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SOIL CONCENTRATION OF C AND N SHAPED BY LONG-TERM UNIDIRECTIONAL FERTILIZATION VERSUS NOXIOUS SOIL MACROFAUNA

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Abstract

Unidirectional fertilization, if applied for many years, has a strong and sometimes negative effect on soil and natural environment. Such fertilization can cause unfavourable processes including humus degradation, the leaching of nutrients (mainly nitrogen), soil erosion as well as accumulation of weed seeds, pathogens and plant pests. In the last ten years threats caused to agricultural habitats by noxious soil macrofauna, particularly polyphagous insects representing *Agrotinae, Elateridae*, *Scarabaeidae* and *Tipilidae*, have become more explicit. Long-term unidirectional organic or mineral fertilization applied in a long-term static experiment established in 1972 on grey-brown pozdolic soil caused elevated concentrations of organic carbon and total nitrogen in soil. The highest increase was observed when farmyard manure had been used. Unidirectional application of organic fertilizers in rates balanced for the amount of nitrogen added to soil (rate I of liquid manure and FYM), when carried out for many years, caused a significant increase in the density of soil macrofauna. Fertilization with liquid manure balanced with FYM in terms of organic carbon added to soil as well as with mineral fertilizers did not favour presence of macrofauna.

Key words: fertilization, soil macrofauna, polyphages, *Agrotinae*, *Elateridae, Scarabaeidae, Tipulidae.*

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ZAWARTOŚĆ C ORAZ N W GLEBIE UKSZTAŁTOWANA JEDNOSTRONNYM WIELOLETNIM NAWOŻENIEM A SZKODLIWA MAKROFAUNA GLEBOWA

Abstrakt

Jednostronne nawożenie stosowane przez wiele lat ma znaczący, nie zawsze pozytywny, wpływ na środowisko glebowe, a także przyrodnicze. W wyniku takiego systemu nawożenia mogą zachodzić w glebie procesy polegające na degradacji próchnicy, wymywaniu składników pokarmowych, głównie azotu, erozji oraz nagromadzaniu się nasion chwastów, patogenów i szkodników. W ostatnim dziesięcioleciu szczególnie uwidoczniły się w agrocenozach zagrożenia ze strony szkodliwej makrofauny glebowej, zwłaszcza polifagów reprezentujących *Agrotinae*, *Elateridae, Scarabaeidae* i *Tipulidae.* Wieloletnie jednostronne nawożenie organiczne i mineralne stosowane w doświadczeniu statycznym założonym w 1972 r. na glebie płowej spowodowało wzrost zawartości węgla organicznego i azotu ogólnego w glebie, najwyższy w przypadku stosowania obornika. Stwierdzono istotny dodatni wpływ zawartości węgla organicznego oraz dodatni wpływ azotu ogółem na zagęszczenie potencjalnie szkodliwej makrofauny glebowej.

Słowa kluczowe: nawożenie, makrofauna glebowa, polifagi, *Agrotinae*, *Elateridae, Scarabaeidae, Tipulidae.*

INTRODUCTION

At present there are two types of farms that dominate in Polish agriculture. One group consists of plant production farms, where mainly mineral fertilization is applied. The other group of farms is engaged in animal production and uses high organic fertilization in the form of natural fertilizers (liquid manure, farmyard manure).

Unidirectional fertilization, if carried out for many years, has a strong and sometimes negative effect on soil and natural environment. Such fertilization can cause unfavourable processes including humus degradation, the leaching of nutrients (mainly nitrogen), soil erosion as well as accumulation of weed seeds, pathogens and plant pests.

In the last ten years threats caused to agricultural habitats by noxious soil macrofauna, particularly polyphagous insects representing *Agrotinae, Elateridae*, *Scarabaeidae* and *Tipilidae* (Mrówczyński, Sobkowiak 1999, Walczak, Jakubowska 2001, Kowalska, Wierzbowski 2002, Sądej et al. 2003, Trepashko, Puranok 2006) have become more explicit. Species which belong to *Elateridae* and *Scarabaeidae* are especially dangerous due to their numerous occurrence compounded by the fact that their larvae forage on plants for several vegetative seasons.

The research presented in this paper was based on the hypothesis that a unidirectional fertilization system carried out for thirty years could not have left the soil macrofauna unaffected. The research objectives were: to determine the concentrations of carbon and nitrogen in soil, to assess numbers of individuals belonging to several groups of macrofauna and dominant species and to test correlations between the above factors and densities of some groups of the zooedaphon.

MATERIAL AND METHODS

The research, conducted at the Chair of Phytopathology and Entomology of the University of Warmia and Mazury in Olsztyn, encompassed the years 2002-2004 and was based on a long-term static field experiment established by the Chair of Environmental Chemistry of the UWM in 1972. The experiment was set up on grey-brown pozdolic soil formed from medium boulder clay lying on light loam, which was rated as good wheat complex class IIIb soil in the Polish soil class system. The following crops are grown in a 7-year crop rotation system: potato, spring barley, winter oilseed rape, winter wheat + winter rye aftercrop, maize, spring barley, winter wheat. In 2002 the fifth crop rotation series began. Objects selected for our study were fertilized exclusively with liquid manure, farmyard manure or mineral fertilizers. An unfertilized object served as the control (Table 1).

Table 1

Design of the static experiment together with the rates and quantities of nutrients introduced to soil with fertilizers (annual means for 1972-2004)

Experimental objects	Rates ($t \cdot ha^{-1}$)	N	P	K
		($kg \cdot ha^{-1}$)		
Control	-	-	-	-
FYM	22.4	111	37	98
Slurry rate I	39.6	111	42	125
Slurry rate II	73.0	211	76	227
NPK	-	111	38	106

The experiment was performed in four replications and the size of plots for crop harvest was 52.5 m^2. The objects selected for the study are representative of the tendencies dominating in Polish agriculture, which was signalled in the Introduction to this paper. Before application, chemical composition of the fertilizers was analysed. Liquid manure was applied at two rates: rate I equalled FYM in the amount of total nitrogen introduced to soil; rate II was balanced with FYM in the amount of organic carbon added to soil. The amount of nitrogen added to soil in the form of mineral fertilizers equalled the dose of this component in rate I of liquid manure.

Each year soil samples for chemical analyses were collected after harvest from the soil layer at 0-25 cm depth. The samples were dried and passed through a 0.25 mm mesh sieve. Organic carbon was determined by Tiurin's method whereas total nitrogen was assayed by Kjeldahl's method.

In order to quantify the soil macrofauna, soil samples were collected from each trial plot six times during each vegetative season (May – September) at 3-week intervals. On each occasion 24 samples were taken from each object. The samples were cut out using a cylinder which was 95 mm in diameter and 160 mm in height. The choice of the sampling tool was conditioned by the fact that distances between rows of plants grown in particular seasons differed. Another reason was the specific character of a strict experiment. The samples were passed in the field through a 100 mm mesh sieve and then transferred to a laboratory to be placed in Tullgren's apparatuses. Insects were chased out by the dynamic method for 7-8 days (GÓRNY, GRÜM 1981). The soil fauna thus obtained was identified with an aid of entomological keys.

The statistical calculations consisting of analyses of variance and Duncan's test were performed using Statistica software, version 6 (StatSoft, Inc., 2003). In addition, Pearson's correlation coefficients were computed.

RESULTS AND DISCUSSION

Organic carbon concentrations in the arable layer of soil were found to vary greatly between particular research objects: from 7.05 $g \cdot kg^{-1}$ soil in the unfertilized object to 12.14 $g \cdot kg^{-1}$ soil in the plots fertilized exclusively with FYM (Table 2).

Table 2

Mean concentrations of organic carbon and total nitrogen ($g \cdot kg^{-1}$) in soil in 2002-2004

Year	No fertilization	Slurry rate I	Slurry rate II	FYM	NPK
	organic (C $g \cdot kg^{-1}$ of soil)				
2002	7.10	9.36	10.99	12.14	8.48
2003	7.05	9.99	10.01	10.67	7.74
2004	7.15	8.85	9.75	11.80	7.50
Mean	7.10	9.40	10.25	11.54	7.91
Total N ($g \cdot kg^{-1}$ of soil)					
2002	0.61	0.70	0.87	0.94	0.72
2003	0.62	0.79	0.89	0.75	0.74
2004	0.56	0.70	0.80	0.91	0.68
Mean	0.60	0.73	0.85	0.87	0.71

Fertilization caused an evident rise in the amount of organic carbon compared to the control. This increase ranged from 0.81 to 4.44 $g \cdot kg^{-1}$ soil.

Out of all the fertilization variants analysed, FYM had the most beneficial effect on organic carbon concentration in soil. Liquid manure applied at rate II, equal to FYM in the amount of organic carbon introduced to soil, had a much weaker influence on the accumulation of this component in soil than solid manure.

The content of total N varied from 0.56 $g \cdot kg^{-1}$ soil in the unfertilized object to 0.94 $g \cdot kg^{-1}$ soil in the object fertilized with FYM. Larger increase in the total nitrogen in soil was obtained when soil was fertilized with farmyard manure than liquid manure or mineral fertilizers.

The macrofauna potentially harmful to crops consisted of arthropods *Arthropoda* representing three orders of insects: *Coleoptera* beetles, *Lepidoptera* butterflies, *Diptera* dipterans as well as the order of centipedes *Diplopoda*, which are designated as members of the phylum *Myriapoda*.

Five families were determined among the *Coleoptera* beetles: click beetles *Elateridae* (which made up 31% of the whole group) with the dominant dark elaterid beetle *Agriotes obscurus* L.), scarab beetles *Scarabaeidae* (11%) dominated by cockchafer *Melolontha melolontha* L., ground beetles *Tenebrionidae* (5%), chrysomelid beetles *Chrysomelidae* (3%) and burying beetles *Silphidae* (2%). The latter family was represented by single species (Figure 1).

The butterflies *Lepidoptera* were represented mainly by caterpillars of turnip moth *Agrotis segetum* L., of the family *Agrotinae*, which constituted 3% of the total population. The dipterans obtained from the soil samples, of which most were larvae, belonged to two families: crane flies *Tipulidae* with the species *Tipula scripta* L (11%) and March flies *Bibionidae* with the spe-

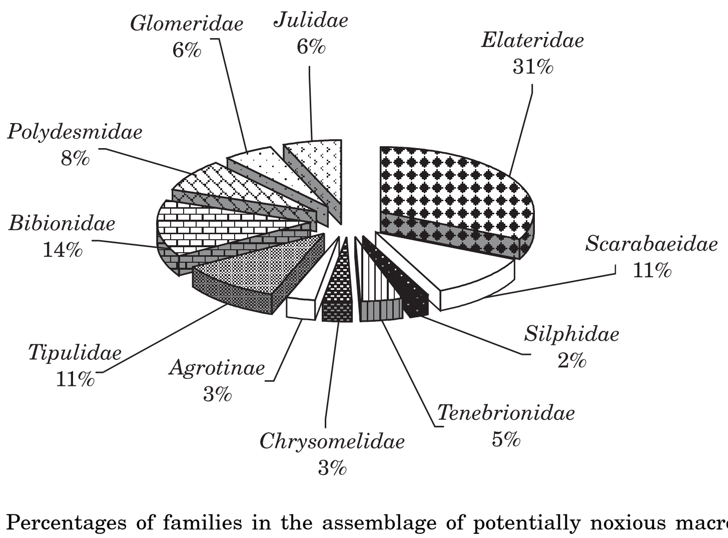

Fig. 1. Percentages of families in the assemblage of potentially noxious macrofauna

cies *Bibio pomonae* L. (14%). The centipedes *Diplopoda* were dominated by adult individuals (14% of all collected individuals of potentially noxious macrofauna) whereas larvae were in minority (4.9%).

The density of the macrofauna varied both between the vegetative seasons and between the research objects (Figure 2). The lowest density (2.4 individuals per 1 m^2) was observed on the control object, which had not been fertilized for 34 years. Significant differences occurred between the objects which were treated with organic fertilizers (rate I of liquid manure and FYM) and the remaining combinations. Low mean densities also appeared on the objects fertilized with mineral fertilizers and rate II of liquid manure, which added to the soil the same quantity of organic carbon as FYM. The respective densities were 2.5 and 3.1 individuals per 1 m^2. The relatively low density of macrofauna noticed on the object fertilized with rate II of liquid manure was most probably caused by high accumulation of nitrates (III and IV), which are noxious to soil organisms – the fact mentioned by Wolender (1988). This dose of liquid manure (rate II) added nearly twice as much nitrogen as the other fertilization treatments. Besides, over 60% of nitrogen in liquid manure occurs in easily dissolvable forms, which encourages the accumulation of large amounts of nitrogen in soil.

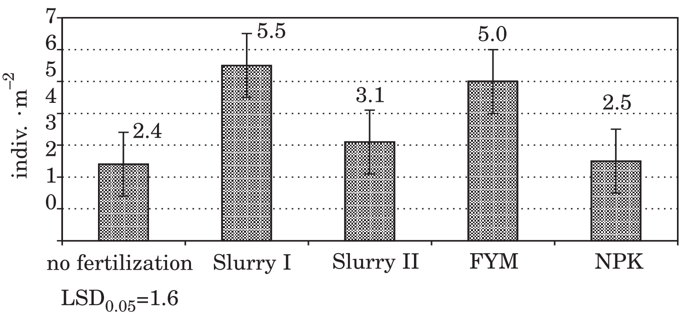

Fig. 2. Average macrofauna density on the experimental objects (individuals · m^{-2})

The diverse densities of noxious macrofauna on particular test objects were obviously conditioned by specific requirements of the analysed insects regarding the soil environment they inhabit. The lowest density, which occurred on the unfertilized object, was a consequence of small annual growths of plant biomass, which in turn resulted in small amounts of post-harvest leftovers.

While comparing the results of the soil chemical analyses and fauna investigations, it was found out that organic carbon concentrations produced strong influence on the density of noxious macrofauna (Table 2). An increase in organic carbon was accompanied by a higher density of the analysed group of zoodaphon. This is evidenced by the positive correlation coefficient $r = 0.61$ (Figure 3).

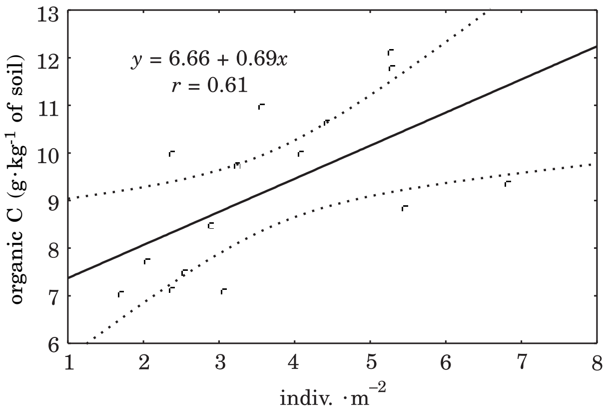

Fig. 3. Correlation between number of noxious macrofauna and organic carbon concentration in soil

In the soil of the objects which were a uniform group according to the highest macrofauna density, the concentration of organic carbon was relatively low. However, there was one exception – the object fertilized with rate I of liquid manure, where the macrofauna density was significantly lower. This was most probably caused by very high rates of nitrogen introduced to the soil together with rate II of liquid manure, and in particular its high concentration of mineral nitrogen. Similar and low densities of macrofauna were determined in the object fertilized each year with mineral fertilizers. As mentioned previously, high concentration of nitrogen in soil, and especially that of nitrate nitrogen, may be harmful to certain soil organisms, particularly young stages of larval soil insects (GÓRNY, GRÜM 1981). The correlation between the content of organic carbon and number of noxious soil insects showed a significant relationship between these two parameters. Organic carbon is the basic component of soil humus and the fact that most soil dwelling organisms prefer habitats rich in organic matter and nutrients may explain the positive effect of carbon on the size of soil macrofauna population. The results of the authors' own studies confirm the relationships described by KOWALSKA, WIERZBOWSKI (2002), who reported that nutrient rich habitats comprised more numerous populations of soil agrophagous organisms than sites poor in nutrients.

The content of total nitrogen in soil and density of harmful macrofauna were also determined to be correlated. The objects which were found to contain the highest densities of macrofauna were the ones which possessed the highest concentrations of nitrogen. On the other hand, the objects with the lowest densities of harmful insects had the lowest nitrogen concentrations in soil (Table 2). Again, there was one exception, namely the object treated with rate II of liquid manure, where the density of noxious macrofauna was very low but the level of nitrogen in soil turned out to be high.

One may presume that this was due to the toxic effect of liquid manure, which added much more nutrients to soil than the other fertilizers. Such high concentration of mineral salts introduced every year with liquid manure must have contributed to the deterioration of biological properties of soil. Positive correlation (r = 0.34) was determined between the mean density of noxious entomofauna and total nitrogen concentration (Figure 4).

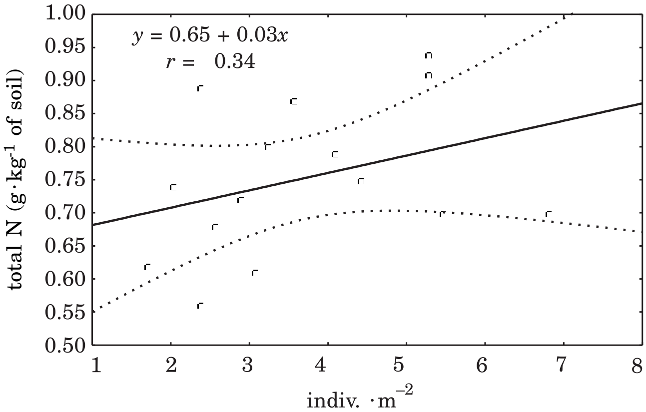

Fig. 4. Correlation between number of noxious macrofauna and total nitrogen concentration in soil

CONCLUSIONS

1. Long-term unidirectional organic and mineral fertilization has led to increased levels of organic carbon and total nitrogen in soil. The highest increase in those components appeared under the influence of farmyard manure fertilization.

2. The following composition of soil macrofauna potentially harmful to cultivated crops was determined: click beetles *Elateridae* with the dominant dark elaterid beetle *Agriotes obscurus* L, March flies *Bibionidae* with the dominant species *Bibio pomonae* L., scarab beetles *Scarabaeidae* with European June beetle *Amphimallus solstitialis* L., and ground beetles *Tenebrionidae* which were dominated by *Tipula scripta* Mig.

3. Unidirectional application of organic fertilizers in rates balanced for the amount of nitrogen added to soil (rate I of liquid manure and FYM), when carried out for many years, caused a significant increase in the density of soil macrofauna.

4. Fertilization with liquid manure balanced with FYM in terms of organic carbon added to soil as well as with mineral fertilizers did not favour presence of soil macrofauna.

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