EFFECT OF LIMING ON THE DYNAMICS OF WATER-STABLE AGGREGATES AND ORGANIC CARBON IN MORAINE LOAM SOIL

Danute KARCAUSKIENE[1], Ieva JOKUBAUSKAITE[1], Regina REPSIENE[1], Dalia AMBRAZAITIENE[1], Alvyra SLEPETIENE[2]
[1]Vezaiciai Branch of Lithuanian Research Centre for Agriculture and Forestry
Gargzdu 29, 96216, Vezaiciai, Klaipeda distr., Lithuania
[2]Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry,
Instituto aleja 1, 58344, Akademija, Kedainiai distr., Lithuania
Email: danuteo@vezaiciai.lzi.lt

Abstract. *The paper summarises the data of field and laboratory trials made in Lithuania (Vezaiciai Branch of Lithuanian Research Centre for Agriculture and Forestry) during the period of 1996-2013. The effect of liming with different intensity (at a rate 0.5 every 7 years and 2.0 every 3-4 years) was investigated in the topsoil of acid moraine loam Bathygleyic Dystric Glossic Retisol on the dynamics of water-stable aggregates and organic carbon. Data showed that systematic liming over 56 years (1949-2005) affected the structure of moraine loam soil. The largest amount (68.4-72.1%) of water stable aggregates (>0.25mm) was determined in the relatively most intensively limed soil when perennial grasses and winter wheat were grown in 2002-2003. During the study period the decrease of water-stable aggregates was appointed in both soil backgrounds: acid (from 57% to 25%) and limed (from 72% to 29%) soil. These data suggest that the climatic conditions (swelling clay under warm and wet conditions in autumn-winter periods and drying and rewetting cycles in spring-summer periods) have a substantial negative effect on the aggregates formation. The effect of systematic soil liming on the distribution of soil organic carbon and it's fractional composition was evaluated. Study showed that periodical liming decreased the amount of organic carbon in the soil. Soil organic carbon amount was approximately by 0.11-0.18 persentage points lower compared to the unlimed plots (1.44%). Periodical liming significantly decrease the content of humic and fulvic acids and dissolved organic carbon content, as one of labile fractions of soil organic carbon. Fulvic acids was dominated in the soil in all treatments, that could be associated with a slow humification processes in the soil.*

Key words: *soil, aggregates, organic carbon, liming.*

INTRODUCTION

Soil aggregates stability is a crucial soil property affecting soil sustainability [1]. Physical protection of soil organic matter by aggregates is considered to be an important mechanism for soil carbon stabilization [2]. Soil organic carbon (SOC) has been increasingly considered as an indicator of soil quality, one of the component of biosphere sustainability and stability [3]. The SOC does not degrade completely to carbon dioxide. It forms humic substances through secondary synthesis reactions. Humic substances account from 65% to 75% of the SOC and are also important aspects of soil fertility as they are involved in the stabilization of soil aggregates and binding of anthropogenic organic chemicals [4],[5]. Dissolved organic carbon (DOC) represents one of the most mobile and reactive organic matter fraction in the ecosystem, which is much more sensitive to soil management than is SOC as a whole, and can be used as a key indicator of soil natural functions [6],[7]. According to Haynes (2000), SOC (total and labile) content are important in relation to water-stable aggregation [8]. In accordance with Bronich (2005), aggregation results from the rearrangement, flocculation and cementation of soil particles. It is mediated by soil organic carbon, biota, ionic bridging, clay and carbonates. The complex interactions of these aggregates can be synergetic or disruptive to aggregation. Clay-sized particles are commonly associated with aggregation by rearrangement and flocculation, although swelling clay, drying and rewetting cycles can disrupt aggregates. Rewetting events after a drought produce a pulse of soil respiration that leads a loss of carbon from soil and destruction (crushed 9-4mm aggregates) of internal structure of soil, especially in Mediterranean ecosystems. Therefore maintaining high stability of soil aggregates and large amount of organic carbon is necessary for sustaining soil productivity and decreasing soil degradation [9].

Dynamics of organic carbon and soil aggregates can be significantly influenced by management practices and environmental changes [9]-[12]. Application of organic substances and lime materials could be an effective measure for improving the soil physical and chemical properties and the fertility of the moraine loam soil (*Bathygleyic Dystric Glossic Retisol*) [13],[14]. Liming effect on the content of SOC and stabile aggregates in soil is diverse and not always positive. According to Chan and Heenan (1999), SOC loss as a result of liming was mainly (up to 84% of total loss) in the form of light fractions bound to macro aggregates [15]. Increased aggregate stability in limed soil suggested about the formation of new bonding involved Ca bridges. According to a Swedish study, an intensive liming is appropriate until the base saturation of soil does not reach 70% [16]. When soil pH is less than 5.5, microbial activities of nitrifying bacteria are lower and SOC mineralization rate is reduced [17]. In summary, the soil texture, the type of lime materials and their exposition time as well as climatic conditions are very important factors for the liming efficiency on soil structure and stocks of carbon. There exist opinions that liming efficiency depends on geochemical environment that lime materials get into.

The aim of this particular investigation is to evaluate the changes of acid moraine loam soil water-stable aggregates and organic carbon content under long-term liming conditions.

MATERIALS AND METHODS

Study site. The field experiment was conducted during the period of 1996-2013 at the Vezaiciai Branch of Lithuanian Research Centre for Agriculture and Forestry, on the eastern part of the seacoast lowland with moderately warm, humid agro-climate. Seeking to determine the dynamics of water-stable aggregate and soil organic carbon, the analysis were done in 1996 (after 50 years of systematic soil liming) and in 2013 (after 64 years of liming). This long-term field experiment was started in 1949. Object of investigation – naturally acid soil and the same soil exposed to different liming intensity (Table 1). The soil of the experimental site is *Bathygleyic Dystric Glossic Retisol* (texture – moraine loam with clay-sized particles content of 12-14%). Before the start of the experiment (1949) the arable soil layer thickness was19-22 cm, soil carbonates were found deeper than 2 meters below the surface. Arable soil layer was very acid (pH_{KCl} 4.2-4.4), high levels of plant-available aluminium in the arable layer of soil (70-100 mg kg^{-1}), amount of bases in topsoil was low 25-50%, content of humus was 2.0-2.9%, low levels of phosphorus (plant-available P_2O_5 50 mg kg^{-1}) and potassium (plant-available K_2O 130 mg kg^{-1}).

Table 1

Experimental design, Vezaiciai, 1949-2013

Liming intensity	**Amount of $CaCO_3$ applied, t ha^{-1}**		**Total amount of $CaCO_3$ applied, t ha^{-1}**
	1949-1998	**1998-2005**	**1949-2005**
Unlimed	–	–	–
Periodical liming using ×**0.5** of the liming rate calculated based on the soil hydrolytic acidity (3.3 t ha^{-1} $CaCO_3$) **every 7 years**	18.1	–	18.1
Periodical liming using ×**2.0** of the liming rate calculated based on the soil hydrolytic acidity (15.0 t ha^{-1} $CaCO_3$) **every 3-4 years**	89.9	15.0	104.9

Applying the long-term liming system (primary (1949), repeated (1965) and periodical liming (1985-2005)) during the period of 1949-2005, formed the different soil pH levels (Table 2).

Table 2

Effect of liming of topsoil chemical properties

Treatments	**pH_{KCl}**		**Al^{3+}, mg kg^{-1}**		**Total N, %**		**P_2O_5, mg kg^{-1}**		**K_2O, mg kg^{-1}**	
	1996	***2013***	***1996***	***2013***	***1996***	***2013***	***1996***	***2013***	***1996***	***2013***
Unlimed	4.0	4.1	98.05	99.86	0.100	0.110	197	160	265	108
0.5 rate every 7 years	5.9*	5.4*	27.12*	23.75*	0.110	0.112	166	139*	159*	90*
2.0 rate every 3-4 years	6.8*	6.4*	0.03*	0.18*	0.110	0.111	192	118*	167*	82*

*Note: * - significantly different from control ($P < 0.005$)*

Periodical liming was done by pulverized limestone (92.5% $CaCO_3$) on the background of primary and repeated liming by slaked lime. Minimal organic fertilizing (40 t ha^{-1} manure during 7-field rotation), conventional tillage and intensive crop rotation: sugar beets, spring barley with under-sowing grasses, perennial grass (two years), winter wheat, vetch-oats mix for grain and pees-barley mix for forage. In 2008, the long-term experiment was restructured. In 2005-2013 soil hasn't been limed repeatedly. Crop rotation was shortened to 4-field: spring barley with under-sowing grasses, perennial grass (two years), winter wheat and spring rape. Before the soil limed with relatively lower intensity (by 0.5 rates every 7 year) during study period was low acid (pH_{KCl} 5.4-5.9) and soil limed with relatively higher intensity (2.0 rates every 3-4 year) reached the close to neutral reaction (pH_{KCl} 6.4-6.8). In these essentially different by pH soils the study of structure and organic carbon compounds was made.

Soil analysis. Soil structure. The soil samples for soil structure analyses were taken from the topsoil (0-20cm) when the harvest of various crop rotation plants was taken off in periods: 1996-1999, 2002-2005 and 2008-2011. Soil aggregate stability in water was estimated according to Savinov in Vezaiciai Branch of Lithuanian Research Centre for Agriculture and Forestry [18].

For the organic carbon analysis, soil samples were taken randomly by using a steel auger from three replicates of the topsoil (0-20 cm) after the harvest in 2013. All samples were air-dried, visible roots and plant residues were manually removed. Then the samples were crushed, sieved through a 2-mm sieve and homogeneously mixed. For the analyses of SOC content the soil samples were passed through a 0.25-mm sieve. Analyses of SOC and DOC were carried out at the Chemical Research Laboratory of Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry. SOC content was determined by photometric procedure at the wavelength of 590 nm using the UV-VIS spectrophotometer Cary 50 (Varian) equipped with computer program, and glucose as a standard after wet combustion according to Nikitin (1999) [19]. Soil organic carbon fractional composition was determined by Ponomariova and Plotnikova version of classical Tyurin method [20]. Dissolved organic carbon (DOC) was analyzed using an ion chromatograph SKALAR in water extract at soil–water ratio 1:5.

Statistical analysis. Statistical analysis was done using the computer program ANOVA from the package SELEKCIJA. One-way analysis of variance was then used to analyse the differences in the tested parameters among the treatments. The least significant difference method (LSD) at the 5% probability level was used to test the significance of differences between treatment means [21].

RESULTS AND DISCUSSION

Structure of acid moraine loam soil due to low amount of water-stable aggregates is poor and changeable under various climatic and anthropogenic factors. Results of our investigations showed that 56- year of systematic liming (by 0.5 rates every 7 year and 2.0 rates every 3-4 year) on the background of minimal organic fertilizing and conventional tillage, affected the structure of moraine loam soil (Table 3). According to 11- years data the largest amount (68.4-72.1%) of water stable aggregates (>0.25mm) occurred in relatively most intensively limed soil when perennial grasses and winter wheat were grown in 2002-2003.

The increase (by 28-34%) of water stable aggregates was determined in limed soil compared to the unlimed. These data suggest that growing of perennial grasses in limed soil is an effective measure for the improvement of moraine loam soil structure. During the study period the decrease of water-stable aggregates was determined in both acid (from 57% to 25%) and limed (from 72% to 29%) soil. These data suggest that the climatic conditions (swelling clay under warm and wet conditions in autumn-winter periods and drying and rewetting cycles in spring-summer periods) has a substantial negative effect on aggregates formation. Similar results were obtained in long-term field experiments by other researches [22]. Also, the decrease of water stable aggregates in moraine loam soil is caused by the intensive anthropogenic activity inducing the decrease of organic carbon.

Soil organic carbon. Soil organic carbon is the most important indicator of soil quality and productivity. The data about the liming effect on the dynamics of SOC in soils are often contradictory, especially in arable soils. According to Abril (2008), intensive soil liming resulted higher SOC content compared to the unlimed soil [23]. However, other studies, showed that liming decreases the SOC content due to increased microbial activity [24],[25].

Our study showed a negative statistically significant effect of liming on SOC amount in the soil (Table 4). In 2013, SOC amount was 1.44% for the unlimed treatment and in periodical liming was thus approximately by

0.11-0.18 persentage points lower compared to the unlimed plots. The same tendency was observed in 1996. The lowest amount of soil organic carbon in 1996 and 2013 (1.28 and 1.44 respectively) was obtained in the periodically limed soil using 2.0 liming rate. It could be related to soil pH, which influences the mineralization processes in the soil. The higher soil pH (more than 6.5 pH_{KCl}) activates carbon mineralization processes in soil, and intensive soil liming, when pH_{KCl} ranges from 6.8 to 7.2, can reduce soil organic carbon amount in soil. The humus content showed similar patterns as for SOC content.

Table 3

The effect of periodical liming on the content (%) of water-stable aggregates (>0.25mm)

Treat-ment	Investigation year and vegetation type										
	1996 winter wheat	**1997** mixture of vetch and oat	**1998** mixture of pees and barley	**2002** pere-nnial grasses	**2003** winter wheat	**2004** mixture of pees and barley	**2005** mixture of vetch and oat	**2008** spring barley	**2009** perennial grasses	**2010** winter triticale	**2011** spring rape
Unlimed	57.3	50.4	56.5	56.2	50.9	40.1	42.0	34.2	37.7	26.0	24.8
0.5 rate every 7 years	51.5	48.9	53.4	64.7	63.8*	53.5*	51.4*	47.1*	43.8	32.0	29.8
2.0 rate every 3-4 years	56.0	55.9*	58.4	72.1*	68.4*	50.5*	50.6	42.4	53.2*	30.5	28.8

*Note: * - significantly different from control (P < 0.005)*

Table 4

The effect of periodical liming on the content of soil organic carbon and humic substances

Treatments	Humus,%		Soil organic carbon,%		HA/FA	
	1996	**2013**	**1996**	**2013**	**1996**	**2013**
Unlimed	2.21	2.48	1.28	1.44	0.53	0.79
0.5 rate every 7 years	2.33*	2.29*	1.35*	1.33*	0.60*	0.93*
2.0 rate every 3-4 years	2.20	2.17*	1.27	1.26*	0.59	0.83

*Note: * - significantly different from control (P < 0.005)*

One of the most resumptive indicators of humus quality is the HA/FA ratio. This ratio increased in the periodical limed soil (0.83-0.93) at the both liming rates. The lowest HA/FA ratio was determined in the unlimed soil. In 1996, this ratio was significantly lower in all treatments compared to 2013. The increase of HA/FA ratio showed that the SOC in general became richer in humic acids compared to unlimed soil. It means that the quality of humus improved.

Table 5

The effect of periodical liming on quantity of soil organic carbon forms, Vezaiciai, 2013

Treatments	Dissolved organic carbon	Humic acids	Fulvic acids
	g kg^{-1}		
Unlimed	0.189	0.493	0.617
0.5 rate every 7 years	0.161*	0.506*	0.542*
2.0 rate every 3-4 years	0.156*	0.498	0.595*

*Note: * - significantly different from control (P < 0.005)*

There was found a statistically significant effect of liming on quantity of carbon forms accumulated in the soil (Table 5). The labile fractions of SOC play an important role in the formation of aggregates, and because

of their rapid turnover time they are the most sensitive to changes in soil management. The highest DOC content (0.189 g kg^{-1}) was determined in the unlimed soil. Periodical soil liming resulted in lower DOC content compared to unlimed soil. Various mechanisms have been suggested to explain this phenomenon, such as increased organic matter solubility, increased microbial activity, an increase in the production of soluble molecules due to the decrease in biologically toxic Al at higher pH, and the displacement of the previously adsorbed DOC by other mobilised anions [26].
The effect of periodical soil liming on the distribution of soil carbon in chemical humus fractions was evaluated. Periodical liming significantly decrease the content of humic and fulvic acids. Significant higher carbon content of humic acids was established in the periodical limed soil using 0.5 of the liming rate (3.3 t ha^{-1} $CaCO_3$) every 7 years (0.506 g kg^{-1}). Fulvic acids was dominated in the soil in all treatments. This could be associated with a slow humification processes in the soil, due to the low carbon content, when the content of fulvic acids is always considerably higher compared with humic acids in the soil [24].

CONCLUSIONS

Systematic periodical liming over 56 years (by 0.5 rates every 7 year and 2.0 rates every 3-4 year) on the background of minimal organic fertilizing and conventional tillage, has a positive effect on structure of moraine loam soil *(Bathygleyic Dystric Glossic Retisol).* The largest amount (68.4-72.1%) of water stable aggregates (>0.25mm) occurred in relatively most intensively limed soil than perennial grasses and winter wheat were grown in 2002-2003.

The decrease of water-stable aggregates was appointed in both acid (from 57% to 25%) and limed (from 72% to 29%) soil during the study period. It was influenced by climatic conditions.

Systematic periodical liming decreased the soil organic carbon amount in the soil. SOC amount was approximately by 0.11- 0.18 persentage points lower compared to the unlimed plots (1.44%).

The unlimed soil contained more labile, dissolved organic carbon, which shows it's higher predisposition to transformation. Periodical soil liming resulted in lower dissolved organic carbon content due to the decrease in biologically toxic Al at higher pH.

Periodical liming significantly decrease the content of humic and fulvic acids. Fulvic acids were dominated in the soil in all treatments as a consequence of the low carbon content and slow humification processes in the soil.

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