

## Nutritional disorders of arable crop growth in eastern Croatia

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### Summary

Nutritional imbalances accompanied with growth retardation of crops at early growth stage were found since the last 40 years on certain arable lands in eastern Croatia. In this regard, phosphorus (P) deficiencies in maize and wheat were found mainly on acid soils of the western part of the region, potassium (K) deficiencies in maize, soybean on the hydromorphic neutral to alkaline calcareous drained gleysols of Sava valley lowland, while zinc (Zn) deficiencies were observed mainly in seed-maize and soybean on neutral calcareous eutric cambisols of the eastern part of the region. Cold and moist spring is factor promoting P deficiency symptoms. As oasis of normal crops existed on same arable land, comparison of plant and soil composition was possible from typical sites. P nutrition disorders were in connection with the lower P and the higher aluminum (Al) and iron (Fe) concentrations in the top of plants and the lower soil pH values. K-deficiency as result of strong K fixation and imbalances with high levels of magnesium (Mg) were the main responsible factors of low maize and soybean yields on some drained gleysols. Chlorosis incidences typical for Zn deficiency in maize and soybean were in close connection with the higher soil pH, the lower quantities of mobile Zn, here and there the higher mobile P in soil, the lower concentrations of Zn and the higher levels of Al and Fe in plants. Overcoming the above mentioned disorders and normalization of yields were achieved using ameliorative fertilization either by K or P fertilizers and in case of Zn by foliar spraying of crops with 0.75% ZnSO<sub>4</sub> solution. Also, alleviations are possible by selection of more tolerant genotypes of field crops to specific types of nutritional disorders. From this aspect, some practical solutions were recommended for maize with reference to K nutritional problems.

**Keywords:** phosphorus, potassium, arable crops, eastern Croatia, nutrient deficiency

### Introduction

Sixteen nutrient elements are essential for the growth and reproduction of plants. The source of carbon (C) and oxygen (O) is air, while water is source of hydrogen (H). About 94 percent or more of dry plant tissue is made up of C, H and O. Remaining thirteen elements, represent less than 6 percent of dry matter: nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn),

boron (B), zinc (Zn), copper (Cu), molybdenum (Mo) and chlorine (Cl). Nutritional imbalances or mineral stress estimated as limiting factors of soil fertility in about 23% world's soils (Blair, 1983) and their existing and intensity depends on soil and climate. Also, some nutritional problems could be caused by deficit or excess one or more nutrients in soil, antagonism in their uptake by plants and other environmental factors (Bergmann, 1992; Mengel and Kirkby, 2001).

Nutritional imbalances were found also on some arable lands in eastern Croatia (Jurić et al., 1986; Kovačević et al., 1988ab, 1991, 2015ab; Žugec et al., 1988; Bertic et al., 1989; Richter et al., 1990; Kovačević and Vukadinović, 1992; Kovačević, 1993; Josipović et al., 1997; Kovačević and Bašić, 1997; Kádár et al., 1998; Kristek et al., 1999, 2000; Lončarić et al., 2006, 2007).

With that regard, P deficiencies in maize and wheat were found mainly on acid soils of the western part of the region, K deficiencies in maize, soybean on the hydromorphic neutral to alkaline calcaric drained gleysols of Sava valley lowland, while Zn deficiencies were observed in seed-maize and soybean on neutral calcaric eutric cambisols of the eastern part of the region. Aim of this study was survey of mineral nutrition problems on arable crops under environmental conditions of eastern Croatia and possible direction for their alleviation and solutions based on our about 40-year long-term experiences.

### **Material and methods**

#### *Description of eastern Croatia area with emphasis on soil and climate characteristics*

Eastern Croatia region covers area 12 452 km<sup>2</sup> or 22.0% of the state territory which is divided in five counties (Vukovar-Sirmium, Osijek-Baranya, Brod-Posavina, Požega-Slavonia and Virovitica-Podravina). It is geomorphologic part of Pannonian plain. The Holocene terrace is the lowest part of Pannonian Croatia, with altitudes ranging from 80 to 120 m. These are mainly valleys around the Danube, Drava and Sava rivers and their tributaries. The Pleistocene terrace is the largest geomorphological whole of the region with 100–200 m altitude. It is made up for various pleistocene sediments of aeolian origin. Loess, viz. calcaric loess, prevails on the Vukovar loess plateau and the foothills of Fruska Gora around Ilok and in Baranja, on which Brod-Dakovo-Donji Miholjac, covered with alibic and gleyic luvisol (Bašić, 2013). Soil and moderate continental climate of this area are mainly favorable for intensive field crops growing although soil fertility decrease from east toward western part of the region (Janeković, 1971). Arable land is

dominant structure of agricultural land with wheat, maize, soybean barley, sunflower and sugar beet as main field crops (Mogaš, 2013).

#### *Nutritional disorders of arable crops in eastern Croatia*

In the last forty years, monitoring of nutritional disorders and many field experiments with application fertilizers were performed on less fertile soils with aim of yield increase of main field crops. Until 1992 these investigations were created in Department of Crop Management, Agricultural Institute Osijek and after this period in Department of Crop Farming, Faculty of Agriculture. The results of these investigations were published in numerous scientific, reviewing and professional studies published in scientific journals and proceedings (about 175: Kovačević, 2018 – bibliography).

### Results and discussion

#### *Phosphorus*

P deficiency is the most important nutritional disorders of arable crops, particularly in the highly weathered acidic soils that contain large quantities of Al and Fe oxides (Bergmann, 1992; Mengel and Kirkby, 2001). About 40% of cultivated soils globally have acidity problem leading to significant decreases in crop production due to toxicities of H, Al and Mn and deficiencies of P, Ca and Mg (von Uexküll and Mutuert, 1995). Growth retardation and chlorosis of maize (*Figure 1–3*) and wheat (*Figure 4–5*) typical for P deficiency (Bergmann, 1992) were found on some acid soils. This type of mineral nutrition disorders in maize was in close connection with the lower concentrations of P and the higher concentrations of Al and Fe (*Table 1*).

Table 1. *Nutritional disorders provoked by P deficiency*

Locality*	Aerial part of maize plants at 6–9 leaves stage (DM = dry matter)				
	DM (g plant <sup>-1</sup> )	Height (cm)	P (% DM)	Al (mg kg <sup>-1</sup> of DM)	Fe
	The chlorotic plants				
A	1.80	24.0	0.25	388	1565
B	2.78	30.3	0.29	3816	3470
	The normal plants				
A	18.43	70.8	0.51	253	400
B	18.83	72.0	0.46	470	410

Source: Petošić et al. (2003); Note: \* A = Valpovo (Osijek-Barannya County in Croatia), B = Nova Topola (Gradiška municipality in the northern Bosnia).

Figure 1. *Impact of ameliorative (Thomas phosphate 1056 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>) and band P fertilization on maize status*



Photo: Ivan Žugec

Figure 2. *Impact of band (200 kg ha<sup>-1</sup> NPK 10:30:20 with sowing) on maize status at early growth stage*



Photo: Ivan Žugec

Figure 3. *Growt-retardet – P-deficiency – and normal maize plants in the experiment*



Photo: Ivan Žugec

Figure 4–6: P-deficiency symptoms in what (up) and status of the same crop at maturity (middle); impact of band-fertilization of the previous crop (maize: June 5, 2009) with NPK 10:30:20 on alfalfa status at beginning of July the next year



Source: Kovačević and Jovic (2015)

Adequate fertilization with P on Feričanci dystric luvisol resulted by average increase of maize yield for 19% on P-deficient acid soils (Table 2) and normalization status of maize crop (Figure 1–3). With that regard, the most effective was combination Thomas phosphate and liming with yield  $9.31 \text{ t ha}^{-1}$  or for 28% higher compared to application of raw phosphates (average yield  $7.28 \text{ t ha}^{-1}$ ).

Table 2. Response of maize to P fertilization

Impact of ameliorative P-fertilization (PF)* on maize yield on Feričanci dystric luvisol					
Fertilization (kg P <sub>2</sub> O <sub>5</sub> per ha)**					
PF	156 (a)	606 (b)	1056 (c)	1506 (d)	Mean
Grain yield (t per ha) of maize					
RP	7.30	7.29	7.25	7.27	7.28
SP	7.14	8.19	8.43	8.37	8.03
TP	7.17	9.30	9.65	10.01	9.03
TPL	8.23	9.34	9.79	9.87	9.31
Mean	7.46	8.53	8.78	8.88	8.41

Source: Kovačević et al. (1992); Note: \* RP (raw phosphate: (30% P<sub>2</sub>O<sub>5</sub>), SP (superphosphate 18% P<sub>2</sub>O<sub>5</sub>), TP (Thomas phosphate), TPL (TP+10 t/ha CaCO<sub>3</sub>); \*\* increasing phosphorus levels to 30 cm of soil depth to 10 (b), 20 (c) and 30 (d) mg P<sub>2</sub>O<sub>5</sub> per 100 g of soil; a=standard fertilization (the control).

By liming with by-product of Osijek Sugar Factory (carbocalk) average grain yields increases on dystric luvisol were up to 95%, 235% and 37%, for maize, wheat and soybean, respectively, while impact of P fertilization was lower (up to 8%, 17% and 15%, respectively (Table 3). However, the more effective was combination liming and P fertilization with yield increases for 124% (maize), 318% (wheat) and 63% (soybean).

#### Potassium

Strong K-fixation and oversupplies of exchangeable Mg are limiting factors of some field crops yield, particularly maize and soybean, on the drained hydromorphic soils of Sava valley lowland (Vukadinović et al., 1988; Richter et al., 1990; Kovačević and Bašić, 1997). With that regard, sugar beet (Kristek et al., 1996) and wheat (Kovačević et al., 1990) were more tolerant to this type of nutritional disorders. Both low K- and P-supplies were found on some hydromorphic soils due to their fixation but K fertilization was more effective than P fertilization in increase yields of maize and soybean (Kovačević, 1993; Kovačević and Grgić, 1995).

K-deficiency and high levels of Mg were main responsible factors of low yields of soybean yields on arable lands of Županja, Vinkovci and Jasinje State Farms (Table 4), while both P- and K-nutrition problems resulted by considerably decreases of maize and soybean yield on arable lands of Nova Gradiška State Farm (Table 5).

By ameliorative KCl- fertilization of drained hypogley of State Farm Vinkovci were increased yields (3-year averages) of maize about 4-fold (7.65 t ha<sup>-1</sup> compared to 1.93 t ha<sup>-1</sup>) and soybean about 2-fold (2.61 t ha<sup>-1</sup>) compared to 1.28 t ha<sup>-1</sup>). These yield increases were in close connection with leaf-K and leaf-Mg status in maize (0.60% K and 1.94% K, 1.58 5 K and 1.01% Mg, for the control and the highest ameliorative treatment, respectively) and soybean (0–66% K and 1.65% Mg, 1.89% K and 0.90%

Mg, respectively). As results of K-fertilization is elimination K-deficiency symptoms and normalization of crops growth (Figure 7–10).

Table 3. Response of field crops to liming and P fertilization on Donji Miholjac dystric luvisol

Impacts of liming in spring 2003 with carbocalk (factor A) and fertilization (factor B) on grain yields (t per ha) and soil pH*					
Maize (2004)					
Lime (t per ha)	Fertilization (kg per ha)			x A	Soil pH
	0	150	300		
	Maize yield (t per ha)				
0	5.0	5.3	6.3	5.5	4.23
10	10.7	10.5	10.6	10.6	5.47
20	10.6	10.4	11.2	10.7	6.17
x B	8.7	8.7	9.4		
Yield: LSD-values					
5%	A: 0.78	B: 0.78	AB: 1.36		
1%	1.08	ns	1.87		
Winter wheat (2005)					
Lime (t per ha)	Fertilization (kg per ha)			x A	Soil pH
	0	150	300		
	Wheat yield (t per ha)				
0	1.7	2.0	2.4	2.0	4.16
10	6.1	6.1	6.9	6.4	5.04
20	6.5	6.6	7.1	6.7	6.00
x B	4.7	4.9	5.5		
Yield: LSD-values					
5%	A: 0.73	B: 0.73	AB: 1.27		
1%	1.01	ns	1.74		
Soybean (2006)					
Lime (t per ha)	Fertilization (kg per ha)			x A	Soil pH
	0	150	300		
	Soybean yield (t per ha)				
0	2.7	2.8	3.5	3.0	4.27
10	3.7	4.0	3.6	3.8	4.97
20	3.8	4.1	4.4	4.1	5.84
x B	3.4	3.6	3.9		
Yield: LSD-values					
5%	A: 0.85	B: ns	AB: 1.47		
1%	ns		ns		

Source: Lončarić et al. (2006, 2007); Note: \* carbocalk: by-product of sugar factory: 344 mg Ca per kg); two steps of P were fertilized every year with constant amount of K (300 kg K<sub>2</sub>O per ha) and N (kg N per ha: 200 and 140, for maize + wheat and soybean, respectively); soil pH in 1n KCl (0–30 cm depth).

Table 4. Soybean and soil performances on K-deficient gleysols

Soybean and soil (0–30 cm depth) status on K-deficient soils of the State Farm (SF), Županja (Ž), Vinkovci (V) and Jasinje (J)						
SF	K-deficient soybean			Soil status		
	Leaf* (% in dry matter)			Yield (t per ha)	pH KCl	K <sub>2</sub> O** (mg per 100 g)
	K	Ca	Mg			
Ž	0.98	1.20	0.73	1.93	6.91	15.9
V	1.05	2.22	2.14	0.78	6.87	12.2
J	0.87	1.30	1.11	1.41	7.20	10.2

Source: Kovačević et al. (1991); Note: \* The uppermost full-developed threfoil leaf before anthesis; \*\* AL-method.

Table 5. Yields of wheat, maize and soybean on K-deficient soils and rest of the State Farm Nova Gradiška

Nova Gradiška State Farm (the 1983–1990 period): the harvested area (ha) and grain yield (t per ha)*											
K- and P-deficient Runice soil complex						The rest soils of Nova Gradiška State Farm					
Wheat		Maize		Soybean		Wheat		Maize		Soybean	
ha	t ha <sup>-1</sup>	ha	t ha <sup>-1</sup>	ha	t ha <sup>-1</sup>	ha	t ha <sup>-1</sup>	ha	t ha <sup>-1</sup>	ha	t ha <sup>-1</sup>
571	5.11	305	4.54	189	2.01	12024	4.68	8247	5.97	7051	2.39
(5)	(109)	(4)	(76)	(3)	(84)	(100)	(100)	(100)	(100)	(100)	(100)

Source: Kovačević (1993); Note: \* in the brackets: index of the harvested area and yields (the rest of the State Farm=100).

Figure 7–10: Response of soybean and maize to KCl fertilization (the data in Table 6)





Also, K fertilization considerably affected on stalk lodging of maize at maturity: average 55% and 4%, for the control and the highest rate of applied K (Table 6). However, responses of maize and soybean on the drained hypogley of State Farm Nova Gradiška to KCl-fertilization were considerably lower because yields were increased for 87% (maize) and 32% (soybean, respectively (Table 7).

Table 6. Response of soybean and maize to K fertilization on Vinkovci State farm

KCl Fertilization (KCl) impacts on grain yield, leaf-K and -Mg (in dry matter) and stalk lodging (SL) at maturity													
(1987)	The 1987 growing season				The 1988 growing season				The 1989 growing season				
K <sub>2</sub> O kg ha <sup>-1</sup>	Yield t ha <sup>-1</sup>	Leaf (%) K	% Mg	% SL	Yield t ha <sup>-1</sup>	Leaf (%) K	% Mg	% SL	Yield t ha <sup>-1</sup>	Leaf (%) K	% Mg	% SL	
Soybean (leaf=the uppermost full-developed threfoil leaf before anthesis)													
150	1.28	0.57	1.60		1.80	0.82	1.18		0.78	0.60	2.16		
1000	2.70	1.90	0.95		2.35	1.74	0.84		1.47	0.75	1.79		
2670	2.55	2.28	0.78		2.74	2.22	0.52		2.53	1.17	1.41		
LSD <sub>5%</sub>	0.27	0.20	0.20		0.45	0.09	0.18		0.24	0.07	0.21		
LSD <sub>1%</sub>	0.36	0.27	0.27		0.60	0.13	0.24		0.32	0.09	0.27		
Maize (leaf=the ear-leaf at silking stage)													
150	1.75	0.64	2.03	42	3.17	0.61	2.06	69	0.87	0.54	1.73	55	
1000	7.76	1.43	1.39	5	5.73	0.91	1.48	23	2.69	0.76	1.29	12	
2670	8.88	1.86	1.33	2	7.54	1.69	0.72	6	6.52	1.20	0.99	4	
LSD <sub>5%</sub>	0.65	0.10	0.16		0.48	0.11	0.18		0.29	0.06	0.13		
LSD <sub>1%</sub>	0.87	0.14	0.21		0.64	0.15	0.24		0.39	0.08	0.17		

Note: Kovačević and Vukadinović (1992b)

Table 7. Response of maize and soybean to KCl fertilization on State Farm Nova Gradiška

Impact of KCl fertilization on maize and soybean performances: Runice trial at Nova Gradiška State Farm										
K <sub>2</sub> O kg ha <sup>-1</sup>	Maize (the hybrid OsSK247)					Soybean (the cultivar Vuka)				
	Yield	Leaf * (% in dry matter)				Yield	Leaf * (% in dry matter)			
	t ha <sup>-1</sup>	K	Mg	Ca	P	t ha <sup>-1</sup>	K	Mg	Ca	P
150	3.81	0.70	1.46	1.51	0.28	2.13	1.17	1.04	1.80	0.32
2550	7.13	1.74	0.73	1.29	0.25	2.82	2.37	0.74	1.85	0.33
LSD <sub>5%</sub>	0.57	0.13	0.22	0.13	0.02		0.13	0.08	0.19	ns

Source: Kovačević (1993), Kovačević and Bašić (1997); Note: \* the ear-leaf of maize at silking stage; the uppermost full-developed threfoil leaf of soybean before anthesis.

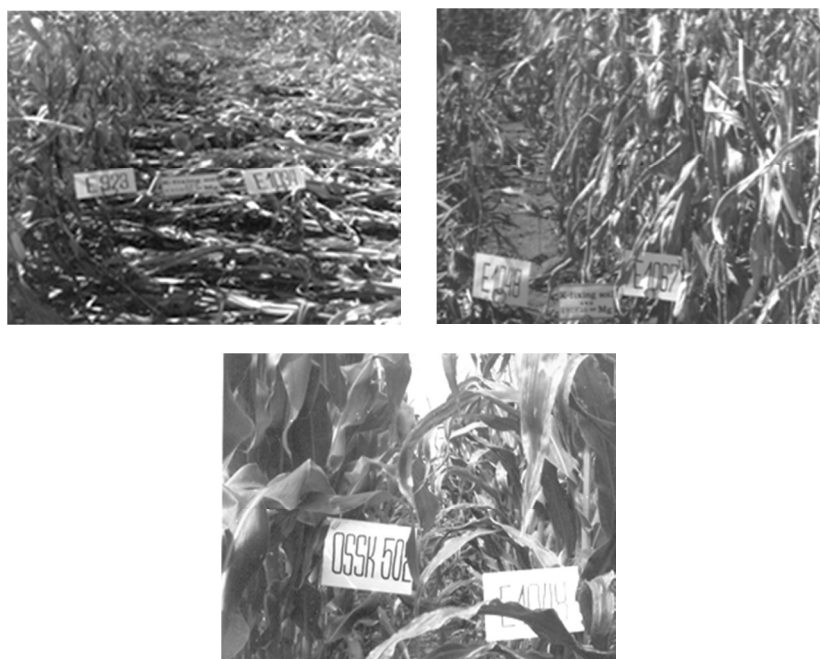
Alleviation of K-nutritional problems and stalk lodging under stress soil conditions is possible by selection of more tolerant maize hybrids. For example, The Os1-48 as male parent transferred lodging tolerance to its hybrids (average 4.9% lodging), while at the other hand, the hybrids of the Os87-24 parent had considerable higher stalk lodging incidences in average 59.1% (Table 8, Figure 11-13).

Table 8. Response of maize hybrids on K-deficient soil of State Farm Vinkovci

K-deficient drained hypogley of State Farm Vinkovci: Impact of male parent on yield and stalk lodging of maize hybrids											
Pedigree* (♀ x ♂)	Yield (t ha <sup>-1</sup> )	L** (%)	Stalk***			Pedigree* (♀ x ♂)	Yield (t ha <sup>-1</sup> )	L** (%)	Stalk***		
			K	Mg	P				K	Mg	P
Corn hybrids of Os1-48 inbred line (the A group)						Corn hybrids of Os87-24 inbred line (the B group)					
Os87-44xA	5.23	8.8	0.30	0.48	0.11	Os87-61xB	2.83	79.0	0.18	0.64	0.18
Os84-15xA	6.30	4.8	0.30	0.55	0.07	Os88-15xB	4.71	83.3	0.21	0.88	0.29
Os84-25xA	5.56	4.1	0.18	0.52	0.14	Os86-92xB	2.90	23.7	0.17	0.74	0.22
Os84-24xA	5.89	4.6	0.17	0.48	0.08	Os87-56xB	3.52	52.1	0.21	0.74	0.21
Os86-39xA	4.45	7.5	0.18	0.71	0.16	Os84-24xB	5.45	95.6	0.18	0.68	0.24
Os89-24xA	7.20	4.1	0.30	0.45	0.07	Os87-57xB	4.28	74.1	0.19	0.68	0.22
BxA	4.83	0.7	0.21	0.52	0.27	AxB	5.40	5.3	0.18	0.69	0.19
Mean A	5.64	4.9	0.24	0.53	0.13	Mean B	4.16	59.1	0.19	0.72	0.22
LSD <sub>5%</sub>	0.53		0.04	0.09	0.03	LSD <sub>5%</sub>	0.53		0.04	0.09	0.03
LSD <sub>1%</sub>	0.72		0.05	0.12	0.04	LSD <sub>1%</sub>	0.72		0.05	0.12	0.04

Source: Kovačević and Vujević (1993); Note: \* ♀ (female parent) x ♂ (male parent); \*\* L=stalk-lodged plants at maturity; \*\*\*composition of three developed the lowest nodes of stalk at maturity (percent in dry matter).

Figure 11–13: Stalk lodged and erected hybrids of parent B and A (Table 8) at maturity (left and right); two hybrids (down) different degree of tolerance to K-deficit in soil (left: normal; right: K-deficiency symptoms)

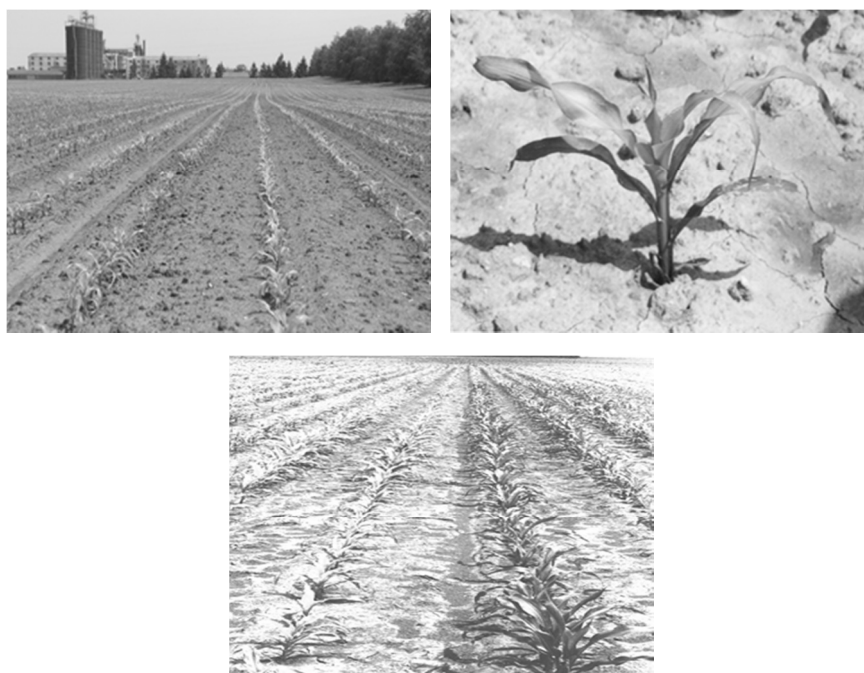


Acute K-deficiency was connected with very low K concentrations in maize and soybean leaves (less than 1.0% K according Bergmann, 1992). Csathó (1998) by the long-term field experiments with K-fertilization in nine localities of Hungary determined 1.50% K in dry matter of leaves in flowering as the lowest border of adequate supply of maize with K.

### Zinc

Growth retardation and chlorosis of maize and soybean crops were observed at the early growth stage on neutral to slightly alkaline calcareous soils. These chlorosis (*Figure 14–16*) are typical symptoms of Zn deficiency (Bergman, 1992; Alloway, 2008).

Figure 14–16. *The seed-maize crop on Lovas Agricultural Cooperative (left and right) and response of the seed-maize on foliar fertilization with 0.75% ZnSO<sub>4</sub> solution (down) (Agricultural Institute Osijek)*



Chlorosis incidences were in close connection with the higher soil pH, the lower quantities of mobile Zn, here and there the higher mobile P in soil, the lower concentrations of Zn and the higher levels of Al and Fe in plants (*Tables 9–12*).

Critical concentration Zn in upper 3<sup>rd</sup> leaf of 6 week-old maizes is 16 mg Zn per kg and in 3<sup>rd</sup> leaf blade of 41 days-old soybean 14 mg Zn per

kg (Srivastava and Gupta, 1996). In our study (Table 10 and Table 12) Zn concentrations in chlorotic maize and soybean were close to critical values.

Table 9. Seed-maize at early growth stage an soil status on Agricultural Institute Osijek eutric cambisol Zn-deficiency symptoms and growth retardation in the chlorotic plants

Maize and soil status (A=chlorotic maize; B=oasis of normal plants on the same plot)														
Aerial part of maize at early growth stage (% in dry matter) (mg kg <sup>-1</sup> in dry matter)								Soil (0–30 cm depth)* (mg 100 g <sup>-1</sup> ) (mg kg <sup>-1</sup> )						
P	K	Ca	Mg	Fe	Mn	Zn	Al	KCl	P <sub>2</sub> O <sub>5</sub>	K	Ca	Fe	Zn	
June 6, 1986: means of 6 samples														
A	0.73	4.82	1.11	0.49	2983	118	28.0	2545	7.38	41.7	32.2	711	11.6	1.84
B	0.74	4.80	0.86	0.40	1380	88	28.0	1565	6.24	34.3	26.7	361	16.7	2.25
June 7, 1990: means of 15 samples														
A	0.33	3.72	1.39	0.57	5139	162	44.0	1990	6.43	37.1	33.2			
B	0.35	4.35	1.19	0.52	2713	130	48.5	1202	5.56	27.5	31.2			

Source: Josipović et al. (1997); Note: \* extraction as follows: ammonium-lactate (pH=3.75; AL-method) for phosphorus; 1n NH<sub>4</sub>-acetate (pH=7.0) for Ca and K, EDTA/CaCO<sub>3</sub> for Fe and Zn.

Table 10. Maize status on six soils of eastern Croatia – symptoms of Zn deficiency in the chlorotic plants

The aerial part of maize at 6–8 leaves stage (A=chlorotic maize; B=oasis of normal plants on the same plot)*											
	PH (cm)	DM (g plant <sup>-1</sup> )	(% in dry matter – DM)				(mg kg <sup>-1</sup> in dry matter – DM)				
			P	K	Ca	Mg	Fe	Mn	Zn	Cu	Al
A	33	4.52	0.72	5.01	0.72	0.56	1266	113	18	20	564
B	69	22.29	0.56	4.30	0.60	0.46	378	62	27	13	249

Source: Kovačević et al. (1997); Note: \* averages of 9 and 13 samples, for A and B, respectively; PH=plant height;

Table 11. Soil properties at the places of normal and growth retarding maize plants on six soils of eastern Croatia

Soil properties (0–30 cm) on the places of the chlorotic (A: symptoms of Zn deficiency) and normal (B) maize growth on the same plot (averages of 12 and 8 samples of six soils in eastern Croatia)												
Soil pH	AL-method (mg 100 g <sup>-1</sup> )		1n NH <sub>4</sub> acetate-extraction (mg 100 kg <sup>-1</sup> of air-dried soil)					EDTA-(NH <sub>4</sub> ) <sub>2</sub> -extraction (mg kg <sup>-1</sup> of air-dried soil)				
	H <sub>2</sub> O	KCl	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Ca	Mg	K	Na	Fe	Mn	Zn	Cu
A	7.76	7.09	24.5	18.2	840	44	13.7	17.7	34.6	16.8	2.4	3.3
B	6.92	6.17	23.6	19.3	608	51	15.0	17.7	35.3	22.6	5.8	3.7

Source: Kovačević et al. (1997)

Table 12. Plant and soil status on Osijek eutric cambisol – symptoms of Zn deficiency in soybean crop

Plant and soil status (A=chlorotic soybean – symptoms of Zn deficiency; B=oasis of normal plants of same crop)*												
	The uppermost full-developed trifoliolate leaf of soybean (% in dry matter) (mg kg <sup>-1</sup> in dry matter)						Soil status (0–30 cm depth) Soil pH (mg 100 g <sup>-1</sup> **					
	P	K	Ca	Mg	Zn	Mn	Fe	Al	H <sub>2</sub> O	KCl	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
A	0.39	2.36	2.51	0.88	16.3	124	547	301	7.47	6.60	62.6	45.3
B	0.37	2.52	1.93	0.68	26.8	86	195	147	6.70	5.90	42.5	54.5

Source: Kovačević et al. (1991); Note: \* averages of three and five samples, for A and B, respectively; \*\* AL-method.

Also, our data are in accordance with general opinion that soils affected by Zn deficiency are high in calcium carbonate, pH and iron and aluminum oxides and low in organic matter and moisture (Marschner, 1993). Using 0.75% ZnSO<sub>4</sub> solution was very effective in elimination of Zn-deficiency symptoms after only five days after application (Figure 16).

Total 16 field trials were conducted in seed-maize crops during three growing seasons (Kovačević et al., 1998). Zn in amount 13 kg Zn per ha as ZnSO<sub>4</sub> and NPK (kg per ha: 80 N+170 P<sub>2</sub>O<sub>5</sub> and 170 K<sub>2</sub>O) was incorporated in soil prior to sowing of seed-maize, while standard fertilization was used as a control. Response of the mother parent to Zn and NPK application depended on numerous factors including weather conditions and soil/plant characteristics (soil type and genetic properties of mother parent of seed-maize). Significant impact of Zn fertilization was found in eight and NPK fertilization in four (Table 13) from 16 performed trials.

Table 13. Response of maize to fertilization\*

	Yield of seed of maize (t ha <sup>-1</sup> ) at 8 experiments							
	e-1	e-2	e-3	e-4	e-5	e-6	e-7	e-8
Cont	4.06	6.13	3.55	4.04	2.02	4.36	6.11	4.10
Zn	4.47	6.73	4.15	4.49	2.69	4.74	6.09	5.06
NPK	4.00	5.40	3.28	4.76	2.73	5.07	6.74	4.71
LSD	0.34	0.51	0.41	0.43	0.41	0.38	0.45	0.51
	Soil pH (1n KCl) at 0–30 cm depth							
	-	-	6.25	4.18	4.24	4.07	4.26	-

Source: Kovačević et al. (1998); \* Cont = control; incorporation in soil before sowing; Zn=13 kg Zn per ha as ZnSO<sub>4</sub>x7H<sub>2</sub>O; NPK=170 P<sub>2</sub>O<sub>5</sub> and 170 K<sub>2</sub>O as NPK 8:26:26; LSD in level 5%.

Rastija (2001) applied 2-year investigations of Zn fertilization under field conditions for five parents of maize hybrids. The foliar application of 0.75% ZnSO<sub>4</sub> solution at early growth stage appeared to be more effective than pre-sowing incorporation 20 kg Zn per ha in ZnSO<sub>4</sub> form, particularly in the second year (1998) of testing. Response of Os373

genotype (the lowest leaf-Zn!) was especially emphasized because of yield increase for 41% what indicate its greater requirements for Zn (Table 14).

Table 14. Response of maize genotypes to Zn

Year	Os	Os	Os	Od	Os
1998	373	87-24	135-88	86-39	1-48
Grain yield of seed-maize parents (t/ha)					
Control	1.98	4.74	4.90	5.09	4.19
Zn-Soil*	2.24	4.28	4.45	5.23	4.31
Zn-Fol.*	2.79	5.61	5.27	5.45	4.78
Leaf Zn of control treatment at silking stage					
Zn (mg kg <sup>-1</sup> )	13.5	21.8	19.9	19.8	26.9

Source: Rastija (2001); Note: \* ZnSO<sub>4</sub>·7H<sub>2</sub>O: Zn-Soil=incorporation in soil 20 kg Zn per ha; Zn-Fol.=foliar at early growth 2x0.75% solution in 10-day interval; LSD<sub>5%</sub>=0.35 (yield) and 2.3 (leaf-Zn).

Zn deficiency in soils has been reported worldwide, particularly in calcareous soils in cereal-growing areas of arid and semiarid regions (Cakmak et al., 1999). Sillanpaa (1990) found that about 50% of the soil samples collected in 25 countries were Zn deficient. Hotz and Brown (2004) estimated that Zn deficiency affects, on average one-third of the world's population, ranging from 4 to 73% in different countries.

Zn deficiency is as widespread as Fe deficiency, which affects half of the world's population (Welch and Graham, 1999; Cakmak et al., 2002).

Turkey is among the countries with the most severe Zn-deficient soils, particularly in Central Anatolia. The effects of Zn deficiency on cereal production in Turkey have received attention only since the early 1990s after findings by soil survey study (Sillanpaa, 1982) that Zn concentrations in Turkish soils were among the very lowest recorded.

Based on these findings, fertilizers enriched with Zn began to apply to soils and as results were drastically increase yields of wheat (Cakmak, 2008).

## Conclusion

In general, soil conditions in eastern Croatia are favorable for intensive field crops growing; particularly in it's the eastern part because eutric cambisols are dominant soil type. However, toward west part of the region less fertile dystric luvisols are prevailing soil type.

Hydromelioration of hydromorphic soils by pipe drainage during 70-ies of the last century grain yields of main field crops were considerable increased. However, retardation of growth, mainly maize and soybean, became serious problem in spite of adequate soil management including

usual fertilization. By soil testing low levels of exchangeable K and oversupplies of Mg were found with correspondingly reflection on plant composition. Under acid soil condition retardation of, mainly maize and wheat crops, were accompanied with low levels P and high levels of Al and Fe. Third type of chlorosis typical for Zn deficiency were found in maize and soybean on calcareous soils. Adequate soil management including fertilization with the ameliorative amounts P and K or foliar application of Zn are directions for overcome these nutritional disorders. Some improvement of crops status and the higher yields is possible by selection of more tolerant cultivars and hybrids, particularly of maize, toward soil stress due to either P, K or Zn deficiencies.

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