations in dry matter of maize leaves lower than 1.0 % K (Kovacevic and Basic, 1997). In general, maize and soybean are more susceptible to this type of nutritional disorder (Kovacevic and Vukadinovic, 1992; Kovacevic and Grgic, 1995) in comparison with wheat (Kovacevic, 1993) and sugar beet (Kristek et al., 1996).

In this study, a survey is given of the mobile fraction (ammonium lactate or AL- soluble form) P and K status in hydromorphic soils of the Sava Valley, while more detailed results were reported in the original studies (Petosic et al., 2003; Kovacevic et 2005). Based on P and K status, conventional P and K fertilization on some drained soils of the area (Petosic, 1997) is not adequate for normal yields of crops. For this reason, field experiments were performed with the aim to test the effects of increased P and K fertilizer rates on maize, soybean, sugar beet and wheat yields and their nutritional status. Selected results from the original and review papers (Kovacevic and Vukadinovic, 1992; Kovacevic, 1993; Kovacevic et al., 1997, 2002; Banaj et al. 2002; Kovacevic and Banaj, 2004; Petosic and Kovacevic, 2010) are presented in this study.

Materials and Method

This study covered a part of agricultural land of three former state-owned farms in the eastern part of the Sava Valley in Croatia (PPK «Zupanja», Zupanja; AK «Jasinje» Slavonski Brod and PPK «Nova Gradiska», Nova Gradiska). This is a narrow belt, longitude appr. 150 km and width 5 to 10 km, extending in the west-east direction. Slobostina and Josava rivers make the border in the west and east, respectively. The area is delimited by the river Sava in the south and by Psunj, Pozeska gora and Dilj Mountains in the north. Geological and pedological characteristics, climate and main soil types of the area were discussed in a previous study (Petosic et al., 2003).

Sources of soil data are professional studies made for the drainage projects elaborated under the leadership of the Faculty of Agriculture (Departments of Soil Amelioration and Soil Science), University of Zagreb, and Jugoinspekt (Agrocontrol Department) Zagreb, mainly in the period from 1980 to 1990. A total of 480 soil profiles, covering an area of 31227 ha, were analysed. Soil sampling and chemical analysis were carried out in the period before 1990. Plant available P and K were determined by the Ammonium-Lactate method (Egner et al. 1960).

Field experiments of ameliorative P and K fertilization were conducted in four replicates applying the randomized block design; more detailed information on the methods was provided in the original studies (Tables 3 -6). Data of leaf composition (P, K, Ca and Mg concentrations) were interpreted using the criteria reported by Bergmann (1992). Adequate nutrient status of maize leaves at silking is from 0.2 to 0.5% P, 1.5 to 3.0% K and 0.2 to 1.0% Mg or Ca. Potassium is deficient when lower than 1% K, while P, Ca and Mg are deficient in amounts lower than 0.1% in dry matter. Similar values can be used for interpretation of data for fully developed leaves at the early growth stage of maize (Table 4). Ranges from 0.26 to 0.50% P, 1.71 to 2.50 % K, 0.36 to 2.00% Ca and from 0.26 to 1.00% Mg in the uppermost fully-developed trifoliate leaf at the beginning of flowering are adequate for the normal nutritional status of soybeans.

Results and Discussion

About 30% of tested agricultural land is poorly supplied with plant available P (up to 5 mg P_2O_5 100 g^{-1} soil), 32% is in the range of low P availability (from 5.1 to 10.0 5 mg P_2O_5 100 g^{-1} soil), 20% is in moderate range, while only 17% is in the range of good or very good P supply. High frequency of low P availability was found especially in vertic gley, amphygley and hypogley soils, while the most favourable P status was found in semigley alluvial soil (Table 1). Regarding the degree of K availability at the depth of 0-30 cm, almost one third of the tested area is poorly supplied with potassium. Especially high frequency of this range of K availability – close to 50% – was found in hypogley, while the most favourable K status was recorded in semigley alluvial soils (Table 2).

Table 1. Ranges of phosphorus (Petosic et al., 2003) availability

Soil type	Range of AL-available P (mg P_2O_5 100 g^{-1} soil)						Area ha	Percent
	Very low	Low	Moderate	Good		Very good		
	Until 5.0	5.1 -10.0	10.1 -15.0	15.1 -20.0	20.1-25.0	Above 25		
	Soil depth 0-30 cm: percent of individual range							
Amphygley	35.2	32.4	18.4	9.1	3.5	1.4	11724	37.5
Hypogley	28.5	31.5	20.6	10.3	6.6	2.5	9550	30.6
Vertic gley	44.0	22.6	15.5	10.7	1.2	6.0	4160	13.3
Semigley alluvial	5.0	25.0	40.0	12.5	7.5	10.0	2315	7.4
Pseudogley-gley	19.2	46.2	19.2	11.5	0	3.9	2147	6.9
Alluvial soil	17.4	43.5	26.1	8.7	0	4.3	1331	4.3
Total (ha)	9440	9897	6445	3157	1271	1017	31227	
Frequency (%)	30.2	31.7	20.6	10.1	4.1	3.3		100

According to our data, P availability in the soil surface layer is less favourable for field crop requirements compared to K availability. For this reason, more attention should be paid to P in the arable land mineral fertilization strategy for the tested area. Adequate P and K fertilization based on soil test results could contribute to higher yields of the main field crops on hydromorphic soils of the Sava Valley. Based on the experience on chernozem soil of the central part of Hungary, approximately half of P fertilizer and one-fifth of K fertilizer introduced into soil could be detected in the AL-soluble form (Kadar et al., 2000; Kadar, 2000, 2012). According to our data, P availability in the soil surface layer is less favourable for field crop requirements compared to K availability. For this reason, more attention to P should be paid in the arable land mineral fertilization strategy for the studied area. Adequate P and K fertilization based on soil test results could contribute to higher yields of the main field crops on hydromorphic soils of the Sava Valley.

Table 2. Ranges of potassium availability in soils (Kovacevic et al., 2005)

Soil type	Range of AL-available K (mg K_2O 100 g $^{-1}$ soil)						Area ha	Percent
	Very low	Low	Moderate	Good		Very good		
	Until 5.0	5.1 -10.0	10.1 -15.0	15.1 -20.0	20.1-25.0	Above 25		
	Soil depth 0-30 cm: percent of individual range							
Amphygley	8.5	20.4	35.2	26.1	4.2	5.6	11724	37.5
Hypogley	9.1	39.5	24.8	16.3	5.4	4.9	9550	30.6
Vertic gley	3.6	21.4	23.8	25.0	20.2	6.0	4160	13.3
Semigley alluvial	0	7.5	7.5	27.5	30.0	27.5	2315	7.4
Pseudogley-gley	7.7	11.5	53.9	11.5	3.9	11.5	2147	6.9
Alluvial soil	0	26.1	30.5	34.8	4.3	4.3	1331	4.3
Total (ha)	2172	7817	9230	7003	2691	2314	31227	
Frequency (%)	7.0	25.0	29.6	22.4	8.6	7.4		100

Table 3. Response of maize and soybeans to potassium fertilization (in autumn 1986 and spring 1987) on strong K-fixing soil (drained hypogley) of the state-owned farm Vinkovci (Kovacevic and Vukadinovic, 1992)

Fertilization K_2O (KCl form) kg ha^{-1}	Maize (3-year averages 1987-1989)					Soybean (3-year averages 1987-1989)			
	Grain yield t ha^{-1}	Stalk lodging %	Maize leaves Percent in dry matter			Grain Yield t ha^{-1}	Soybean leaves Percent in dry matter		
			K	Mg	Ca		K	Mg	Ca
150	1.93	55	0.60	1.94	1.66	1.29	0.66	1.65	1.57
1000	5.39	14	1.03	1.39	1.71	2.17	1.46	1.19	1.58
2670	7.65	4	1.58	0.95	1.64	2.61	1.89	0.90	1.47
LSD 1%	0.63	7	0.12	0.20	ns	0.42	0.16	0.26	ns
Soil: AL-soluble (mg 100 g $^{-1}$): 8.4 K_2O, 200 Mg and 603 Ca; pH in 1n KCl = 7.3									

Table 4. Response of maize to K fertilization on the state-owned farm Vinkovci soil (drained hypogley) situated close to Ivankovo (Petosic and Kovacevic, 2010)

Fertilization (April 1988)				Grain yield of maize, stalk lodging (SL) at maturity and nutritional status (K, Mg and Ca in the aboveground part of maize at the 6-8 leaf stage)									
				Growing season 1988					Growing season 1989				
	kg ha^{-1}			Yield	SL	Percent in dry matter			Yield	SL	Percent in dry matter		
	N	P_2O_5	K_2O	t ha^{-1}	%	K	Mg	Ca	t ha^{-1}	%	K	Mg	Ca
a	170	130	130	6.71	34	1.25	1.33	0.89	5.49	63	1.46	1.23	0.85
b	170	130	410	8.76	6	1.80	1.12	0.85	6.60	26	1.94	1.02	0.69
c	170	130	530	10.05	5	2.26	0.88	0.92	7.78	18	2.27	0.79	0.58
d	170	130	730	10.97	3	3.35	0.75	0.83	8.52	10	2.67	0.79	0.64
			LSD 5%	1.15	7	0.28	0.21	n.s.	1.02	6	0.21	0.18	0.20
Soil: AL-soluble potassium status: 8.8 mg K_2O 100 g $^{-1}$; pH in 1n KCl = 7.3													

Growing season characteristics, mainly weather conditions, had a considerable effect on field crop yields and effectiveness of fertilizers in soil. In this regard, the amount and distribution of precipitation and temperature regime have recently had more detrimental effects in accord with climate change. In general, fertilization is less effective or without effects under dry year conditions (Rastija et al., 2012; Stojic et al., 2012; Kovacevic et al., 2011, 2013).

Results of field experiments are the source of useful information about the effectiveness of ameliorative P and K fertilization on the yield and nutritional status of plants (Tables 3 – 5).

Table 5. Response of maize and soybeans to ameliorative fertilization with phosphorus and potassium on P and K strong fixing Nova Gradiska (Crnac polje) soil (drained hypogley)

Fertilization in spring 1990 (kg ha^{-1})		Growing season 1990									
		Maize (Kovacevic et al., 1997)					Soybean (Kovacevic, 1993)				
		Yield	Leaves (% in dry matter)				Yield	Leaves (% in dry matter)			
P_2O_5	K_2O	t ha^{-1}	P	K	Ca	Mg	t ha^{-1}	P	K	Ca	Mg
150	150	3.81	0.28	0.70	1.51	1.46	2.13	0.32	1.17	1.80	1.04
150	1350	6.34	0.24	1.70	1.30	0.87	2.81	0.33	2.01	1,.66	0.79
150	2550	7.13	0.25	1.74	1.29	0.73	2.82	0.33	2.37	1.85	0.74
1350	150	5.40	0.40	0.74	1.35	1.30	2.57	0.38	1.52	1.94	0.98
2550	150	5.36	0.48	1.15	1.33	1.06	2.52	0.49	1.80	1.92	0.91
	LSD 5%	0.57	0.02	0.13	0.13	0.22	0.49	0.01	0.13	0.19	0.08
Soil characteristics: AL-soluble (mg 100 g $^{-1}$): 3.85 $P_2O_5$and 12.0 K_2O; pH in 1n KCl = 6.92											

Table 6. Response of maize to phosphorus and potassium fertilization on Luzani and Slav.Kobas pseudogley (Banaj et al. 2002; Kovacevic et al., 2002; Kovacevic and Banaj, 2004)

The experiment	Response of maize to P and K fertilization (growing season 2001)						Average	LSD 5%
	Fertilization (kg ha^{-1}) in spring 2001							
	A	B (P_2O_5)	C (P_2O_5)	D (K_2O)	E (K_2O)	F		
	Control	a + 750	a + 1500	a + 750	a + 1500	C + E		
	Grain yield (t ha^{-1}) of maize (averages of three hybrids)							
Luzani (Lu)	7.63	7.94	8.97	7.28	6.91	9.34	8.01	0.51
Slav. Kobas (SK)	8.85	8.78	8.52	8.41	8.27	8.54	8.56	ns
Soil characteristics: AL-soluble (mg 100 g $^{-1}$): 2.05 P_2O_5 and 9.42 K_2O (Lu), 3.04 P_2O_5 and 12.00 K_2O (SK); pH in 1n KCl = 4.82 (Lu) and 5.34 (SK)								

An excess of Mg and a very low K status occurred in maize and soybean plants under conventional fertilization, while unbalances between K and Mg were alleviated as affected by K fertilization. Further, Ca status in maize and soybean plants was mainly independent of K fertilization (Tables 3, 4 and 5). Ameliorative fertilization with K increased grain yields of maize close to four-fold (Table 3), by 60% (Table 4) and by 87% (Table 5). In general, soybean yields were considerably less increased as affected by K fertilization compared to maize, by 55% (Table 3) and by 32% (Table 5). Further, such fertilization contributed drastically to decreases of stalk lodging incidences in maize (Table 4).

Under the conditions of both pseudogley soils (Table 6), considerably lower levels of AL-soluble phosphorus than potassium were found. Also, Kobas pseudogley is characterized by a less acid soil pH value, which finding could be a possible explanation for the absence of effects of applied fertilization upon maize yields. Under less favourable chemical conditions in Luzani pseudogley, maize yields were affected by fertilization and increased by 18% (P effects) and 22% (PK-effects), and decreased by 10% (K-effects).

Conclusions

About 30% of tested agricultural land of the studied area is very poorly supplied with plant available P, while only 17% is in ranges of good or very good P supply. Especially high frequency of low P availability was found in vertic gley, amphygley and hypogley soils. Almost one third of the studied area is poorly supplied with potassium. Especially high frequency of this range of K availability – close to 50% – was found in hypogley, while the most favourable K status was recorded in semigley alluvial soils. Based on these findings, more attention should be paid to P in the mineral fertilization strategy for arable land of the area. Based on our experience and the results of soil tests, we recommend different rates of ameliorative P and K fertilization of 1000 and 500 kg P_2O_5 and K_2O ha^{-1}, every five years, for very low and low ranges of P and K availability, respectively, while standard fertilization with P and K is recommended for the remaining years. Under strong P and K fixation, band fertilization could be given priority over broadcast application.

Our suggestion for soils of moderate and good supplies is P and K fertilization according to K-removal, and lower rates for soils characterized by very good supplies.

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