Original Research

Effect of Fertilization on the Structure of Upland Grassland Soil

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Abstract

The development and maintenance of the structure of humus soil horizons are predominantly influenced by roots and soil fauna, among which earthworms are considered the most important structural engineers in soils of temperate regions. The aim of this paper was to study changes in aggregation in an upland grassland soil following the application of mineral fertilizers and farmyard manure, and to compare excremental pedofeatures in the soil under different fertilization systems. In the studied upland grassland soil a subangular blocky structure was formed, the best developed, with many channels in manured soil, and the weakest in NPK-treated soil. The addition of fertilizers influenced the share of aggregates of fauna origin in studied treatments: FYM application increased the presence of aggregates while mineral fertilization decreased it in comparison with untreated soil. FYM-fertilized soil was characterized by a large presence of macroaggregates, while in NPK soil small aggregates prevailed.

Keywords: upland grassland soil, NPK, FYM treatments, soil microstructure, faunal pedofeatures

Introduction

The development and maintenance of the structure of humus soil horizons are predominantly influenced by roots and soil fauna, among which earthworms are considered the most important structural engineers in soils of temperate regions [1]. Smaller organisms may also contribute to the aggregation, such as enchytraeids or springtails, which are identified as formers of a granular structure with fecal pellets smaller than 300 µm in diameter [2].

Upland grassland soils have an important role as sinks of organic matter, which in turn enhances soil sorption properties, reducing nutrients leaching, which is important, in areas prone to erosion. The effect of changes in animal activity on soil structure may therefore influence the pathways of carbon transfer in the ecosystem, but the understanding of theses processes remains rather poor [3, 4]. A number of publications focus on changes in botanical diversity resulting from different fertilization methods [5-9]. The moderate addition of nitrogen to grassland soils generally improves species diversity, high doses of mineral fertilizers reduce them and the application of farmyard manure on grassland soils favorably limits the natural tendency of meadows to produce bad herbs [6]. Besides the effect of fertilization on plant communities, there is evidence that the addition of nitrogen to grassland soils may also directly affect soil biota [9, 10].

The opportunity to investigate soil-fauna relationships by identifying and quantifying faunal excrements provides the study of thin sections, with their image analysis. Micromorphological techniques are also commonly used to characterize soil structure related to management practices with fertilization systems included, even though most of these studies have been carried out on arable soils [11-13].

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The aim of this paper was to:

(i) study changes in aggregation in an upland grassland soil following the application of mineral fertilizers and farmyard manure, and

(ii) compare soil excremental pedofeatures in the soil under different fertilization systems.

Materials and Methods

The experimental site was located in the upland area in the village Brzozów near Brzesko in southern Poland in the region of Środkowobeskidzkie Foothills (22º02' E and 29 º42' N) at an altitude of 370 m a.s.l. On the experimental plot acid brown soil occurs, derived from the Carpathian flysch. The annual average rainfall of the area is 740 mm, temperature 8.6ºC, and the growing season lasts 205 days. The experiment was established in 1997 in 3 treatments: control plot (without fertilization), NPK-fertilized plot with 120 kg N, 60 kg P_2O_5 and 80 kg $K_2O \cdot ha^{-1}$ per year, and the plot where farmyard manure was applied every year in the spring, in the amount of 25 $t \cdot ha^{-1}$. The experiment was established on a permanent meadow in randomized blocks with three replications [14].

Soil samples were taken from each plot in June 2007, from two depths: 0-10 cm and 10-20 cm. All analyses were performed in three replications. Undisturbed soil samples were taken with the use of Kubiëna boxes of 4 cm x 6 cm x 3 cm. Undisturbed soil blocks were air dried and impregnated with epoxy resin in the Epovac vacuum chamber, then cut, bonded to glass slides, lapped to a thickness of 40 µm and polished using Logitech CS 30 saw and CL 50 lapping and polishing machine. Thin sections were observed through a Nikon Eclipse E400 Pol microscope in plane polarized light [15]. Soil structure was defined applying Stoops nomenclature [16]. Micromophometric image analysis were performed with the use of Aphelion ADCIS S.A. Aai. inc. software. Identified organo-mineral aggregates were divided into three sized fractions, at diameters: below 50 µm, 50-300 µm, and above 300 µm. The dimensions of aggregate fractions were assumed on the basis of sizes of excrements left by different soil fauna groups.

In air-dried disturbed, sifted through a sieve with 2 mm mesh soil samples the following analyses were performed: soil texture by densimetric-sieve method [17], the level of total nitrogen, total, and inorganic carbon with the use of TOC-TN 1200 Thermo Euroglas apparatus. The level of organic carbon was calculated as the difference between total and inorganic carbon. Cation exchange capacity (CEC) was calculated as the sum of hydrolytic acidity determined after the Kappen method and the sum of exchangeable bases assessed in 0.5 $mol \cdot dm^{-3}$ NH_4Cl [18].

Statistical analysis of results was carried out using ANOVA unifactor variation analysis in a random arrangement. To estimate the significance of differences between mean values, homogeneous groups were appointed using the test *a posteriori* of Fisher.

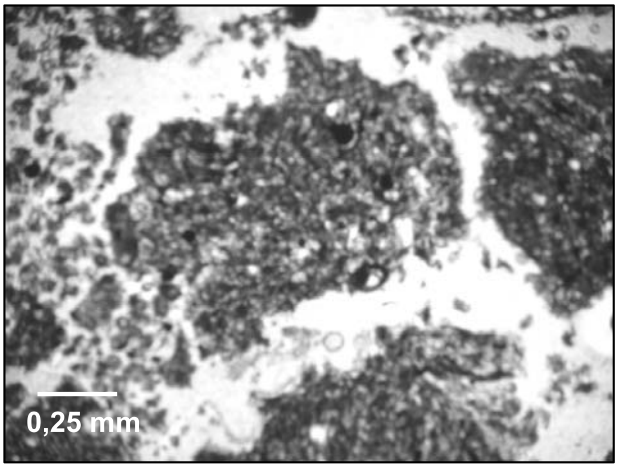
Table 1. Main physical and chemical characteristics of the soil of the three fertilization experiment objects, expressed as mean values of 3 replicates ± SD.

Soil characteristics	Depth in cm	Control plot	NPK-fertilized plot (NPK)	Manured plot (FYM)
Sand (%)	0-10	25±0.5	22±0.3	23±0.2
	10-20	25±1.0	20±0.2	24±0.4
Silt (%)	0-10	60±0.8	64±0.9	63±1.0
	10-20	60±0.5	65±1.0	63±1.0
Clay (%)	0-10	15±1.0	14±0.3	14±0.5
	10-20	15±1.0	15±0.5	13±0.3
pH_{H_2O} (1:2.5)	0-10	5.7±0.1	5.5±0.1	6.0±0.1
	10-20	5.9±0.1	5.7±0.1	5.9±0.1
CEC (mmol(+)$\cdot kg^{-1}$)	0-10	154.7±0.5	174.8±0.8	177.4±0.8
	10-20	139.3±0.4	141.0±0.6	144.8±0.3
Organic C ($g \cdot kg^{-1}$)	0-10	24.0±0.6	25.6±0.3	27.8±0.1
	10-20	17.7±0.6	19.6±0.5	18.1±0.8
Total N ($g \cdot kg^{-1}$)	0-10	1.54±0.02	1.64±0.02	1.87±0.03
	10-20	1.27±0.12	1.09±0.04	1.26±0.07
Inorganic C ($g \cdot kg^{-1}$)	0-10	0.92±0.05	0.96±0.01	1.01±0.05
	10-20	0.68±0.1	0.60±0.13	0.70±0.2

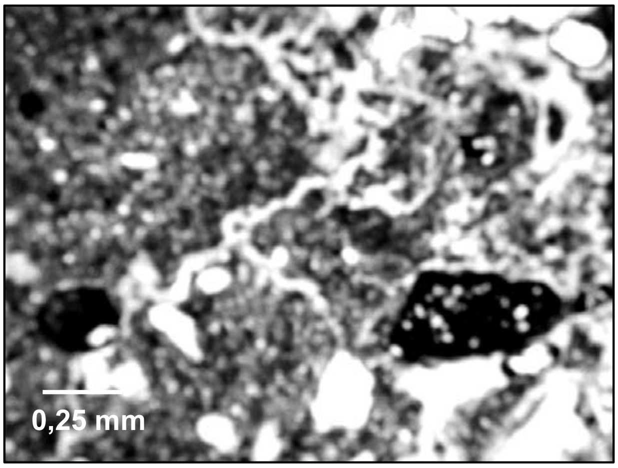
Results and Discussion

Studied soils were characterized by silt texture and acid soil reaction in both studied horizons in all treatments, while values of cation exchange capacities were similar in NPK and FYM fertilized soils and lower in the unfertilized soil (Table 1). Fertilization systems diversified the content of organic carbon and total nitrogen in 0-10 cm horizons of studied soils, from the lowest in the unfertilized control plot (respectively 24.0 and 1.54 $g \cdot kg^{-1}$) to the highest in the plot where FYM was applied (27.8 and 1.87 $g \cdot kg^{-1}$).

In both horizons 0-10 cm and 10-20 cm in all objects of the experiment a microstructure of subangular blocky type were observed. The impact of fertilization on the soil structure, which resulted in different degrees of microstructure development, was noticed only in 0-10 cm horizons, while 10-20 cm horizons developed subangular blocky microstructures. In a top horizon of the manured soil the soil blocks were well developed, with faces largely accommodating each other, separated by large planar voids often interconnected with channels (Fig. 1a). Most large aggregates were of faunal origin, some of them composed of coalesced smaller ones. In the 0-10 cm horizon of NPK-fertilized soil, blocks were less developed and with partially accommodated faces. Aggregates were often dispersed, a)



b)



c)

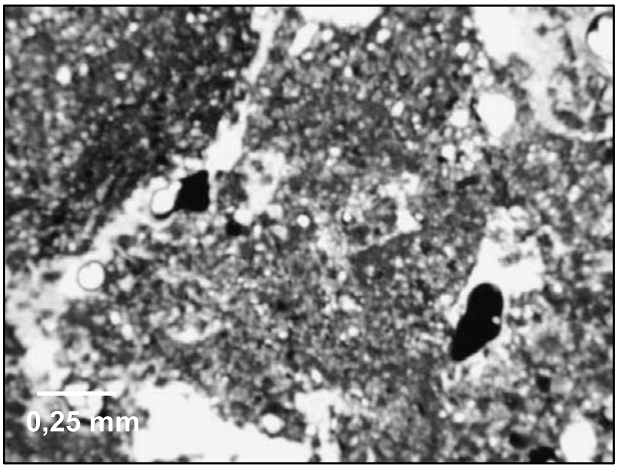


Fig. 1. Microstructures in 0-10 cm horizons of the experiment treatments: a) well developed subangular microstructure with intergrain planar voids accommodated to adjacent aggregates in the object with FYM application, b) weakly developed subangular microstructure formed from crumbled aggregates with faces weakly accommodated to adjacent aggregates in object with NPK-fertilization, c) medium developed subangular structure in the control object.

filling voids and making the soil horizon more compact than the one of manured soil (Fig. 1b). The top horizon of the unfertilized soil had characteristics in-between the NPK and manured soils (Fig. 1c). According to Pachepsky and collaborators [11] one of the reasons of differences in aggregation between mineral and manure treatments may be organic matter composition. This would correspond to the observation that fulvates and humates from manure caused a closing of planes and a formation of larger aggregates, whereas fulvates and humates from mineral fertilization increase vughs, resulting from disruption of microstructure, and smaller aggregates.

Anthropogenic disturbances such as fertilization regimes are among most important factors shaping the diversity of both above and underground communities [9]. Changes in plant species composition due to 7-year-different fertilization treatments on the meadow of this experiment are reported by Kacorzyk [14]. Treatment with NPK-fertilizers reduced the share of dicotyledonous and favored herbs grown in comparison with the unfertilized object, when the repeated application of farmyard manure had the opposite effects, causing a decline of monocotyledonous. Such changes in plant species, resulting in root biomass increase, usually influence the accumulation of soil organic matter, which serves as a main source of faunal feeding. This has a direct effect on diversification and activity of soil fauna, which in turn affects the number of organic and organo-mineral aggregates left in the soil [19]. In this study, the biggest share of aggregates of animal origin exceeding 30% of the analyzed image surface was observed in both horizons of the manured soils (Fig. 2). The share of aggregates in both analyzed horizons of unfertilized soil and in the top horizon of the soil with mineral fertilization were lower than 10% of the image surface and differences among them were statistically insignificant. Only in the 10-20 cm horizon

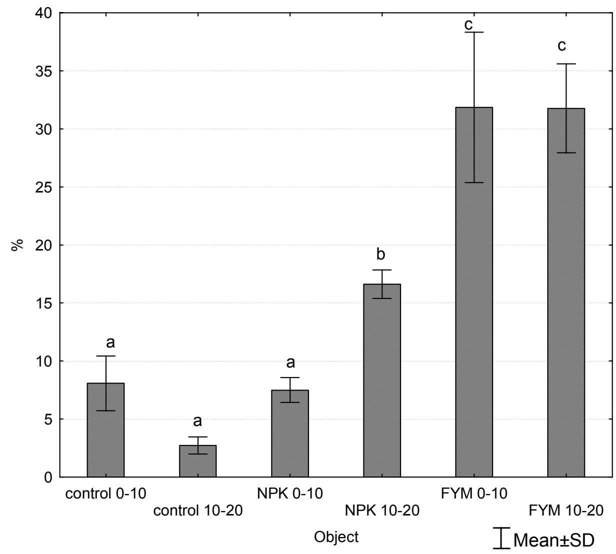


Fig. 2. Share of organic and organo-mineral aggregates of faunal origin in the microscopic image surface in the soil of different fertilization treatments of the experiment. The same letters indicate a lack of statistically significant differences at significance level <0.05.

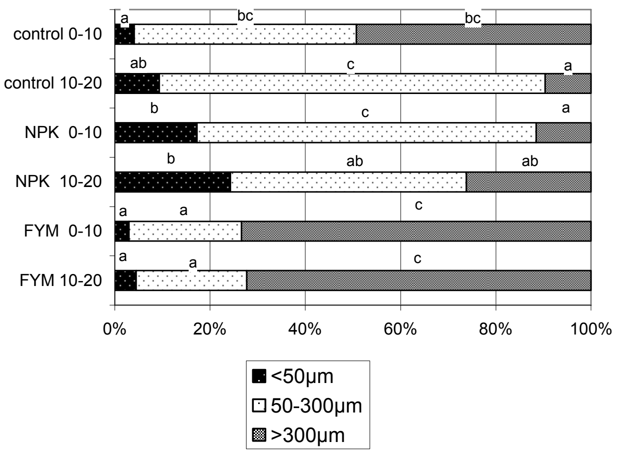


Fig. 3. Share of organic and organo-mineral aggregates of faunal origin with different diameters in the microscopic image surface that they occupy in the soil of different fertilization treatments in the experiment. The same letters indicate a lack of statistically significant differences at significance level <0.05.

of the NPK-fertilized soil was the share of animal aggregates about 17%, making it significantly higher than in the top horizon of this soil and in the control soil, but significantly lower than in both horizons of the manured soil. The last observation corresponds with Murray et al. [9] and how larger fauna can respond to changes in environmental conditions by moving within the soil profile to find more suitable microhabitats.

According to VandenBygaart et al. [1], if the soil didn't pass repeating cycles of getting soaked and drying, its aggregates in humus horizons, for sizes below 1,000 µm, in the huge majority are created as a result of action of the soil fauna. Thus, the formation of aggregates with diameters larger than 300 µm is related to macrofauna activity and, especially, earthworms. Aggregates with diameters 50-300 µm are left by soil mesofauna, mainly springtails, enchytraeids and mites. Whereas a large amount of aggregates with diameters smaller than 50 µm indicates poor soil aggregation, aggregate decomposition and the formation of non-aggregated soil material [2]. Results of the experiment show that long-term FYM application significantly increased the share of aggregates with diameters larger than 300 µm, in both analyzed soil horizons of this type of treatment. Their share amounted to about 75% of all surfaces of image taken by aggregates, while in 0-10 cm the horizon was about 50% (Fig. 3). Organic fertilizers usually favor earthworms more than inorganic fertilizers. Farmyard manure is reported to especially enhance earthworms [20]. Farmyard manure usually increases the pH and the organic matter content of the soil, which might explain its positive effects on earthworm abundance [21]. The lowest share of macroaggregates (about 10% of surface taken by all aggregates) was observed in the surface horizon of NPK treatment. This is in contrast with the general observation that earthworm abundance is higher under fertilized conditions [22, 23]. Murray et al. [9] results show that mineral fertilized soil was consistently drier than in the control plot. Authors explain the fact that enhancing the above-ground mass leads to the increase of evapotranspiration. The observation may explain the reason for the larger presence of macroagregates in lower horizon of NPK-fertilized soil than in the surface one. In both analyzed horizons of mineral fertilized soil dominated aggregates with diameters 50-300 µm, attributed to mesofauna, mainly enchytraeids, and a considerable share of disaggregated material was also noted. This is consistent with the opinion that smaller representatives of soil fauna are less exigent, as far as water is concerned than earthworms [24]. On the other hand, a relatively high presence of macroaggregates found in 10-20 cm horizon of NPK-treated soil can be influenced by a higher carbon content in this horizon than at this depth in soils of other treatments, as well as a lack of direct chemical influence of mineral fertilizers. The findings of the study confirm the complexity of interactions in the soil. Application of fertilizers can have both direct and indirect (via plants) effects on soil structure.

Conclusions

1. In the studied upland grassland soil under different fertilization systems, subangular blocky structure was formed, the best developed, with many channels in manured soil, and the weakest in NPK-treated soil.
2. The addition of fertilizers influence the share of aggregates of fauna origin in studied treatments: FYM application increased the presence of aggregates while mineral fertilization decreased it in comparison with untreated soil.
3. FYM-fertilized soil was characterized by a large presence of macroaggregates, mainly of earthworm origin, while in NPK soil mesofauna aggregates prevailed.

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