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UNFAVOURABLE INFLUENCE OF MOBILE ALUMINIUM ON CEREAL PLANTS

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A b s t r a c t. A significant increase of pH_{KCl} values was noted by the transfer from objects A (the plants fell completely out) to objects C (the plants grew normally). In the places where the arable layer of soil contained over 70 mg Al kg^{-1} the grains showed distinct symptoms of physiological illness, and at the content over 90 mg Al kg^{-1} the plants fell out completely. In spite of distinct differences in the growth and development of plants between several objects (A,B,C), the content of basic macroelements and aluminium in the above-ground parts and roots of plants proved stable. The increase of physiological illness symptoms in the particular grain plants was mostly connected with the occurrence of mobile aluminium. The increaes in Al^{3+} concentration in soil limited the growth and development of plants and, in extreme cases, drying and falling out proceded.

K e y w o r d s: mobile aluminium, cereal plants, chemical composition, soil reaction, soil fertility

INTRODUCTION

Poland is the only country marking itself by a great percentage of acid soils (60 % of arable land, in this number 20 % of soil has pH_{KCl}< 4.5), [2,3]. The acidification of soils increases all the time which is the result of natural conditions, their agricultural usage, and the influence of growing industry and using insufficient amounts of calcium fertilizers.

The research carried out in aquaculture and in soils of various reaction proved that the unfavourable effect of low pH on plants is caused, not so much by high hydrogen ions concentration, but by, so called, secondary effects of acidification among which in mineral soils the high concentration of aluminium ions plays the greatest role [1,4,6-8,13].

In soils with pH_{KCl}<5.0 aluminium is released from weathering minerals and is translocated to the soil solution.

The toxic action of Al^{3+} ions on the plants begins already at an active aluminium content in the range of 20-40 mg kg^{-1} of soil [9]. The content of this element in mineral soils - above 50 - and in organic soils - above 100 mg kg^{-1} of soil is considered critical for some plant species [14].

Aluminium is easily uptaken by plants and it is collected mainly in roots which causes their damaging and growth inhibition [1,6,10,15,16].

Aluminium indeed damages mainly roots, but symptoms of its toxicity occur also in the form of leaves necrosis and the dying of the sprout tops [10]. Leaves and sprout damages may be caused directly by aluminium but, more often, they are indirect. They are similar to those caused by the lack of N, Ca, P and Mg [5,6].

The aim of the research presented here was to determine the conditions of occurring the effects of Al^{3+} presence in soils.

MATERIALS AND METHODS

The recognition of the problem was carried out in the northern area of the middle-east region of Poland where distinct symptoms of secondary effects of strong acidification of soil were visible (Fig. 1).

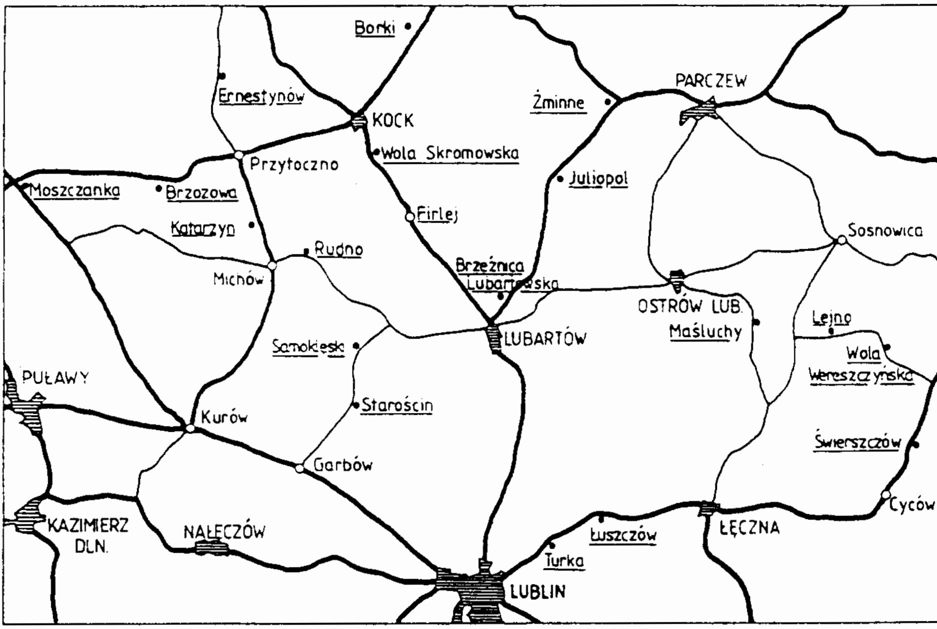

Fig. 1. Research area (• Rudno - sampling sites).

The plantations were divided into the following objects:

A - those where plants completely fell out or they did not achieve the generative phase of development,

B - those where plants showed distinct symptoms of strong soil acidification, they were worse than normal, but they reached the phase of generative development,

C - those where plants grew well, they did not show any symptoms of physiological illness.

Soil samples were taken from the 0-20, 20-40, 40-60 cm layers of these objects. Plant samples of cereals (barley, wheat, rye and oats) were taken in the heading phase (10.5 according to Feekes'scale).

Strict research in glass house was also carried out. In the pot experiment the soil acidification was differentiated through additional acidification of pots from object I and II by adding H_2SO_4 according to 0.4 and 0.2 Hh. The object III had the initial level of acidity, while the objects IV to X were laimed with CaO acording to the following level of hydrolytic acidity respectively: 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, and 1.5. There was 5.5 kg of soil in each pot and the same NPK fertilization was aplied. The test plant was spring barley of the LGR_1 breed and Ars variety.

The following chemical analyses of the soil material were carried out: pH_{KCl}, hydrolytic acidity with Kappen's method, exchangeable acidity and mobile aluminium with Sokolov's method, available phosphorus and potassium with Egner-Riehm method and available magnesium with Schachtschabel's method.

The following elements were determined in the plant material: total N with Kiejdahl's method, potassium and calcium with flame photometry, phosphorus and aluminium - colorimetrically; both in over ground parts and in roots.

RESULTS

A significant increase in pH_{KCl} value from object A to object C in the fields of all four basic cereals was noted, taking into account only the layer of 0-20 cm in which the greatest changes were noted (Table 1). In the

Table 1. The state of soil acidification

Soil under	Object*	Depth (cm)	pH_{KCl}	Hh	He	Mobile Al	Soil under	Object*	Depth (cm)	pH_{KCl}	Hh	He	Mobile Al
				mmol H^+ kg^{-1}		mg kg^{-1}					mmol H^+ kg^{-1}		mg kg^{-1}
Barley	A	0 - 20	3.68	53.8	17.7	139.3	Rye	A	0 - 20	3.93	44.6	12.4	103.3
		20 - 40	4.94	26.0	1.7	7.8			20 - 40	4.15	37.7	10.4	86.9
		40 - 60	5.64	21.4	0.7	4.2			40 - 60	4.49	29.3	5.2	43.6
	B	0 - 20	3.87	48.1	10.9	85.4		B	0 - 20	3.91	46.6	12.4	100.0
		20 - 40	4.99	26.8	2.6	20.2			20 - 40	4.21	37.6	8.3	66.6
		40 - 60	5.65	20.4	0.8	5.5			40 - 60	4.89	26.2	3.2	27.0
	C	0 - 20	4.46	41.6	5.8	42.0		C	0 - 20	4.27	41.7	7.4	57.6
		20 - 40	4.51	25.9	2.0	15.9			20 - 40	4.62	33.2	6.0	69.3
		40 - 60	5.03	27.5	0.8	6.8			40 - 60	4.93	26.1	3.6	28.1
	LSD		-	n.s.	2.9	23.4		LSD		-	n.s.	3.2	27.8
		LSD	-	5.4	2.9	23.4			LSD	-	4.6	3.2	27.8
Wheat	A	0 - 20	3.85	47.6	13.3	101.7	Oats	A	0 - 20	3.74	51.0	14.1	109.0
		20 - 40	4.44	30.5	6.9	57.7			20 - 40	4.36	32.7	9.4	75.8
		40 - 60	4.90	24.0	3.1	25.0			40 - 60	4.61	25.3	4.7	39.4
	B	0 - 20	3.79	47.6	12.7	100.7		B	0 - 20	3.79	47.0	15.0	125.0
		20 - 40	4.36	33.8	6.9	55.8			20 - 40	4.15	36.9	8.0	66.1
		40 - 60	4.90	25.7	5.0	42.7			40 - 60	4.42	25.6	3.2	27.2
	C	0 - 20	4.08	47.6	10.3	84.8		C	0 - 20	4.06	43.0	9.0	65.8
		20 - 40	4.42	37.1	8.2	68.7			20 - 40	4.83	30.2	5.8	45.9
		40 - 60	4.90	30.2	3.5	25.7			40 - 60	4.88	27.2	4.0	33.3
	LSD		-	n.s.	n.s.	n.s.		LSD		-	n.s.	n.s.	n.s.
		LSD	-	5.24	3.0	26.0			LSD	-	6.7	3.2	29.7

*For explanation see Materials and Methods. Hh - hydrolytic acidity; He - exchangeable acidity

Table 2. Content of some elements in four basic cereals (%)

Plant	Object*	Above-ground parts						Roots					
		N	P	K	Ca	Mg	Al	N	P	K	Ca	Mg	Al
Barley	A	4.00	0.54	0.95	0.84	0.08	0.14	2.14	0.29	1.74	0.16	0.08	0.24
	B	4.00	0.60	3.32	0.70	0.09	0.13	1.98	0.25	1.60	0.14	0.07	0.23
	C	4.12	0.86	3.60	0.63	0.10	0.38	2.31	0.37	0.11	0.20	0.08	0.24
Wheat	A	2.32	0.31	2.65	0.38	0.04	0.10	1.61	0.22	1.56	0.11	0.04	0.28
	B	2.34	0.34	2.77	0.30	0.04	0.13	1.34	0.18	1.50	0.13	0.04	0.27
	C	1.69	0.29	2.50	0.29	0.05	0.12	0.81	0.15	1.18	0.10	0.05	0.29
Rye	A	2.36	0.56	2.36	0.29	0.05	0.12	1.69	0.26	1.69	0.13	0.05	0.27
	B	1.96	0.33	2.23	0.26	0.06	0.13	1.07	0.22	1.46	0.11	0.05	0.27
	C	2.11	0.34	2.38	0.28	0.06	0.13	1.04	0.21	1.30	0.07	0.05	0.26
Outs	A	3.91	0.55	3.21	0.67	0.06	0.11	1.92	0.24	1.52	0.12	0.07	0.29
	B	4.06	0.62	3.06	0.65	0.09	0.12	2.05	0.31	1.90	0.15	0.07	0.24
	C	4.29	0.60	3.74	0.79	0.11	0.10	2.31	0.35	2.05	0.19	0.09	0.26

*For explanation see Materials and Methods.

layers of 20-40 and 40-60 cm the hydrogen ion concentration changed a little along with the disappearance of the physiological illness symptoms in the subsequent objects. Hydrolytic acidity significantly decreased along with the depth within each object.

Exchangeable acidity showed the greatest dynamics of the decrease along with the depth. Evidently lower values of exchangeable acidity were noted in objects C in comparison to objects A and B. The exchangeable acidity was mainly influenced by mobile aluminium. Its content influenced to the greatest extent the increase of physiological illness of the subsequent plants. In places where the plough layer of soil contained over 70 mg Al kg^{-1} the cereals showed distinct symptoms of physiological illness, and at the content over 90 mg Al kg^{-1} the plants completely fell out.

In spite of distinct differences in growth and development of plants in the subsequent objects (A,B,C), the basic elements and aluminium content in the above-ground parts and roots showed stable (Table 2). The examination of the cereals mineral composition, differing to a great extent in their growth, practically did not explain the disturbance in their nutrition. The increase in physiological illness symptoms in subsequent plants caused by secondary effects of strong soil acidification was to the greatest extent connected with the presence of mobile aluminium. The increase in the Al^{3+} concentration in soil limited the growth and development of plants and, in extreme cases, the drying and falling out of plants proceeded.

Table 3. The content of available P, K and Mg in soil

Object*	Available forms (mg kg^{-1})		
	P	K	Mg
I	89.71	489.85	19.97
II	90.17	435.89	17.14
III	86.46	370.63	16.95
IV	85.40	303.04	12.97
V	87.96	244.95	16.81
VI	98.46	178.21	61.54
VII	100.48	122.34	50.25
VIII	100.59	157.57	51.90
IX	109.32	180.87	46.51
X	115.10	160.47	47.70
$\bar{x}$	96.36	264.38	34.17
LSD P=0.05	n.s.	160.88	16.91

The differentiation in the content of available K, Mg and P forms was noted between the objects (Table 3), but these components' availability in the examined soils was in medium and high range. The greatest amount of the available potassium form was noted in objects I and II (the addition of H_2SO_4), which might be the result of primary aluminosilicate decomposition and K^+ mobilization:

$$K_2O\,Al_2O_3\,6SiO_3 + 2H^+ + SO_4^{2-} \rightarrow$$

orthoclase

$$H_2O\,Al_2O_3\,6SiO_2 + 2K^+ + SO_4^{2-}$$

six alsifer acid

Table 4 shows the mineral composition of spring barley roots from LGR_1 breed and Ars variety. The roots contained large amounts of phosphorus and aluminium, at the same time P contents were on more or less similar level in all objects for LGR_1 breed and also Ars variety. On the other hand, aluminium content in strongly acid objects was over 1 %, especially in LGR_1 breed.

DISCUSSION

The distinct decrease of mobile aluminium content in soils from the objects C (the lack of the illness symptoms in plants) was the result of higher pH_{KCl}, which lead to the transition of Al^{3+} into $Al(OH)^{2+}$, $Al(OH)_2$ and $Al(OH)_3$, [9,16]. The amount of mobile aluminium in soil above 70 mg Al kg^{-1} caused in cereals distinct symptoms of physiological illness, and over 90 mg Al kg^{-1} the plants completely fell out. It is confirmed by the results of other authors [2,13]. Large amounts of Al^{3+} caused plant chlorosis, also noted earlier by *other authors [4,7,8].*

The content of available P and K in soil was from medium to very high. However, strong soil acidification and its large mobile aluminium content did not allow the proper

Table 4. Content of elements in spring barley roots during earing (in %)

Object*	Total N			P			K			Ca			Mg			Al		
	LGR_1	Ars	$\bar{x}$	LGR_1	Ars	$\bar{x}$	LGR_1	Ars	$\bar{x}$	LGR_1	Ars	$\bar{x}$	LGR_1	Ars	$\bar{x}$	LGR_1	Ars	$\bar{x}$
I	3.00	1.32	2.16	0.20	0.40	0.30	0.72	0.84	0.78	0.14	0.18	0.16	0.08	0.06	0.07	1.01	0.95	0.98
II	2.84	1.99	2.41	0.16	0.43	0.29	1.28	1.44	1.36	0.17	0.19	0.18	0.04	0.03	0.03	1.19	0.26	0.72
III	2.33	2.38	2.35	0.28	0.43	0.35	1.51	1.11	1.31	0.27	0.27	0.27	0.04	0.05	0.04	0.25	0.34	0.29
IV	1.99	2.32	2.15	0.28	0.33	0.30	1.34	1.63	1.48	0.33	0.32	0.32	0.05	0.05	0.05	0.31	0.25	0.28
V	2.06	2.13	2.09	0.31	0.28	0.29	1.63	1.49	1.56	0.54	0.53	0.53	0.06	0.05	0.05	0.33	0.30	0.31
VI	1.43	1.92	1.67	0.30	0.28	0.29	1.23	1.12	1.17	0.31	0.38	0.34	0.14	0.13	0.13	0.30	0.38	0.34
VII	1.53	1.82	1.67	0.28	0.21	0.24	0.98	0.80	0.89	0.40	0.62	0.51	0.10	0.10	0.10	0.25	0.26	0.25
VIII	1.55	1.88	1.71	0.29	0.25	0.27	0.69	0.82	0.75	0.58	0.52	0.55	0.08	0.11	0.11	0.25	0.28	0.26
IX	1.49	1.68	1.58	0.25	0.22	0.23	0.70	0.85	0.77	0.71	0.55	0.63	0.08	0.12	0.12	0.28	0.25	0.26
X	1.59	1.81	1.70	0.25	0.20	0.22	0.89	0.76	0.82	0.95	0.80	0.87	0.09	0.10	0.10	0.31	0.11	0.21

*For explanation see Materials and Methods.

growth and development of plants [2,6,14]. The nutrients (and especially phosphorus) were probably reversed in the plant roots and also in the soil solution by the mobile aluminium, which is in agrement with the conclusions drawn by other researchers [5,7,8,15].

The analysis of mineral composition of plants did not explain in principle, any disturbances in their nutrition. Weak and drying plants showed high content of basic microelements. However, as they produced smaller biomass, which was caused by toxic conditions, so as the components uptake was smaller than in case of healthy and shapely plants[7].

CONCLUSIONS

From the studies carried out the following conclusions can be drawn:

1. Soils from cereal plantations, on which plants showed acute symptoms of illness, contained over 90 mg Al kg^{-1}.

2. The external symptoms of cereal physiological illness on strongly acid soils were the symptoms of Mg, P and K deficiency. The analysis of plant mineral composition did not confirm the dependence between the available forms of macroelements in acid soils and in plants, and it cannot be used at the evaluation of nutrition conditions of plants.

3. It seems that phosphorus and magnesium deficiency symptoms in plants were more the result of the excess of Al^{3+}, than the deficiency of available forms of Mg, P, K, and Ca in soil.

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NIEKORZYSTNY WPŁYW GLINU RUCHOMEGO NA ROŚLINY ZBOŻOWE

Zaobserwowano znaczny wzrost wartości pH przy przejściu od obiektów A (rośliny wypadały całkowicie) do obiektów C (rośliny rosły normalnie). W miejscach w których warstwa orna gleby zawierała powyżej 70 mg Al kg^{-1} zboża wykazywały wyraźne symptomy choroby fizjologicznej, a powyżej 90 mg Al kg^{-1} rośliny wypadały całkowicie. Pomimo wyraźnych różnic we wzroście i rozwoju roślin w poszczególnych obiektach (A,B,C), zawartość podstawowych makroelementów i glinu w częściach nadziemnych i korzeniach roślin, okazała się stabilna. Nasilenie symptomów chorób fizjologicznych na poszczególnych zbożach, miało największy związek z występowaniem glinu ruchomego. Wzrost stężenia Al^{3+} w glebie ograniczał wzrost i rozwój roślin, a w skrajnych przypadkach następowało zasychanie i wypadanie roślin.

S ł o w a k l u c z o w e: glin ruchomy, rośliny zbożowe, skład chemiczny roślin, zasobność gleby, odczyn gleby.