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Impact of land use change on organic carbon sequestration in Arenosol

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Conversion of arable soils into other land uses can stabilize and increase accumulation of soil organic carbon (SOC) and in addition prevent deterioration in its properties. The data has shown changes in SOC sequestration in Ap horizon after arable land conversion (1995–2015) into managed grassland, abandoned and pine afforested. SOC in Arenosol topsoil was positively affected by long term fallow and conversion into grassland. Abandoned land and fertilised managed grassland accumulated significantly more SOC, 48% and 38% respectively compared with arable land. In unfertilised managed grassland SOC stocks decreased 2.3% during 21 years, but losses were lower than in fertilised arable land. Pine afforestation of loamy sand helped to reduce the intensity of SOM mineralization compared to arable land. The Ap horizon thickness in pine forest soil increased from 28 to 31 cm during 21 years period. However, SOC stock decreased by 1% due to reduction in carbon concentration.

Key words: soil organic carbon storage, land use change, loamy sand, arable Arenosols, soil organic carbon sequestration

Introduction

Loamy sand soils can be found in all parts of the continent, and can be dominant in North-East Europe. These coarse textured soils are usually not environmentally friendly due to properties like low soil organic matter (SOM) and high risk of nutrient leaching. Furthermore, they often have a very low agronomic value. In general terms sandy soils (coarse texture) retain low amounts of SOM, because organic matter is fast decomposed, due to great soil pores and thus high decay rates (Panagos et al. 2014). Globally, the European Union countries have endorsed an ambitious objective of reducing greenhouse gas (GHG) emissions from the agricultural sector. Therefore, improved agricultural practices can help mitigating climate change by reducing emissions from agriculture and storing carbon in plant biomass and soils. Lands of low productivity, but presenting a possibility to sequester large amounts of carbon in soils, create a suitable and cost-effective way to mitigate GHG emissions.

All ecosystems like forests, grasslands, croplands take up atmospheric carbon dioxide (CO_2), mineral nutrients and transform them into organic products. The potential of sequestering atmospheric carbon in soils of all these ecosystems is different which depends on the type of the system, species composition, age of component species, geographic location, various environmental factors, and of course on management practices (Kätterer et al. 2012). Equally, the amount of natural SOC varies depending on the type and texture of soil, waterlogging conditions and the degree of soil cultivation (Tripolskaja et al. 2010).

According to Liu et al. (2014) land use and soil cultivation can not only change the total amount of SOM which is stabilized through physical and chemical processes but they may also change the relative importance of the processes that protect SOM. Accordingly, the changes in SOC formation are expected to act the same. As a rule, traditional arable land use leads to a depletion of SOC stock due to too little input of biomass. In this way, soils contain a lower carbon pool than their potential capacity (Wang et al. 2013). Otherwise, traditional cropland use including fertilisation, manure and other soil amendments increase SOC because it can increase biomass productivity and thus add plant residues. In addition, increased use of forage plants in crop rotations increases SOC because forage plants leave more residues compared to other crops.

Land use change (LUC) can seriously affect soil carbon stocks. Transformation into grasslands or abandonment of agricultural activities may be the best ways to enlarge accumulation of carbon in soil. Other researchers point out that carbon sink effect after abandonment may not be sustainable (Zhang et al. 2012). Compared with tree plantation, natural vegetation restoration requires a long-term process to restore the function of the ecosystem (Jin et al. 2014). Anyway, after a rest period of abandonment soil brings higher yields and at the same time – larger SOC accumulation in traditional agriculture (Navarro and Pereira 2012).

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A forest ecosystem stores larger amounts of carbon than any other one because tree plantations have the potential to increase the carbon pool in biomass and soil. Therefore, many countries, especially developing ones, have chosen tree plantations as a priority method of promoting ecosystem restoration and carbon sequestration (Jin et al. 2014). Forest types influence soil microbial biomass and activities by determining the quantity and quality of SOM inputs in the forest floor. On the other hand, afforestation can lead to lower incorporation of aboveground biomass and lower input of belowground biomass (Perez-Cruzado et al. 2012). The results of soil carbon stocks in forest are likely to be different and an increasing trend of soil carbon is not always represented in the entire forest or at each depth. Some authors have found that pioneer and transition forests have limited effects on SOC accumulation, even if the aboveground biomass rapidly accumulates and reaches a high level (Lv & Liang 2012).

In this study, we examined the effects of LUC (arable land to managed grassland, arable land to abandoned agricultural land, and arable land to afforested land) on SOC sequestration in the topsoil of Arenosol during 21 years transformation period.

Materials and methods

Study site

The long-term experimental sites of this study are located in the South-Eastern part of Lithuania, in the experimental field of the Lithuanian Research Centre for Agriculture and Forestry Voke Branch (54° 33’49.8”N 25° 05’12.9”E). The soil is classified as a loamy sand Arenosol by WRB classification principles (FAO 2015). Soil is formed in fluvioglacial carbonate gravel covered with moraine loamy sand. The total amount of clay particles in the upper part of the profile is low: around 3.75% in Ap horizon, and increases around 7.50% in B1 layer (Table 1). The upper layer of the soil is relatively poor in organic carbon and its amount is significantly reduced in the AB and B1 horizons. The soil reaction is weakly acid (pH_{KCl} 5.8–6.2), because the experimental area was used as arable land for a long time (about 50 years, until 1995) and during that time soil was periodically limed. At the depth of 80–100 cm, the carbonate gravel horizon begins, with the amount of carbonates rising around 7.69–10.07%. The upper part of the profile consists of non-carbonate loamy sand, and the lower part consists of carbonate pebbles and cobbles. This soil has the following profile: Ap-AB-B1-B2-C1-C2.

Table 1. Soil characteristics of experimental site

Profile horizon	Depth (cm)	Texture					
		Sand	Silt	Clay	C_{org}	$CaCO_3 + MgCO_3$	pH_{KCl}
		%					
Ap	0–28	88.58	7.67	3.75	1.02	2.11	6.0
AB	28–43	86.89	8.66	4.45	0.24	1.73	5.8
B1	43–70	84.55	7.95	7.50	0.13	1.59	6.2
B2	70–96	86.80	4.55	8.65	nd	2.05	nd
C1	96–107	91.43	3.53	5.04	nd	7.69	nd
C2	107–121	98.42	1.16	0.42	nd	10.07	nd

nd = *not determined*

The four types of land use in this study were (1) cropland (control) with traditional crops (C); (2) arable land transformed to managed grassland with predominantly hybrid lucerne (MG); (3) uncultivated (abandoned agriculture) site (A) and (4) site afforested with Scots pine (PA) (Fig. 1). The total size of the each site was 400 m^2 (20×20). The cropland site and managed grassland site were divided into two subplots – the unfertilised and fertilised ones. Although the treatments were not replicated, the same cropping history before 1995, and relatively similar soil carbon concentration and bulk density between the sites support the idea to compare changes in soil characteristics after 21 years of different treatments.

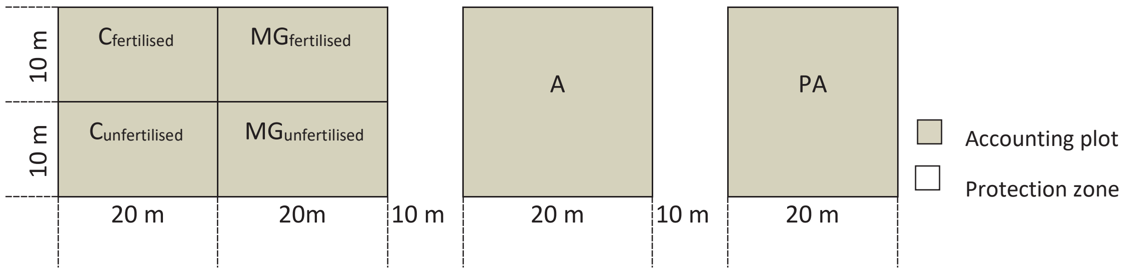

Fig. 1. Design of the experiment

During the period from 1995 to 2015, various agricultural plants were cultivated in the cropland site. During this period the crop rotation was as follows: 23.8% of the cereal crops (*Secale cereale* L.*, Hordeum vulgare* L., *Triticosecale wittmack, Triticum aestivum* L.), 14.3% – cereal crops with perennial grass undercrop, 19% – the *Polygonaceae* (*Fagopyrum esculentum* Moench), 14.3% – perennial leguminous grasses (*Trifolium pratense*), 14.3% – row plants *(Solanum tuberosum* L.) and 14.3% other plants (*Brassica napus* L., *Lupinus angustifolius* L.). The plants were fertilised with mineral NPK fertilisers according to the plants' nutrient demand and plant available phosphorus and potassium concentration status in the soil: the average for N was 0–100 kg ha^{-1}, for P 13–26 kg ha^{-1} and for K 25–100 kg ha^{-1}. In years 1995 and 2000, 40 t ha^{-1} solid manure (78% DM) was applied to the fertilised cropland. No further organic fertilisation was applied. In the cropland site, crop sowing and maintenance were carried out in accordance with the recommended cultivation technologies.

During 1995–2006, in the managed grassland site hybrid lucerne (*Medicago varia* L.) and a mixture of 4 grasses, namely, red fescue (*Festuca rubra* L.), bromegrass (*Bromus inermis* Leyss.), cock's-foot grass (*Dactylis glomerata* L.) and meadow-grass (*Poa pratensis* L.), was cultivated. After 12 years, as the grassland grew old, it was re-sown in 2007, and during 2008–2015 similar grasses were cultivated, but cock's-foot grass was replaced with timothy (*Phleum pratense* L.). The managed grassland site (400 m^2), was equal to the cropland site, and was divided into two subplots – the unfertilised and fertilised ones (200 m^2 each). Mineral fertilisers N 60 kg ha^{-1}, P 39 kg ha^{-1} and K 100 kg ha^{-1} were applied each year. Perennial grass biomass yield was mowed twice during the growing season.

No agro-technical activities were performed on the abandoned land site and on the site afforested with pines. During the investigation period, natural plant community typical of loamy sand soils formed in the abandoned land site; its composition varied depending on hydrothermal conditions of the growing season. In 1995, 39 plant species were established, in 2015 only 18. The dominant species were couch grass (*Elytrigia repens L.*), birds-foot trefoil (*Lotus corniculatus* L.), tall fescue (*Festuca arundibances* Schreb.), cock's-foot grass (*Dactylus glomerata* L.) and Canadian horseweed (*Conyza canadiensis* L.).

Scots pine (*Pinus sylvestris* L.) grew in the pine-afforested site; the density of a 10 year-old site (in 2004) was 8547 trees ha^{-1}; in 2009 the thinning of the site was performed. The density of a 21 year-old site (in 2015) was 3509 trees ha^{-1}.

Meteorological conditions

This region is characterized by temperate climate with a mean long-term (1961–1990) annual precipitation value of 664 mm, and annual mean air temperature of 6.0 °C (the standard climate normal – SCN).

During the experimental years (1995–2015) the weather conditions varied substantially. During the entire period the wet years with rainfall exceeding SCN by 10% were 1998, 2005 and 2009–2015. In those years, the annual rainfall ranged from 731 to 976 mm. Only 1996 was a dry year with 28% of rainfall lower than SCN (519 mm). During the investigation period the temperature regime varied dramatically as well. Starting with 1999 the annual average air temperature exceeded SCN by 0.5–1.8 °C annually. Particularly warm years, when temperatures were above SCN by +1 °C, were 1999, 2000, 2006–2008 and 2013–2015. These variations in precipitation and air temperatures could have affected the dynamics of organic matter decomposition in soil typical of the region.

Soil analyses and estimation SOC stocks

Estimation of SOC stocks required estimates of carbon concentration, bulk density and the depth of a respective soil layer. Texture is relatively homogeneous between plots, which allows a comparison of stable SOC at the field scale (Table 1).

In this study the Ap horizon thickness of all sites was evaluated from the soil profiles prepared at each site in 1995 and 2015. Soil bulk density was also determined twice (at the beginning of the experiment and after 21 years) by core method using a metal ring pressed into the soil (intact core), and determining the weight after drying (McKenzie et al. 2004). For determining organic carbon concentration of the Ap horizon on the abandoned agricultural land site and pine-afforested site, sites were sampled in a 20 m × 20 m grid with 3 replications each. Cropland (fertilised and unfertilised) and managed grassland (fertilised and unfertilised) were sampled in a 20 m × 10 m grid with 3 replications each. These samples were taken in 1995 and 2015. The soil samples were air-dried, gently crushed and passed through a 2-mm mesh sieve. These samples were used for analytical determinations.

Organic carbon concentration of soil was determined by ISO 10694:1995 (Dumas method). SOC stocks in the Ap horizon were calculated as follows (Poeplau et al. 2017):

$$SOC_{stock}\ (\mathrm{Mg\ ha^{-1}}) = SOC_{con} \times BD_{sample} \times depth \div 10,$$

where SOC_{con} is SOC concentration (g kg $^{-1}$), BD is bulk density of the total sample (Mg m^{-3}), depth is the thickness of the Ap horizon (cm), 10 – coefficient to calculate SOC stocks in Mg ha^{-1}.

Statistical analysis

The data were evaluated by analysis of variance (ANOVA) using the Fisher's test and Duncan's multiple range test ($p<0.05$). Significant differences in this study were evaluated by the least significant difference (LSD) and with a confidence at the level of $p<0.05$. The data were reported as a mean value ± standard deviation in Table 2. The data was structured and analyzed using the software Microsoft Excel software package.

Results and discussion

21 years ago, when the experiment began, arable land areas were abandoned, transformed into managed grasslands and afforested with pines. The transformation of arable land into different land uses caused changes in the humic Ap horizon thickness in two directions: one associated with the ploughing depth in the soil profile and the other associated with humification and forms a litter of large thickness.

Arable land use

An evaluation of variations in soil properties carried out in 2015 confirmed that it is very complicated to stabilise organic carbon supply in unfertile arable loamy sand soils. Applying the traditional field crop rotation with 38.2% of *Poaceae* (cereal crops) and 14.3% of perennial grasses, and without the use of organic fertilisers the organic carbon concentration in the Ap horizon decreased from 9.5 to 8.8 g kg^{-1} organic carbon over the 21 year period (Table 2). This testifies to the fact that the amount of stubble and other plant residues of the crops in rotation entering soil after harvesting were insufficient to restore humus mineralisation losses associated with tillage. Mikha et al. (2017) obtained results confirmed that a stable humus balance in coarse texture soils can be maintained only by fertilisation with manure or including a major part of perennial and annual *Fabaceae* plants in rotation.

Table 2. Organic carbon accumulation in soil

LUC	Years	T (cm)	SOC_{con}(g kg^{-1})	BD (Mg m^{-3})	SOC (Mg ha^{-1})
$C_{unfertilised}$	1995	28	9.5±0.08	1.36±0.02	37.8 a
	2015	28	6.8±0.12	1.39±0.03	26.5 c
$C_{fertilised}$	1995	28	9.5±0.08	1.32±0.02	35.1 a
	2015	28	8.8±0.21	1.34±0.03	33.0c
$MG_{unfertilised}$	1995	28	9.9±.0.08	1.41±0.02	39.4 a
	2015	30	9.4±0.12	1.37±0.02	38.5 bc
$MG_{fertilised}$	1995	28	9.9±0.08	1.45±0.02	40.2 a
	2015	32	10.8±0.12	1.32±0.05	45.6 abc
A	1995	28	9.9±0.08	1.33±0.02	39.4 a
	2015	34	10.5±0.15	1.37±0.05	49.0 abc
PA	1995	28	9.7±0.08	1.30±0.02	35.3 a
	2015	31	8.8±0.38	1.28±0.02	35.1 a
$LSD_{0.05}$	1995		0.13	0.02	
	2015		0.69	0.14	

LUC = land use change; T = thickness of Ap horizon (cm); BD = bulk density; SOC = soil organic carbon; SOC_{con} = soil organic carbon concentration; $C_{unfertilised}$ = cropland unfertilised; $C_{fertilised}$ = cropland fertilised; $MG_{unfertilised}$ = managed grassland unfertilised; $MG_{fertilised}$ = managed grassland fertilised; A = agriculture abandoned; PA = pine afforested; mean value ± standard deviation

Calculations of carbon sequestration developments in the Ap horizon revealed that during the 21 year period its stock in the soil of a fertilised field in crop rotation declined by 2.10 Mg ha^{-1}, which is about 0.1 Mg ha^{-1} organic carbon lost each year (Fig. 2). The losses were associated with the reduction in carbon levels as the Ap horizon thickness had not changed during 21 years. In 2015 as in 1995 it remained 28 cm thick and it confirms the fact that humus accumulation in the loamy sand soil of arable land is hardly possible as the major part of biomass is brought out, and the remainder does not counter balance organic matter consumption and the extent of mineralisation. Humus accumulation is stimulated by such agrotechnical measures as incorporation of non-organic and organic fertilisers, plant residues and other biomass as well as zero tillage (Kätterer et al. 2012, Lal 2013, Jin et al. 2014).

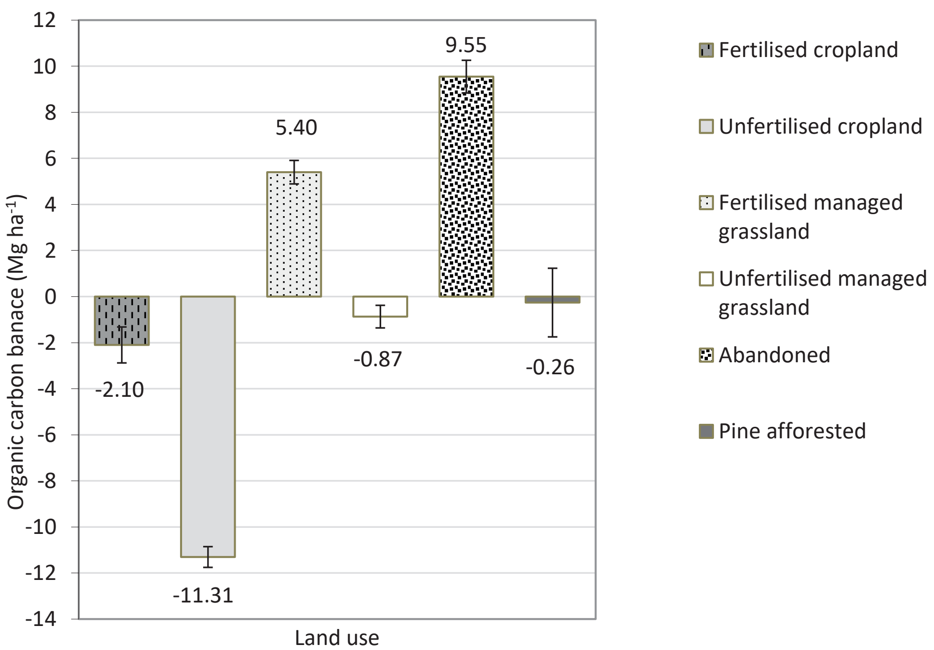

Fig. 2. Changes of organic carbon sequestration (Mg ha^{-1} ± standard deviation) in soils of different land use during 21 years

During the 21 year period organic carbon stocks in the Ap horizon decreased by 11.31 Mg ha^{-1} organic carbon and its concentration – from 9.5 to 6.8 mg kg^{-1}. An annual loss was 0.54 Mg ha^{-1} carbon. Compared to the soil of a fertilised field in crop rotation, after 21 years of different soil use, carbon stock level differed by more than 5 times. This data once again confirms the fact, that unfertile land must undergo a balanced application of organic and mineral fertilisers to produce sufficient amounts of plant residues and other organic matter sources, which would cover losses induced by SOM mineralisation in arable land. A drastic decrease of organic carbon concentrations in unfertilised land is noted by other scientists as well (Jia et al. 2005).

Arable land transformation into abandoned land

One of the easiest ways to reduce degradation process of unfertile arable land is land abandonment. Such type of land use enables increasing organic carbon sequestration in soil, as the aboveground and belowground vegetation biomass replenishes the Ap horizon with humus matter during biochemical transformation after vegetation is over, thus reducing CO_2 emissions into the atmosphere. Scientists (Kurganova et al. 2014, 2015), who explored the SOC accumulation in unmanaged soils formed of previously arable lands, confirmed that unmanaged land areas in Russia and Kazakhstan can accumulate about 18% of global CO_2 release and respectively compensate for about 36% and 49% of annual emissions due to fossil fuel use in these countries. Our data indicates that loamy sand soil being abandoned over 21 years increased its organic carbon stock by 24.3%. On abandoned site, naturally growing plants accumulated 31.1 Mg ha^{-1} of dry matter yield (Kazlauskaite-Jadzevice et al. 2016).

The annual increase of soil organic carbon content averaged to 0.46 Mg ha^{-1} in abandoned land. The influence of herbaceous plants on carbon accumulation under humid and relatively warm climatic conditions was significantly positive: Ap horizon thickness increased from 28 to 34 cm, while carbon concentration increased from 9.9 g to 10.5 g kg^{-1}. Zhang et al. (2012) found that SOC stock increased when arable cropland had been abandoned for 6 years. The research showed that during this period of time SOC storage increased by 5.1% after abandonment of arable land. Where the arable land was converted to artificial grassland and abandoned, the SOC storage at the 0–20 cm depth increased by 22.6%.

The experimental results obtained by our and other authors show that rapid organic carbon accumulation processes in the soils of abandoned land improve soil properties and open up a possibility to include such soils back into arable land fund in case of need. Such a way of preserving soils of low productivity allows improving soil properties and carbon sequestration without huge costs, however, in terms of economy it entails losses.

Arable land transformation into grassland

Another way of reducing degradation processes of low productivity arable land is its transformation into managed grassland. Hydrothermal conditions in Lithuania are favourable for the growth of herbaceous plants, therefore, managed grassland and pasture areas comprise 23% of agricultural land. A variety of scientific publications indicates that soils with managed grassland plant community are characterised by organic carbon accumulation (Martens et al. 2003, Stypinski and Mastalerczuk 2006). According to de Deyn et al. (2009) faster carbon accumulation occurs when several species of herbaceous plants are grown. They found that the co-occurrence of species from specific functional groups is crucial for the maintenance of multifunctionality with respect to carbon and nitrogen storage in grasslands.

The experimental results showed that the accumulation of SOC in managed grassland, low-productive soil depends also on fertilisation. In the case of unfertilised managed grassland SOC concentration in the Ap horizon over 21 years changed marginally (–0.5 mg kg^{-1}), while ongoing sod formation processes (accumulation of organic fallings on the soil surface and their humification) resulted in its thickness increase of about 2 cm (from 28 to 30 cm). These changes resulted in organic carbon stock decrease in the Ap horizon. Mineralisation losses over 21 years accounted only for 0.87 Mg ha^{-1} organic carbon or 0.04 Mg ha^{-1} annually.

Compared to the unfertilised land in crop rotation (organic carbon balance –11.31 Mg ha^{-1}), herbaceous plants reduced organic carbon losses 13 times (organic carbon balance –0.87 Mg ha^{-1}). However, compared to abandoned land, grassland was much less effective in terms of SOC sequestration, as managed grassland vegetation biomass was removed and used for animal feed, and new humus matter was actually formed only from the belowground part of plants.

Application of mineral fertilisers increases both aboveground and belowground biomass of herbaceous plants and creates preconditions for faster soil carbon sequestration in soil (Kätterer et al. 2012, Lal 2013). In our experiment fertilised grassland SOC stock increased by 13.4% over 21 years in Ap horizon. On average, 0.46 Mg ha^{-1} organic carbon was accumulated per year. Supposedly, such increase is associated with the botanical composition of herbs, the mixture of which consisted of 4 kinds of *Poaceae* grasses and lucerne. Fornara and Tilman (2008) propose that the accumulation of SOC in grassland soil depends on plant root biomass. The combination of key C4 grass–legume species may greatly increase ecosystem services such as soil carbon accumulation and biomass production in both high- and low-diversity N-limited grassland systems. The importance of root biomass in SOC accumulation in soil is indicated in the works of other scientists as well. Researchers (Chen et al. 2007, Wei et al. 2012), who were exploring the SOC accumulation in forest and grassland soils, indicated that higher carbon accumulation occurs in grassland soil because of a strong and well developed root system. It is indicated that carbon accumulation is higher in grassland soil as some part of the aboveground biomass dies each year and becomes a part of SOC, whereas in forests a certain share of biomass does not enter soil but is accumulated in plant perennial parts. This data support the universally growing interest related with the effects of climate change and the increase in SOC pool in grasslands. A change in land use and management can be a strategic commitment to increase SOC sequestration with the help of managed grasslands (Lal 2013).

Arable land transformation into pine afforested land

Transformation of arable land into forest causes significant carbon cycle changes within the ecosystem. Carbon accumulation is concentrated in tree biomass and carbon stock in soil is increased only by microbial biomass carbon and tree fallings, and the role of roots in organic carbon accumulation becomes less important. According to our experimental data, pine afforestation of loamy sand arable land helped to reduce the intensity of SOM mineralisation. SOC concentration in the Ap horizon in forest soil decreased during the study period by 0.9 mg kg^{-1}, while the losses in unfertilised soil in crop rotation were three times as high (2.7 mg kg^{-1}). Similarly, Zhiyanski et al. (2015) reported that in Bulgaria afforestation by coniferous species helped accumulate and preserve soil carbon, but even several decades after the conversion from arable cropland or abandoned land to forest land use, this effect was expressed only weakly and could not compensate the organic carbon loss due to previous active cultivation. Also in Northern Europe (Barcena et al. 2014), afforestation with conifers for the periods <30 years and >30 years since afforestation revealed a shift from initial loss to later gain of SOC. Paul et al. (2002) found that soil carbon in the <10 cm (or <30 cm) layers generally decreased by 3.46% per year (or 0.63% per year) relative to the initial soil carbon content during the first 5 years of afforestation.

Fontaine et al. (2007) found, that adding fresh plant-derived carbon to the soil stimulated the microbial mineralization of old carbon, which can accelerate old SOC decomposition. Moreover, a lack of supply of fresh carbon may prevent the decomposition of the organic carbon pool in soil in response to future changes in temperature. Thus, the amount of SOC in the upper layer of forest soil depends in particular on the type of forest fallings; it is also associated with soil pH and the period of renaturalisation. Annual SOC replenishment with needle fallings contributes to soil acidification and accelerates the breakdown of old SOC, however, during the first decade, when trees only start growing, the amount of fallings is low. The amount of fallings increases when the trees become older. Therefore, the accumulation of SOM in a pine forest is not as high compared to grassland and abandoned land.

Although SOC concentration in pine forest land decreased over 21 years, the Ap horizon thickness increased from 28 to 31 cm that is associated with floor formation and development of new humic substances in the process of mineralisation. Therefore, in spite of the decrease in organic carbon concentration its stock in the Ap horizon over 21 years decreased marginally – only by 1%.

In summing up SOC sequestration processes, it can be stated that afforestation with conifers in unfertile loamy sand soils of fluvioglacial origin does not ensure the increase of carbon stock, however, it allows a substantial decrease in SOM mineralisation processes compared to arable land. Potentially, the conversion period of two decades is too short for soil improvement in a territory afforested with conifers and can only become useful in the long term. Nevertheless, having evaluated organic carbon sequestration in soil when afforestation with coniferous species is applied, it can be proposed that this conversion method will facilitate SOC accumulation in the longer term, compared to other land use type. In the experiment (John et al. 2005), comparing possibilities of different land uses (cropland, grassland and spruce forest) in silty loam to accumulate SOC, the results showed that even an 80-year-old coniferous (spruce) forest was able to accumulate only the lowest amount of carbon. The research data obtained by Schulp et al. (2008) indicates that organic carbon accumulation in forest soil depends on tree species and can differ by more than 2 times. Coniferous forests accumulate less SOM compared to deciduous forests and this must be taken into account in selecting the way of unfertile land afforestation. However, it should also be noted that in Lithuania, favourable conditions for broadleaf stands, the fallings of which form mull humus, are only in locations with predominant fertile carbonate loam soils. Therefore, in providing recommendations account should be taken of the carbonate content of subsoil and parent material (C horizon).

Conclusions

Intensity of SOC accumulation in low-productivity soils depends on land use intensity and agro-technical measures undertaken, fertilisation as well as the removal of biomass. In order to increase SOC accumulation in such soils, permanent grassland should be maintained, fertilisation applied and biomass removal reduced. This would make it possible to maintain and increase soil economic potential and contribute to the mitigation of climate change.

In optimising the use of low-fertility fluvioglacial loamy sand soils and in stimulating SOC sequestration, abandoned land and managed grassland should be chosen because SOC sequestration is faster in grass vegetation community. Compared to managed grassland, SOC accumulation in abandoned land is much faster (0.46 Mg ha^{-1} $year^{-1}$) as the entire vegetation biomass of abandoned land is involved in the cycle of new humic substance formation. The soil carbon stock increase in managed grassland ecosystems (0.29 Mg ha^{-1} $year^{-1}$) takes place solely due to the application of mineral fertilisers that increases biomass production.

Compared to field crop rotation, afforestation with coniferous (pine) species facilitated the reduction of SOM mineralisation and stabilisation of organic carbon stock in soil during the first 21 years.

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