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MONITORING OF BIOGENIC ELEMENT CONCENTRATIONS IN DRAINAGE WATER OF THE PRODUCTION FIELD

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Abstract

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Studies on the monitoring of biogenic element content concentrations in drainage water were carried out on a production field in 2009-2010 belonging to the Experimental and Didactic Station of the Poznan University of Life Sciences, with a branch in Swadzim. During the two years of the research, it was found that the amount of N-NO_3, P, K, Mg, Ca, and the salinity of drainage water from the production field depended on the time when the water was collected for analysis.

Key words: drainage water, concentration of biogenic elements, production field, nitrogen, potassium

Introduction

High chemicalization of agriculture in recent times makes surface runoffs from agricultural areas contain significant quantities of minerals (biogenic elements) that contribute to excessive fertilization, and consequently, eutrophication of water reservoirs. According to Rafałowska and Skwierawski (2009) water out flowing from the areas used for agriculture is enriched with substances the type and amount of which depend on the geological structure of substrate, terrain, soil type and the buffer and sorption capacities. Therefore, the intensification of agricultural production, on the one hand, contributes to a higher crop yielding, on the other hand, it significantly changes the properties of both soil and groundwater quality, leading not only to their pollution (eutrophication), but also, by the migration of nutrients, to surface water quality changes (Rauba, 2009).

The largest source of biogenic ingredients out flowing with drainage water into open water reservoirs is improper (incorrect) use of mineral and organic fertilizers. This results from the fact that minerals unused by cultivated plants pose a potential threat to environment. Applying doses of nitrogen, which exactly correspond to crop requirements, may consequently contribute to a smaller amount of NO_3^- in the soil available for leaching, and affect the quality of environment (Andraski et al., 2000). Hence, it is also very important to match an appropriate dose and keep the fertilizer application deadlines adequately to the nutritional needs of crops. In order to reduce the dosage of fertilizers and the risks of environmental contamination with the excess of unused nutrients, new agronomic solutions are looked for. The effectiveness of nitrogen application depends on forecrops, tillage and water availability (Timsina et al., 2001).

Exploiting the yield-forming potential of a plant depends not only on the amount of nutrients introduced into soil in the form of mineral fertilizers, but also on the physical and chemical conditions affecting their uptake. Each of these nutrients in fertilizers requires a separate designation of optimum dose that can be reduced by increasing its application (Szulc, 2010).

Studies concerning the effects of fertilization on the purity of groundwater and open water have intensified after the introduction of the 1991 Nitrates Directive (Fotyma, 2006). The Directive set an upper limit of nitrate (50 mg NO_3 or 11.3 mg N-NO_3 in 1 dm^3 of water) in water intended for drinking purposes.

Draining areas used for agriculture accelerates the outflow of water and intensifies the leaching of soil constituents, which is particularly evident in the case of light soil drainage (Grochowska and Tandyrak, 2009).

Hence, the subject of the present study was to investigate seasonal changes in concentrations of biogenic elements and

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their mutual relations in drainage waters conditioned by the course of crop vegetation.

Materials and Methods

Experimental Field

Studies on the monitoring of biogenic element content concentrations in drainage water were performed on a production field belonging to the Experimental and Didactic Station of the Poznań University of Life Sciences, with a branch in Swadzim (52°26'N, 16°45'E). Observations were carried out in 2009-2010. The study area of the production field was 18 ha. In 2009, this area was sown with winter barley, while in 2010 – with winter rape.

After harvesting, mineral nitrogen content in the soil was assessed (0-30 cm, 31-60 cm) in accordance with the research procedure/standard of the District Chemical and Agriculture Station in Poznan (OSCHR):

N-NH_4 - PB.50 ed. 6 dated 17.10.2008.

N-NO_3 - PB.50 ed. 6 dated 17.10.2008.

Thermal and humidity conditions

Thermal and humidity conditions are presented graphically (Figures 1 and 2). Total precipitation in 2009 was 634.9 mm, and in 2010 it was higher by 90.8 mm and reached 725.7 mm. Average daily air temperature measured at 2 m during the growing season (IV-X) in 2009 amounted to 15.2°C, while in 2010 it amounted to 14.5°C.

Soil conditions

Physiographical, the research area belongs to the Middle Poland Lowlands, the macro-region of the Greater Poland Lake District and the meso-region of the Poznan Lake District. This is a typical moraine bottom of the North Poland (Baltic) glaciation's, Poznan stadial, built of clay or sand-clay. Typologically, the soil of the experimental field belongs to the black (browned) earth, which, according to the current systematic of the Polish Society of Soil Science (PTG), belongs to the department of semihydrogenic soils of the black earth type. This department groups soils in which groundwater or strong precipitation gleying partly covers the bottom and middle parts of the soil profile. In topsoil, precipitation management dominates, which can be somewhat modified by the deeper parts of the soil profile.

Sampling of drainage water

Water samples for physicochemical analysis were collected once a month from drainage wells. Each time 0.5 dm^3 of water for chemical analysis was taken. Evaluation of an individual nutrient content was made according to the test standards and procedures of the Regional Chemical and Agricultural Station in Poznań (OSCHR):

pH in H_2O - PB. 01 ed. 5 dated 10.17.2008.

N-NO_3 - PB. 02 ed. 6 dated 10.17.2008.

P-PB. 06 ed. 6 dated 10.17.2008.

K - PB. 08 ed. 6 dated 10.17.2008.

Ca - PB. 08 ed. 6 dated 10.17.2008.

Mg - PB. 05 ed. 5 dated 10.17.2008.

Cl - PB. 03 ed. 6 dated 10.17.2008.

Salinity - PB. 04 ed. 6 dated 10.17.2008.

Statistical analysis

A one-way analysis of variance (ANOVA) was carried out to determine the effects of months on the variability of content of N-NO3, K, P, Ca, Mg, Cl as well as pH and salinity. When critical differences were noted, multiple comparisons

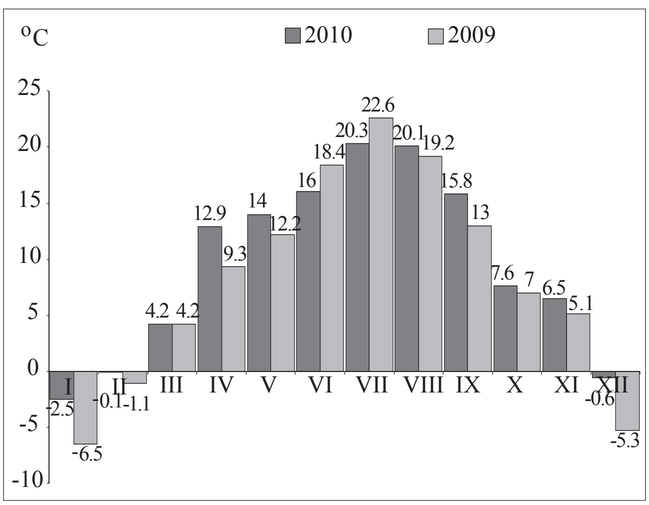

Fig. 1. Average monthly air temperature measured at a height of 2 m

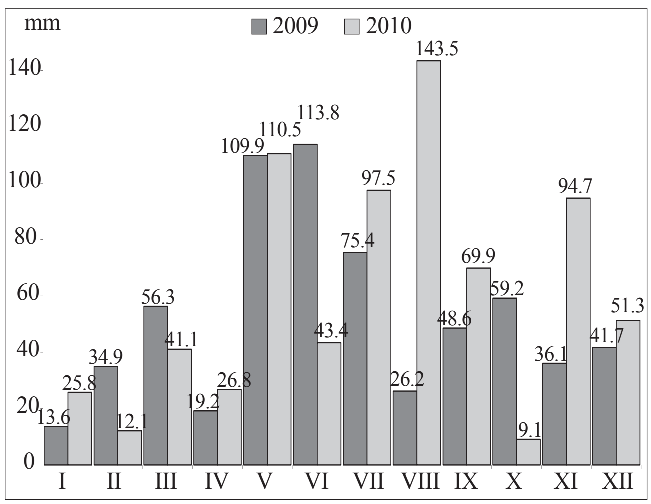

Fig. 2. Monthly total precipitation

were carried out, using Turkey's least significant differences (LSDs) for each trait; based on this, homogeneous groups (not significantly different from each other) were determined for analyzed traits. The one-way analysis of variance was conducted to study the impact of crop species on the formation of mineral nitrogen content in the soil. The relationships between N-NO_3, K, P, Ca, Mg, Cl, pH and salinity were estimated using Pearson correlation coefficients (Sokal and Rohlf, 1995). Data analysis was performed, using the statistical package GenStat Release 10.1 (GenStat, 2007).

Water purity classes

Water purity classes in Poland are defined by the Environment Minister's Regulation of 11 February 2004 on the classification of the present status of surface water and groundwater, the way of monitoring and interpreting results and presenting the status of these waters. The limits of water quality in water purity classes are shown in Table 1.

Results and Discussion

The need for environmental protection necessitates a new approach to the problems of fertilization. Agricultural activity significantly intervenes in the natural nutrient cycling, but in addition to the positive effects of economic production, negative results of nutrient excesses and deficiencies occur, manifested in a measurable way in the change of soil fertility indicators and the chemical composition of groundwater (Šimunić et al., 2002). Hence, a correct mineral management is a key task of a modern agricultural producer. From the point of view of environmental hazard, it is particularly important to control two elements, i.e. nitrogen and phosphorus.

During the two-year period of the research it was found that the amount of N-NO_3, P, K, Ca, Mg and salinity in drainage water on the production field depended on the date of water collection for analysis (Table 2). The content of N-NO_3, K, P and Mg in drainage water was described in equations 1°, and for the content of N-NO_3, K, P it was a directly proportional relationship, while for Mg - inversely proportional (Figure 3). For Ca, Cl, salinity and pH no trend was designed.

Indeed, the greatest mean concentration of N-NO_3 in drainage water was found in September (24.5 mg·dm^{-3}), No-

Table 2
Mean squares from the analysis of variance for studied traits

Source of variation	Month	Residual
Degrees of freedom	11	12
N-NO_3	123.394***	9.833
K	2.977***	0.386
P	0.03496***	0.00292
pH	0.06121	0.04667
Ca	1093.8*	389.3
Mg	31.682**	4.833
salinity	0.1495**	0.0265
Cl	403.9	233

* P<0.05, ** P<0.01, *** P<0.001

Table 1
Water quality limits in water purity classes (Journal of Laws. No 32, pos. 284 of 11 February 2004)

Water quality index	Unit	Limits in classess I-V				
		I	II	III	IV	V
Surface water						
Reaction	pH	6.5-8.5	6.0-8.5	6.0-9.0	5.5-9.0	< 5.5 or > 9.0
Nitrates	mg NO_3·dm^{-3}	5	15	25	50	> 50
Phosphorus	mg P·dm^{-3}	0.2	0.4	0.7	1.0	>1.0
Chlorides	mg Cl·dm^{-3}	100	200	300	400	> 400
Calcium	mg Ca·dm^{-3}	50	100	200	400	> 400
Magnesium	mg Mg·dm^{-3}	25	50	100	200	>200
groundwater						
Reaction	pH		6.5-9.5		< 6.5 or > 9.5	
Nitrates	mg NO_3·dm^{-3}	10	25	50	100	>100
Chlorides	mg Cl·dm^{-3}	25	250	300	500	> 500
Calcium	mg Ca·dm^{-3}	50	100	200	300	> 300
Magnesium	mg Mg·dm^{-3}	30	50	100	150	>150
Potassium	mg K·dm^{-3}	10	10	15	20	> 20

vember (31 mg·dm^{-3}) and December (27.5 mg·dm^{-3}), while the smallest in January and February, respectively: 5.0 mg·dm^{-3} and 6.5 mg·dm^{-3}. It should be noted that only in January and February the content of nitrates in drainage water was below the upper limit of those given in the Nitrates Directive (11.3 mg·dm^{-3}). In August, after harvest of crops and the reduced uptake of nitrogen by other crops, the mineralization of organic nitrogen in the soil increases. Plants fail to keep up with the collection of the total quantity of mineral nitrogen released and the concentration of nitrates in the soil increases (Sapek, 1996). This coincides with excessive rainwater and its seepage into groundwater. Hence, nitrate leaching occurs overwhelmingly in late autumn and winter, when the increased concentration of nitrates in the soil coincides with the renewal of groundwater (Sapek, 1996). Nitrate leaching can be prevented through appropriate agricultural practices. All are designed to minimize nitrate content in the soil in autumn and winter after harvest. A good solution is the cultivation of secondary crops after plants harvested in the period from July to September. Secondary crops intercept residual mineral nitrogen in the soil, resulting in reduced nitrate concentrations in the soil. Therefore, secondary crop cultivation manages the effects of nitrogen soil eutrophication.

In the presented studies, a common method N_{min} was used to evaluate the quantity of mineral nitrogen remaining in the soil after harvest (Müller and Görlitz, 1990 and Szulc, 2010). A statistical analysis of the results obtained indicated that crop species shape mineral nitrogen content in the soil (Table 3). This is suggested by a strongly oriented impact of the crop on shaping the content of N_{min} in the soil after harvest and allows for generalization of the inference for the entire climate and soil district. Winter rape was a plant that more aggravated soil environment with mineral nitrogen (nitrogen eutrophication), compared to winter barley (Table 3). After harvest of winter oilseed rape in the soil profile of 0-60 cm, 143.5 N_{min} kg·ha^{-1} was left, while with wither barley the value of this feature was lower by 24.6 N_{min} kg·ha^{-1} (Table 3). Müller and Görlitz (1990) draw attention to the danger of excessive amounts of mineral nitrogen in the soil after harvest, and indicate that the average content of this form of nitrogen in autumn, in the soil with mechanical composition of loamy sand in the layer of 0-60 cm, is more than 107 kg N_{min}·ha^{-1}. In our study, after harvest of winter barley and winter oilseed rape, the amount of residual mineral nitrogen in the soil profile of 0-60 cm was over 107 kg N_{min}·ha^{-1}. The remaining nitrates move relatively slowly deep into the soil profile. In Polish conditions, the speed of the movement into the soil profile averages from 0.5 to 1 meter annually (Sapek, 1996). Therefore, in a few years, an increase for N-NO_3 in drainage water of the production field in Swadzim should be expected.

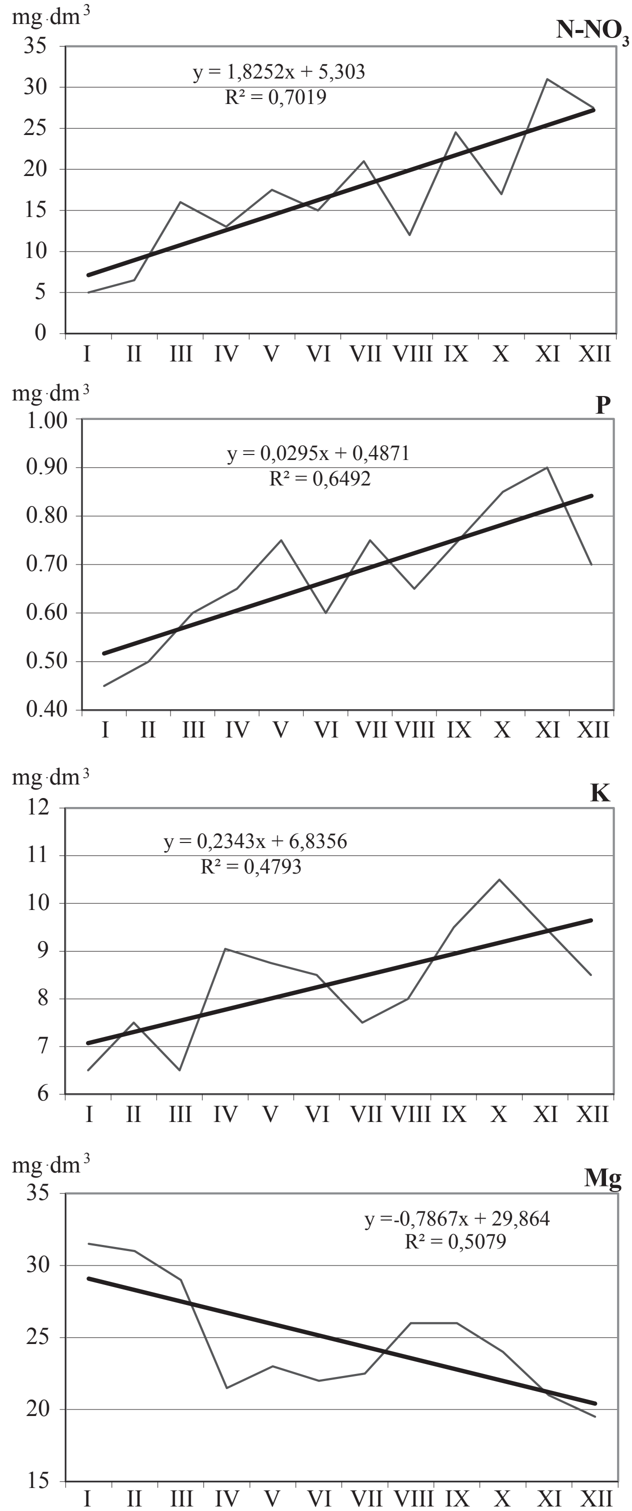

Fig. 3. The content of biogenic elements in drainage water (2009-2010)

In the case of potassium content in drainage water, indeed the highest concentration of this water quality index was recorded in September (9.5 mg·dm^{-3}), October (10.5 mg·dm^{-3}) and November (9.5 mg·dm^{-3}) (Table 4). In turn, the lowest potassium content was recorded in January (6.5 mg·dm^{-3}), February (7.5 mg·dm^{-3}), March (6.5 mg·dm^{-3}) and July (7.5 mg·dm^{-3}). The coefficient of variation for this trait was 15.25% (Table 4).

Phosphorus is one of the components that play an important role in agricultural production and environmental protection. Thus monitoring its content in the soil is important for agro systems. Concentrations of phosphorus (as phosphate) of 35-100 ug P·dm^{-3} are dangerous because of the ongoing process of water eutrophication (Fotyma, 2006). In our studies, phosphorus concentration in drainage water, in each month of the chemical analysis conducted, was below the

Table 3
The content of Nmin in the soil after harvest

Plant species	N_{min} kg·ha^{-1}						
	$N\text{-}NO_3$		$N\text{-}NH_4$		NH_4NO_3		NH_4NO_3
	0-30 cm	31-60 cm	0-30 cm	31-60 cm	0-30 cm	31-60 cm	0-60 cm
Winter barley (2009)	9.9	8.7	53.6	42.7	63.5	51.4	114.9
Winter oilseed rape (2010)	14.8	11.2	61	52.5	75.8	63.7	139.5
$LSD_{0.05}$	2.56	1.78	2.91	4.12	10.99	9.47	15.32

Table 4
Mean values, least significant differences (LSDs) and homogeneous groups for studied traits

Month	$N\text{-}NO_3$	K	P	pH	Ca	Mg	Salinity	Cl
I	5	6.5	0.45	7.05	205	31.5	1.465	92.5
	f	e	f	ab	ab	a	a	ab
II	6.5	7.5	0.5	7.15	195	31	1.455	85.5
	ef	de	e	ab	abc	a	a	abc
III	16	6.5	0.6	7.35	210	29	1.48	78
	cd	e	de	a	a	ab	a	abc
IV	13	9.05	0.65	7.25	160	21.5	1.285	65.5
	de	bc	cd	ab	cd	cd	a	bc
V	17.5	8.75	0.75	7.15	150	23	1.405	63.5
	cd	bcd	bc	ab	d	cd	a	bc
VI	15	8.5	0.6	7	151.5	22	1.295	80
	cd	bcd	de	ab	d	cd	a	abc
VII	21	7.5	0.75	6.85	145	22.5	0.545	64
	bc	de	bc	b	d	cd	b	bc
VIII	12	8	0.65	7.4	187.5	26	1.54	104.5
	de	cd	cd	a	abcd	bc	a	a
IX	24.5	9.5	0.75	7.05	205	26	1.555	70
	ab	ab	bc	ab	ab	bc	a	bc
X	17	10.5	0.85	7.45	175	24	1.455	79.5
	cd	a	ab	a	abcd	cd	a	abc
XI	31	9.5	0.9	7.1	172.5	21	1.425	63.5
	a	ab	a	ab	abcd	d	a	bc
XII	27.5	8.5	0.7	7.2	162.5	19.5	1.53	55.5
	ab	bcd	cd	ab	bcd	d	a	c
$LSD_{0.05}$	6.83	1.35	0.12	0.47	42.99	4.79	0.35	33.26
Coefficient of variation	46.65%	15.25%	19.89%	3.23%	15.26%	16.99%	21.33%	23.60%

top eutrophication rate (Tables 1 and 4). However, in fact the smallest amount of phosphorus was found in drainage water in February (0.5 mg·dm^{-3}), but significantly the biggest in October and November (respectively: 0.85 mg·dm^{-3} and 0.9 mg·dm^{-3}) (Table 4). According to Fotyma (2006), the annual net rainfall of 100 mm (seepage of water through the soil profile) is enough to wash out 0.23 kg P_2O_5 from 1 ha so that the concentration of phosphorus in seepage water reaches 100 ug P·dm^{-3}. In Poland, the content of phosphorus in agriculture is just balanced, and the soil is less rich in this macro-element in comparison with other EU countries. Hence, phosphorus fertilizers should be applied in such a manner and at such times as to reduce the risk of movement of the components contained therein to the surface water (Hooda et al., 1999 and Hughes et al., 2000).

As for magnesium content in drainage water, the highest significant content of the water quality index was recorded in January, February and March (respectively: 31.5 mg·dm^{-3}, 31.0 mg·dm^{-3} and 29.0 mg·dm^{-3}), while the lowest in autumn and winter months (Table 4).

The content of Ca, Cl, pH and salinity did not show significant trends during the research.

In the two years of the research, a statistically significant correlation of N-NO_3 z P, N-NO_3 with Cl, K with P, Ca with Mg was observed (Table 5). Besides, in 2009 salinity was significantly correlated with pH and salinity with Ca (Table 5). Only in the second - 2010 - year of the research: N-NO_3 with Mg, P with Mg, P with Cl, Ca with Cl and Mg with Cl were correlated (Table 5). Considering the two years of the research, 14 statistically significant correlation coefficients out of the 28 tested were observed (Table 6).

Conclusions

- Cultivation of winter oilseed rape compared to winter barley significantly burdens the soil environment with nitrogen eutrophication.
- The course of vegetation determines the concentration of drainage water quality indices (N-NO_3, K, P, Ca, Mg, Cl, pH and salinity).
- In the seasonal system, the largest values of N-NO_3, K, P concentrations were recorded in autumn and winter, while Mg in spring. For other drainage water quality indices, no impact of the plant-growing season on their content was shown.

Table 5
The correlation matrix for the traits studied for 2009 (above diagonal) and 2010 (below diagonal)

Trait	N-NO_3	K	P	pH	Ca	Mg	Salinity	Cl
N-NO_3	1	0.572	0.782**	-0.21	-0.096	-0.53	0.015	-0.579*
K	0.443	1	0.722**	-0.16	-0.095	-0.558	0.037	-0.354
P	0.775**	0.636*	1	-0.3	-0.323	-0.562	-0.075	-0.461
pH	-0.093	0.399	0.305	1	0.423	0.251	0.635*	0.356
Ca	-0.443	-0.342	-0.536	0.11	1	0.726**	0.654*	0.485
Mg	-0.829***	-0.461	-0.777**	-0.1	0.768**	1	0.29	0.575
Salinity	-0.169	0.307	-0.232	0.407	0.503	0.329	1	0.384
Cl	-0.746**	-0.216	-0.600*	0.044	0.621*	0.823**	0.289	1

* P<0.05, ** P<0.01, *** P<0.001.

Table 6
The correlation matrix for the traits studied for both years together

Trait	NNO_3	K	P	pH	Ca	Mg	salinity	Cl
N-NO_3	1							
K	0.468*	1						
P	0.715***	0.674***	1					
pH	-0.215	0.234	0.158	1				
Ca	-0.144	-0.227	-0.430*	0.036	1			
Mg	-0.584**	-0.510*	-0.660***	-0.049	0.747***	1		
salinity	0.02	0.141	-0.182	0.235	0.627**	0.339	1	
Cl	-0.448*	-0.291	-0.485*	-0.065	0.586**	0.652***	0.432*	1

* P<0.05, ** P<0.01, *** P<0.001.

- A number of interesting correlations were observed. Especially between the content of Mg and the remaining features studied. A greater number of statistically significant correlation coefficients were observed in the second year of the study.

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