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CHANGES IN SELECTED CHEMICAL PROPERTIES OF SOIL UNDER MAIZE GROWN IN MONOCULTURE FOR SILAGE AS A RESULT OF APPLICATION OF AFTERCROP, STRAW OR NATURAL FERTILIZERS

Summary

Between 2005 and 2008 in Swadzim, on the fields of the Experimental and Didactic Station Gorzyń, a department of Poznań University of Life Sciences, the two one factor trials have been carried out on two soil complexes: rye and good wheat ones. The purpose of the study was to determine changes of selected chemical properties of soils under the influence of the use of natural fertilizers, straw or winter aftercrop under maize grown for silage in monoculture. It has been shown that the use of natural fertilizers, straw and intercrops of rye with winter vetch did not cause the changes in nitrogen, phosphorus, potassium and magnesium levels measured in spring and autumn in both soil classes. The significant effect of fertilization was obtained only in the carbon content of soil class IVb.
***Key words**: silage maize, monoculture, natural fertilization, rye straw, winter intercrop, soil chemical properties*

ZMIANY WYBRANYCH WŁAŚCIWOŚCI CHEMICZNYCH GLEBY POD KUKURYDZĄ UPRAWIANĄ W MONOKULTURZE NA KISZONKĘ JAKO SKUTEK WPROWADZENIA POPLONU, SŁOMY LUB NAWOZÓW NATURALNYCH

Streszczenie

W latach 2005-2008 w Swadzimiu, na polach Zakładu Doświadczalno-Dydaktycznego Gorzyń, należącego do Uniwersytetu Przyrodniczego w Poznaniu, przeprowadzono dwa jednoczynnikowe doświadczenia na dwóch kompleksach glebowych: żytnim i pszennym dobrym. Celem badań było określenie zmian wybranych właściwości chemicznych gleb pod wpływem stosowania nawozów naturalnych, słomy bądź poplonu ozimego pod kukurydzą uprawianą na kiszonkę w monokulturze. Wykazano, że stosowanie nawozów naturalnych, słomy oraz międzyplonu żyta z wyką ozimą nie przyczyniło się do zmian zawartości azotu, fosforu, potasu i magnezu oznaczanych wiosną i jesienią na obu klasach gleby. Istotny wpływ nawożenia uzyskano jedynie w zawartości węgla w glebie klasy IVb.
***Słowa kluczowe**: kukurydza na kiszonkę, monokultura, nawożenie naturalne, słoma żytnia, międzyplon ozimy, właściwości chemiczne gleb*

1. Introduction

In recent years the monoculture system of cultivation has been very popular in Poland, especially in maize. Introduction of the obligation to provide integrated protection system in the cultivation of agricultural plants (in Poland since 01.01.2014) has limited such use of land. However, the Common Agricultural Policy of the EU in 2014-2020 includes maize into feed crops, whose cultivation does not require mandatory crop rotation. Maize, to a lesser extent than other species, is affected by decrease in crop yields grown in monoculture, but with the use of such a system, crop yields can be reduced to as much as 30% compared to that obtained in normal crop rotation.

As a factor reducing the risk of crop yield decline in monocultures, it is reported increased fertilization including natural and organic forms [30]. The yielding effect of organic/natural fertilizers is slower than mineral fertilizers. Their action resulting from the cumulative increase and stabilization of soil fertility usually appears in later years. Organic and natural fertilizers are an important source of humus in the soil, they are almost an exclusive factor in improving other soil properties such as: structure, water capacity, density, etc. Also they are a source of nutrients and energy for soil microbes and improve water retention in soil.

The content of organic matter mainly determines the productivity of the soil. On light soils, the processes of organic matter mineralization occur at a much faster rate than on heavy soils. Studies on the processes that regulate the carbon cycle in nature is extremely important for agricultural producers, but it also has an economic dimension. In recent times, issues related to greenhouse gas emissions including carbon dioxide have increased to a very high level of importance [8].

The aim of the study was to identify the most beneficial fertilization methods that would limit the degrading impact of silage maize cultivation in monoculture and improve soil chemical properties.

In the research hypothesis, it is assumed that natural fertilization, or introduction of winter aftercrop or straw will contribute to beneficial changes in the soil's chemical properties and that the changes will depend on the soil class and the type of organic matter applied.

2. Materials and methods

The trials were carried out in the years 2005-2008 at the Experimental and Didactic Department of Gorzyń, in Swadzim, belonging to the University of Life Sciences in Poznań on the IVb soil, the good rye complex and in the years 2006-2008 on the class IIIa soil, the good wheat complex on the field 1250m away from the station. At each location single factorial trials were carried out in randomized block designs in four replications with silage maize cultivated in monoculture. The experimental factor was the use of organic matter and fertilization in the following combinations: a) control (130 kg N, 34.9 kg P, 116.2 kg K·ha^{-1}, b) manure (30 t·ha^{-1}) d) straw + Nmin (5 t·ha^{-1} + 5 kg Nmin·ha^{-1} straw), e) straw + slurry (5 t·ha^{-1} + 40m^3), f) winter aftercrop rye with vetch (10-15 t·ha^{-1}), g) slurry (40 m^3). All objects were additionally fertilized with NPK to balance the control object, taking into account the content of the nutrients and their availability in the first year after ploughing. In the spring, before sowing of mineral fertilizers and in autumn, after harvesting it was determine: carbon content of soil - humus by weight method, total nitrogen by the Kjeldahl method, available phosphorus and potassium by the Egner-Richm method, available magnesium by the Schachtschabel method.

3. Results

Annual analyzes of nitrogen content in soil carried out in spring and autumn showed uneven influence of applied fertilization on the content of this element in individual years of experiment (Table 1 and 2). A slightly higher total nitrogen content was found in experimental combinations conducted on class IIIa soil than on class IVb soil. The synthesis from years of spring and autumn studies did not show significant changes in the total nitrogen content of soil between the objects.

Comparing the effect of fertilizers between spring and autumn, it was found that in both experiments, ploughing the half of the manure dose increased N content compared to control by 11.9 mg·100g^{-1}soil in class IIIa, and 1.39 mg·100g^{-1}soil of class IVb. Such growth has also been reported on class IIIa soil, after slurry with straw and in lighter soil class IVb, after application of winter aftercrop. The application of all tested fertilizers, apart from half of the manure dose, tended to increase of total nitrogen content compared to control in spring on soil IIIa. The highest increase in N content compared to control was observed on objects with winter aftercrop 102.8 mg·100g^{-1} soil (increase by 7.9%) and after ploughing straw with mineral N with 102.5 mg·100g^{-1}g (by 6%). In the IVb soil yearly ploughing of the tested organic and natural fertilizers, during the three years' study period, the tendency to increase nitrogen content in the following crops was observed at the following objects: a full dose of manure after ploughing straw with N mineral and straw with slurry (Table 2).

Objects located on better soil were almost twice as high in phosphorus content as in soil of class IVb (Table 3 and Table 4). Comparing the results of spring and autumn analysis, the tendency for uneven soil response to organic fertilization was observed. On a better soil, organic fertilization (except for the full dose of manure) led to an increase in the content of phosphorus, and on the soil of class IVb, similar result was observed after application of 30 dt·ha^{-1} manure, winter aftercrop and slurry. These differences were not confirmed statistically. On the other hand, on the soil of class IVb, in the spring analysis, there was a tendency to decrease phosphorus content compared with the control of after the majority of applied fertilizers, whereas the increase of its content was observed only after half the dose of manure and ploughing of straw with mineral nitrogen. The analysis carried out in the autumn in most cases (except for slurry with slurry and winter aftercrop) showed a tendency to increase the phosphorus content.

Table 1. Dynamics of changes in nitrogen content (mg N_{total}·100 g^{-1}soil) in soil of class IIIa following application of fertilization
Tab. 1. Dynamika zmian zawartości azotu (mg $N_{og.}$· 100 g^{-1}gleby) w glebie klasy IIIa w następstwie stosowanego nawożenia

Object	Years							
	2006		2007		2008		Average	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
Control – NPK	95,1	92,4	105,2	89,6	85,6	92,9	95,3	91,6
Manure 30 t·ha^{-1}	95,1	89,6	113,1	110,3	85,7	89,6	98,0	96,5
Manure 15 t·ha^{-1}	84,0	95,1	104,6	109,8	87,8	104,0	92,1	103,0
Straw + N min	106,4	92,2	113,7	103,5	87,4	95,2	102,5	97,0
Straw + slurry	95,0	100,7	112,6	112,6	85,0	112,6	97,5	108,6
Winter aftercrop	100,7	109,1	119,9	108,0	87,8	86,2	102,8	101,1
Slurry	100,7	95,1	108,1	107,9	86,8	83,3	98,5	95,4
LSD $_{\alpha\ 0,05}$	-						n.s.	n.s.

Source: own study / Źródło: badania własne

Table 2. Dynamics of changes in nitrogen content (mg N_{total}·100 g^{-1}soil) in soil of class IVb following application of fertilization
Tab. 2. Dynamika zmian zawartości azotu (mg N_{og}· 100 g^{-1} gleby) w glebie klasy IVb w następstwie stosowanego nawożenia

Object	Years							
	2005		2006		2007		Average	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
Control – NPK	95,1	92,3	78,3	84,0	87,9	86,8	87,1	87,7
Manure 30 t·ha^{-1}	89,6	96,2	81,1	72,8	94,4	84,0	88,4	84,3
Manure 15 t·ha^{-1}	89,5	92,2	78,3	78,4	89,1	90,1	85,6	86,9
Straw + N min	95,1	95,1	83,9	84,0	99,7	92,9	92,9	90,7
Straw + slurry	89,4	87,6	89,5	90,0	90,0	87,9	89,6	88,5
Winter aftercrop	92,3	89,5	78,4	78,4	88,8	95,8	86,5	87,9
Slurry	100,7	96,5	78,2	78,4	87,8	86,2	88,9	87,0
LSD $_{\alpha\ 0,05}$	-						n.s.	n.s.

Source: own study / Źródło: badania własne

Table 3. Dynamics of changes in phosphorus content (mg $P_2O_5 \cdot 100$ g^{-1} soil) in soil of class IIIa following application of fertilization
Tab. 3. Dynamika zmian zawartość fosforu (mg $P_2O_5 \cdot 100$ g^{-1} gleby) w glebie klasy IIIa w następstwie stosowanego nawożenia

Object	Years							
	2006		2007		2008		Average	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
Control – NPK	12,8	13,3	15,1	14,4	10,9	16,6	12,9	14,8
Manure 30 t·ha^{-1}	13,1	13,6	18,0	15,6	11,9	13,1	14,3	14,1
Manure 15 t·ha^{-1}	12,6	12,9	17,8	14,2	11,3	21,7	13,9	16,3
Straw + N min	13,1	13,3	17,2	14,7	11,1	18,0	13,8	15,3
Straw + slurry	15,3	14,6	17,8	13,9	10,6	23,1	14,6	17,2
Winter aftercrop	13,7	16,0	18,0	14,7	12,1	15,4	14,6	15,4
Slurry	11,8	12,7	17,2	14,1	11,9	14,7	13,6	13,8
LSD $_{\alpha\ 0,05}$	-						n.s.	n.s.

Source: own study / Źródło: badania własne

Table 4. Dynamics of changes in phosphorus content (mg $P_2O_5 \cdot 100$ g^{-1} soil) in soil of class IVb following application of fertilization
Tab. 4. Dynamika zmian zawartość fosforu (mg $P_2O_5 \cdot 100$ g^{-1} gleby) w glebie klasy IVb w następstwie stosowanego nawożenia

Object	Years							
	2005		2006		2007		Average	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
Control – NPK	6,7	7,2	7,4	6,7	10,9	9,4	8,3	7,8
Manure 30 t·ha^{-1}	6,1	5,8	6,2	6,8	10,8	10,7	7,7	7,8
Manure 15 t·ha^{-1}	7,2	7,5	7,4	6,6	13,8	12,4	9,5	8,8
Straw + N min	6,2	7,7	8,0	7,0	13,1	11,1	9,1	8,6
Straw + slurry	6,0	6,9	7,1	5,5	11,6	10,3	8,2	7,6
Winter aftercrop	5,5	5,5	5,2	6,0	4,9	10,1	5,2	7,2
Slurry	7,3	6,9	7,9	13,3	7,5	9,9	7,6	10,0
LSD $_{\alpha\ 0,05}$	-						n.s.	n.s.

Source: own study / Źródło: badania własne

Soil class IIIa, in each of the fertilization objects, was characterized by higher potassium concentration than class IVb (Table 5 and Table 6). Comparing the average potassium content between spring and autumn, on the soil class IIIa, there was a tendency to increase its amount after each fertilization, but not when the full dose of manure and winter aftercrop were applied, and on the IVb soil when full dose of manure and straw with slurry were applied. Comparing the potassium content at the beginning of experiments, on soil IIIa (spring 2006) and at the end (autumn 2008), the increase of this nutrient was observed after each application, except for the full dose of manure and winter aftercrop. The highest increase in potassium content of 5.8 mg·100g^{-1} was observed after the half of the manure was ploughed. In the IVb soil, the comparison of potassium content between spring 2005 and autumn 2007 showed a decrease in this nutrient after the full dose of manure, straw with slurry and slurry respectively 4.3, 2.1 and 7.2 mg $K_2O \cdot 100g^{-1}$ of soil. Application of other fertilizers led to the increase in this content, the largest after ploughing of winter aftercrop by 8.6 mg $K_2O \cdot 100g^{-1}$ of soil.

Higher magnesium content was found in the IVb soil, which was particularly evident during the autumn when all objects showed more than 10.9 Mg mg·100g^{-1} of soil (Table 7 and 8). At the end of the vegetation period, all objects on class IVb soil showed higher magnesium content than in spring.

The amount of carbon in the soil depended on the soil class, the time of the soil sampling for analyses and the method of fertilization (Table 9 and 10). Class IIIa soil, was characterized by higher carbon content than class IVb soil. Evaluation of changes in the content of this element in spring and autumn, on the soil of class IIIa showed a decrease in the content of the control object, and also after application of half of manure and straw with slurry. The highest increase in soil carbon content between spring and autumn, on average 49.7 mg C·100g^{-1} soil, occurred after the annual manure application.

Table 5. Dynamics of changes in phosphorus content (mg $K_2O \cdot 100$ g^{-1} soil) in soil of class IIIa following application of fertilization
Tab. 5. Dynamika zmian zawartości potasu (mg $K_2O \cdot 100$ g^{-1} gleby) w glebie klasy IIIa w następstwie stosowanego nawożenia

Object	Years							
	2006		2007		2008		Average	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
Control – NPK	26,0	17,0	9,5	14,1	13,9	26,1	16,5	19,1
Manure 30 t·ha^{-1}	24,1	16,0	16,6	15,8	10,5	17,3	17,1	16,4
Manure 15 t·ha^{-1}	19,4	14,9	16,7	15,6	14,2	25,2	16,8	18,6
Straw + N min	23,8	16,9	16,2	18,3	17,0	24,5	19,0	19,9
Straw + slurry	26,3	21,6	18,8	17,2	13,7	28,6	19,6	22,4
Winter aftercrop	28,3	20,2	17,1	15,9	14,7	18,2	20,0	18,1
Slurry	17,0	15,2	14,8	10,3	10,8	19,2	14,2	14,9
LSD $_{\alpha\ 0,05}$	-						n.s.	n.s.

Source: own study / Źródło: badania własne

Table 6. Dynamics of changes in phosphorus content (mg $K_2O\cdot 100$ g^{-1} soil) in soil of class IVb following application of fertilization
Tab. 6. Dynamika zmian zawartości potasu (mg $K_2O\cdot 100$ g^{-1} gleby) w glebie klasy IVb w następstwie stosowanego nawożenia

Object	Years							
	2005		2006		2007		Average	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
Control – NPK	9,6	13,7	19,1	18,5	13,2	17,1	14,0	16,4
Manure 30 $t\cdot ha^{-1}$	13,1	16,7	13,7	10,0	13,5	8,8	13,4	11,8
Manure 15 $t\cdot ha^{-1}$	14,0	18,3	16,1	13,1	12,3	14,2	14,1	15,2
Straw + N min	12,4	17,2	16,3	18,3	13,6	16,9	14,1	17,5
Straw + slurry	13,3	15,7	15,4	12,9	15,4	11,2	14,7	13,3
Winter aftercrop	9,0	12,4	10,8	17,9	7,5	17,6	9,1	16,0
Slurry	15,9	13,6	10,8	14,4	8,9	8,7	11,9	12,2
LSD $_{\alpha\ 0,05}$	-						n.s.	n.s.

Source: own study / Źródło: badania własne

Table 7. Dynamics of changes in magnesium content (mg $MgO\cdot 100g^{-1}$ soil) in soil of class IIIa following application of fertilization
Tab. 7. Dynamika zmian zawartości magnezu (mg $MgO\cdot 100g^{-1}$ gleby) w glebie klasy IIIa w następstwie stosowanego nawożenia

Object	Years							
	2006		2007		2008		Average	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
Control – NPK	6,8	7,6	5,5	4,9	3,3	3,2	5,2	5,2
Manure 30 $t\cdot ha^{-1}$	7,2	7,9	5,4	6,5	5,1	5,3	5,9	6,6
Manure 15 $t\cdot ha^{-1}$	6,6	7,8	6,2	4,6	5,8	3,4	6,2	5,3
Straw + N min	6,0	6,9	5,7	5,4	3,6	3,1	5,1	5,1
Straw + slurry	6,7	8,1	5,7	4,1	4,5	3,8	5,6	5,3
Winter aftercrop	6,6	7,5	6,3	5,4	4,0	4,4	5,6	5,8
Slurry	7,2	7,7	5,6	4,5	3,6	4,5	5,5	5,6
LSD $_{\alpha\ 0,05}$	-						n.s.	n.s.

Source: own study / Źródło: badania własne

Table 8. Dynamics of changes in magnesium content (mg $MgO\cdot 100g^{-1}$ soil) in soil of class IVb following application of fertilization
Tab. 8. Dynamika zmian zawartości magnezu (mg $MgO\cdot 100g^{-1}$ gleby) w glebie klasy IVb w następstwie stosowanego nawożenia

Object	Years							
	2005		2006		2007		Average	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
Control – NPK	8,5	7,9	11,5	12,3	9,1	14,2	9,7	11,5
Manure 30 $t\cdot ha^{-1}$	9,1	8,0	11,0	12,8	9,3	14,8	9,8	11,9
Manure 15 $t\cdot ha^{-1}$	8,4	8,3	11,0	12,7	10,2	18,8	9,9	13,3
Straw + N min	8,3	8,4	12,2	12,0	9,6	15,2	10,0	11,9
Straw + slurry	8,8	8,3	11,0	12,0	9,5	14,8	9,8	11,7
Winter aftercrop	8,4	8,1	11,0	10,2	10,0	14,5	9,8	10,9
Slurry	7,7	8,1	10,4	13,6	10,1	14,6	9,4	12,1
LSD $_{\alpha\ 0,05}$	-						n.s.	n.s.

Source: own study / Źródło: badania własne

Table 9. Dynamics of changes in carbon content (mg $C\cdot 100g$-1 soil) in soil of class IIIa following application of fertilization
Tab. 9. Dynamika zmian zawartości węgla (mg $C\cdot 100$ g^{-1} gleby) w glebie klasy IIIa w następstwie stosowanego nawożenia

Object	Years							
	2006		2007		2008		Average	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
Control – NPK	1005,3	1015,5	990,0	976,0	910,7	928,1	973,2	968,7
Manure 30 $t\cdot ha^{-1}$	1009,7	924,8	1025,0	1008,0	980,3	1020,8	984,6	1005,0
Manure 15 $t\cdot ha^{-1}$	910,0	988,3	1006,0	1000,0	968,7	1102,1	1030,1	961,6
Straw + N min	1105,0	1015,5	987,0	990,0	962,9	928,1	977,9	1018,3
Straw + slurry	1105,0	1051,7	1070,0	1070,0	1026,7	1160,1	1093,9	1067,2
Winter aftercrop	1148,0	1078,9	1047,0	1030,0	991,9	1015,1	1041,3	1062,3
Slurry	1157,2	979,2	1022,0	987,0	968,7	1032,5	999,6	1049,3
LSD $_{\alpha\ 0,05}$	-						n.s.	n.s.

Source: own study / Źródło: badania własne

Comparing the content of carbon in the soil of Class IIIa at the beginning of the experiments (spring 2006) and after their completion (autumn 2008), the increase in this content occurred after the ploughing of half and full dose of manure and straw with slurry. On the other hand, the decrease in the content of this component occurred on the control object, after the ploughing of straw with mineral N, winter aftercrop and slurry. On class IVb soil, the carbon content of all objects except for the ½ dose of manure increased between spring 2005 and autumn 2007 when the study was completed.

Table 10. Dynamics of changes in carbon content (mg C·100g^{-1} soil) in soil of class IVb following application of fertilization
Tab. 10. Dynamika zmian zawartość węgla (mg C·100 g^{-1} gleby) w glebie klasy IVb w następstwie stosowanego nawożenia

Object	Years							
	2005		2006		2007		Average	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
Control – NPK	874,0	923,0	884,4	864,5	895,0	930,0	884,5	905,8
Manure 30 t·ha^{-1}	904,0	943,0	979,7	861,3	990,0	960,0	957,9	921,4
Manure 15 t·ha^{-1}	964,0	964,0	935,3	811,5	940,0	945,0	946,4	906,8
Straw + N min	895,0	908,0	895,4	852,3	903,0	936,0	897,8	898,8
Straw + slurry	931,0	958,0	988,6	947,5	1000,0	967,0	973,2	957,5
Winter aftercrop	968,0	986,0	990,8	897,6	1010,0	990,0	989,6	957,9
Slurry	894,0	976,0	894,6	870,4	880,0	950,0	889,5	932,1
LSD $_{\alpha\ 0,05}$							40,39	43,3

Source: own study / Źródło: badania własne

4. Discussion

Maize, due to high yields of dry matter, has a high demand for nutrient content in the soil. Their availability also affects the feed and consumption value of the harvested crop [23]. Sorting macronutrients according to the importance and amount of untaken by the plant, number one is potassium, then nitrogen, and the least phosphorus. It is extremely important that the listed nutrients are easily and quickly available, as under Liebieg's law, the intake of nutrients is limited by the one which is in the least amount in the soil. The dynamics of individual nutrient uptake by maize depends on the development phase of the plant and there are critical periods for each nutrient. Deficit of minerals in a particular development phase always leads to irreversible yield reductions. Even after a shortage of a particular nutrient, it becomes available to the plant at a later stage of development, but the reduction effect can no longer be reversed [7]. The fertility of the soils in nitrogen depends on the biological activity of the soil, temperature, humidity, as well as the system of cultivation and fertilization. The organic substance, on the one hand, is the main source of nitrogen in the soil, and on the other hand it protects against the loss of this nutrient and activates it only as a result of microbial transformations. Nitrogen in the soil occurs mainly in the form of organic compounds with different susceptibility to mineralization and only after this process becomes available to plants after passing to the available forms of $N\text{-}NH_4$ and $N\text{-}NO_3$. The highest demand of maize for nitrogen appears in the period from a few days before flowering to the middle of the kernel filling phase [6]. Over the 3-year study period, natural and organic fertilizers applied in our own experiments led to insignificant changes in the nitrogen content of the soils. This reaction depended on the soil class, the type of fertilizer, and the date on which the samplings were done. Comparison of the spring in the first and last year of the study carried out on the soil of class IIIa has led to a tendency to decrease nitrogen content following the application of all fertilizers, except half of the manure dose. A similar trend has also been observed in soil class IVb after application of half of manure, after winter aftercrop, and especially slurry. The opposite results indicating a significant increase in nitrogen content in soils intensively fertilized with manure, are reported by Mazur [17], who points out high yields after application of slurry, which was characterized by a high availability of nutrients.

This author has shown that manure, rather than slurry, promotes adequate supply of plants to the necessary nutrients under optimum conditions of their availability to the plants, however, the losses estimated from the leaching of the nutrients are higher for manure than for slurry. Mercik et al. [19] as the main reason of nitrogen losses from manure indicated the leaching into deep soil profile especially $N\text{-}NO_3$. Lipski [12] indicated that the slow initial growth of maize up to the 8-leaf phase and the autumn-winter period after its harvest may cause an intensive mineralization, denitrification and leaching processes that lead to significant nitrogen losses from the soil, modifying the fertility of the soils.

All of the applied fertilizer types, apart from the application of half manure, on soil IIIa in 2006 and 2007 and slurry with straw in 2006 and 2008 increased the availability of this plant nutrient. The strongest increase compared to the control of 7.8% occurred in the case of ploughing of winter aftercrop and straw with mineral nitrogen. After application of organic matter in the tested fertilization combinations on soil IVb, the availability of N in the spring was often lower than in the control and none of the fertilizers tested differed in this regard. Sienkiewicz et al. [24] showed an enriching effect of manure fertilization on nitrogen availability. Ploughing of winter aftercrop grasses in own study conducted on class IVb soil, as well as half of the manure dose, led to decrease in soil fertility compared to controls.

Koper et al. [5] reported about different concentrations of phosphorus in the soil depending on the type of site and fertilization. They have shown that better soil is characterized by higher phosphorus content, which is confirmed by the results of own research. The amount of phosphorus in the soil of class IIIa, determined during the tests, exceeded twice the value of the lighter soil of class IVb. Machul [13] has shown that brown soil is much less likely to undergo phosphorous changes than lighter soil, where, at the end of a multiyear study period, the author noted a decrease in the amount of this nutrient. Evaluation of the effect of fertilization on the dynamics of changes in the content of this element between spring and autumn in own research showed that in soil IIIa the application of organic matter with the exception of manure at full dose tended to increase its content, whereas in the lighter soil class IVb such a trend was noted only on objects fertilized with full manure, slurry and winter aftercrop. The low impact of phosphorus fertilization on the soil at lighter soils is confirmed by previous reports by Kalembasa et al. [4]. Szymańska et al. [27] demonstrate that the use of high doses of manure in the absence of mineral fertilization leads to an increase in the fertility of soils in available phosphorus.

Rabikowska and Piszcz [22] mentioned maize as a plant with very high nutritional and fertilizer requirements for potassium. In addition, the authors have demonstrated a high correlation between the level of nitrogen fertilization and the amount of potassium taken up by the plants. This is confirmed by Machul [13], who noted potassium deficiency as a consequence of maize cultivation in monoculture, especially for silage.

Own studies have shown varying levels of potassium in the soil depending on the date of sampling, the type of soil and the type of fertilization applied. The soil of the IIIa wheat complex had higher content of this macronutrient than class IVb. Maćkowiak [15] indicated a limited increase in potassium in the soil following slurry application, but points out that doubling of its dose leads to an increase in the amount of potassium in the soil. In turn, Kalembasa et al. indicated the positive effect on soil fertility by application of manure and slurry [4]. Grzebisz et al. [3] explain the high physiological efficiency of potassium and nitrogen from slurry mainly by the dynamics of maize nutritional needs and the release of nutrients from the slurry. In both series of spring experiments, the strongest growth tendencies were recorded following the ploughing of straw with slurry, and this involved the cumulative effect of both fertilizers. Cereal straw contains considerable amount of potassium, which supplemented by slurry favors the accumulation of it in the soil. Regardless of the date of sampling and the year, one of the lowest potassium contents was recorded on all objects applied with slurry. Probably it was related to the leaching of the component down in the soil profile during the autumn and winter. On the contrary, Maćkowiak [14], Strączyńska [25] indicated an increase in soil potassium content following the application of slurry, and Strączyńska [25] did not notice the difference in the content of this element in the soil due to different doses of slurry. The author claimed that despite the application of potassium to the soil its amount stabilizes to a certain level. This is due to the increased potassium uptake by the plants, as well as leaching it into the soil profile, which is also confirmed by Mazur and Sądej [18], who estimated twice the increase in potassium leaching on slurry-treated objects compared with the control. Lepiarczyk and Szylak [11] have shown a tendency to significant increase in potassium available forms in the soil as well as phosphorus, total nitrogen and organic carbon following manure fertilization, used together with mineral fertilization.

Fertilization of corn with magnesium promotes yield growth of up to 9-13%, as well as increases the concentration of this component in fresh weight of plants and chlorophyll while decreasing the content of calcium Ca^{2+} ions [31]. The amount of magnesium applied to the soil with post-harvest residues after harvesting 1 ha of maize is 5.7 kg MgO, which is close to that of the half manure dose [9, 10].

In our own experiments, the variable content of magnesium was observed, depending on the type of soil, the timing of sampling and the type of fertilization used. More rich in the this element turned out to be soil IVb class. At this soil, there is a clear tendency for higher magnesium accumulation in autumn compared to spring. A similar trend was observed in soil IIIa after full application of manure, winter aftercrop and slurry. These increases, however, were incomparably lower than for the lighter soil. Kalembasa et al. [4] have shown that manure is a good source of magnesium in the soil, and that it has been found to increase its activity especially on objects located on the weaker soil. Mazur and Sądej [18] observed only slightly more magnesium cations in soil fertilized with slurry, whereas manure fertilization contributed to the increase of this component by up to 100%. Strączyńska [25] and Potarzycki [21] obtained the opposite results for slurry.

Wiater and Kozer [30] show that fertilization based only on mineral fertilizers is insufficient to maintain the soil in adequate fertility. The decomposition of organic matter in the soil is the whole transformation associated with its mineralization and humification. These processes are mainly caused by organisms that feed on the remains of plants and animals leading to their complete mineralization [8]. Thomsen and Christensen [28] in the study of maize monoculture, pointed out that the post-harvest residues left after maize for grain and silage are rich sources of nutrients and humus in the soil. Kubiak [10], and Diatta et al. [1] reported about the complexity of the processes of soil metabolism and the modifying factors, indicating type of organic matter and type of soil, as the most important in this regard.

After harvesting maize for silage, 27.3 $dt \cdot ha^{-1}$ dry matter of crop residues is applied in the form of plant residues and roots, and 88.0 $dt \cdot ha^{-1}$ in case of harvest for grain [10]. The dynamics of organic carbon metabolism in the soil is not determined only by the influence of individual plants or by the introduction of organic matter, but largely depends on the location and climate conditions responsible for the activity of microflora [11].

The soil of the rye complex had lower content of humus compounds than that of class IIIa soil. Regardless of the soil class, both in the spring and after the end of the maize vegetation, each type of organic matter introduced contributed to the increase in carbon content compared to the control. Gonet and Wagner [2] have shown that growing crops in a monoculture leads to decrease of carbon content. Authors showed an increase in carbon and nitrogen content as a result of manure fertilization, especially when this application was repeated annually, with the reaction on lighter soils being stronger. Gonet and Wagner [2] have shown that growing crops in a monoculture leads to decrease a carbon content. Authors showed an increase in carbon and nitrogen content as a result of manure fertilization, especially when this application was repeated annually, with the reaction on lighter soils being stronger. Gonet and Wagner [2] have confirmed that organic fertilization contributes to the increase in humus compounds, but the permanent application of manure does not lead to a continuous increase in humus content, similarly as the lack of fertilization does not lead to total decrease in soil fertility. They claimed that each type of soil has its own unique, minimal and maximum carbon content. The formation of soil humus under the influence of organic fertilizers and crop residues depends primarily on the dose, frequency of application and the species of plant grown. Suwara et al. [26] in their work showed a close relationship between the carbon content of the arable layer and the sampling period. Their results show that in the spring and summer there is a loss of this element, but after harvesting the crop and during the degradation of crop residues it is noted its increase. The weather conditions, however, have the greatest effect on the carbon content of the soil. The course of the weather mainly modifies the intensity of the processes occurring in the soil, directly influencing the amount of this element. There was an increase in carbon content in the spring in each soil as compared to control. On soil IIIa, the strongest stimulating trend was observed on objects that were systematically fertilized with slurry, while on soil IVb, all types of fertilizer combinations tested resulted in significant increase in carbon content, the strongest after ploughing of winter aftercrop. Maćkowiak [14] points to a very beneficial relation of fertilization of straw with slurry, which contributes to limit the leaching of nutrients from slurry. Mazur [16] calculated the humification coefficients of organic carbon, which is 36.2% for manure, 29.3% for slurry, 20% for straw, and 65% for green manure respectively. Mercik et al. [20] achieved an increase in C content by 0.71% points on average in locations fertilized with manure on which bean plants were grown. In turn, Wiater [29] showed an increase in humus content in the soil by 14.6% to 19.6% in cereal monocultures following the manure plough. Author noted a slightly lesser effect as a result of introducing into the soil a straw containing nitrogen, which reached 8-13%.

5. Conclusion

The dynamics of nitrogen, phosphorus, potassium and magnesium content changes analyzed in spring and autumn in both soil classes was not significantly differentiated by the combinations of fertilization applied. However, their influence was only obtained in the content of carbon in the soil of class IVb. Application of all organic matter caused an increase in the carbon content analyzed in spring time with the greatest increase after ploughing of winter aftercrop. In the autumn, similar high carbon increase was also determined after application of straw with slurry.

6. References

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