FERTILIZED SHORT ROTATION PLANTATIONS OF HYBRID ASPEN (*POPULUS TREMULOIDES* MICHX. × *POPULUS TREMULA* L.) FOR ENERGY WOOD OR MITIGATION OF GHG EMISSIONS

Arta Bardule[1,2], Andis Lazdins[1], Toms Sarkanabols[1], Dagnija Lazdina[1]
[1]Latvian State Forest Research Institute "Silava"; [2]University of Latvia
arta.bardule@silava.lv, dagnija.lazdina@silava.lv

Abstract. Agroforestry, an ecologically and environmentally sustainable type of land use, offers great opportunity to sequestrate carbon in above- and below-ground carbon pools. Aspens (*Populus spp.*) are accepted as an agriculture energy crop with rotation period up to 5 years in Latvia since 2011. The research aim was to determine the productivity and removals of CO_2 in a hybrid aspen (*Populus tremula* L. *x P.tremuloides* Michx.) plantation during the 5 years rotation period after managing the plantation as an agroforestry system together with perennial crops – reed canary grass (*Phalaris arundinacea* L.), festulolium (x *Festulolium pabulare*) and fodder galega (*Galega orientalis* Lam.), as intercrop, and fertilized with biogas production residues (30 tonnes·ha^{-1}), wastewater sludge (10 tonnes$_{DM}$·ha^{-1}) and wood ash (6 tonnes$_{DM}$·ha^{-1}). The most important impact on the plantation's productivity has selection of the clone, although relevant impact on the tree growth was observed for fertilizer application and the type of intercrop. The most significant impact on the growth of the most productive clone No 4 demonstrated fertilization with biogas production residues and waste water sludge – 0.3-4.2 fresh tonnes of additional biomass compared to control without intercrop and without fertilizer. Comparing different intercrops, the best results were obtained with galega and red canary grass – 3.3 and 3.7 fresh tonnes of biomass higher stock in comparison to control unfertilized plots. The best combination was clone No 4 fertilized with wastewater sludge or biogas fermentation residues in combination with reed canary grass (*Phalaris arundinacea* L.) intercrop – 16.4 fresh tonnes of biomass (42 MWh of primary energy per hectare) or 16.5 tonnes·ha^{-1} of CO_2 removed in above ground biomass (8.5 tonnes$_{DM}$·ha^{-1}). This study demonstrated that soil bulk density and organic carbon stock in upper soil layers decreased significantly during the 5 years after establishment of the fertilized hybrid aspen plantation in carbon rich mineral agricultural soil.

Keywords: hybrid aspen, carbon stock, biomass, mineral soil.

Introduction

According to the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol afforestation, reforestation, and deforestation (Article 3.3), as well as forest management, cropland management, grazing land management, and revegetation (Article 3.4) can be used to meet the greenhouse gas (GHG) emission reduction goals [1; 2]. Agroforestry systems combining trees or shrubs (perennial crops) with conventional farm crops (annual or perennial) are recommended by the European Rural Development Council regulation 1698/2005 and Clean Development Mechanisms of the Kyoto Protocol to be used to reach the GHG reduction goals in recognition of their role as carbon (C) storage, which can contribute significantly to fulfil the Kyoto Protocol targets [3; 4]. Several studies suggest agroforestry as a system with high potential to accumulate C in 5 main pools, namely, in aboveground plant biomass (tree and understory), plant roots (tree and understory), litter, microbial, and soil C [2; 5; 6]. If agroforestry systems are managed sustainably, C can be retained in these systems for centuries [7], but the potential of C sequestration in agroforestry systems depends on the tree species, growth rate, as well as soil type and land management practices [2; 8; 9].

The area of the short-rotation plantations of hybrid aspen (*Populus tremula* L. x *P. tremuloides* Michx.) for pulp and energy wood production with approximately 25-year rotation period has increased considerably during the last few decades in Northern Europe on non-used agricultural lands. Hybrid aspen has proven to be one of the most promising species for intensive pulp and biomass production in this region due to its fast growth, cold and pathogen resistance and the continuously improving planting material provided by long-term breeding programs [10]. In Latvia, aspens (*Populus* spp.) are accepted as agriculture energy crop with the rotation period up to 5 years since 2011 [11]. The changes made in the law "On Agriculture and Rural Development" at January 1, 2015 proposes that fast growing energy wood tree plantations are agriculture crops with maximum 15 years rotation period. But according to the regulations on implementation of the Rural development programme and national subsidies for farmers energy wood crops are eligible for area payments only if they are managed as short rotation coppice with up to 5 years rotation period [12].

Although both organic and inorganic forms of C are available in soils, land use and management activities typically affect more soil organic matter [13]. Soil organic matter as a complex mixture of plant and animal residues in various stages of decomposition is not only a key indicator of soil health and the main indicator of soil quality, but also natural, effective, and environment friendly carbon storage compensating atmospheric CO_2 emissions, which has become a main strategy for the climate change mitigation [14; 15]. Sequestration of carbon in soil is one of the main tools to reduce the CO_2 concentration in the atmosphere by establishment of long term C storages and replacement effect constituting fossil fuel in heat and power applications through afforestation, reforestation, and restoration of degraded lands [6; 8; 9]. Agroforestry is one of the measures that are currently being promoted to address the climate change mitigation targets through carbon conservation in soil and other C pools [16].

The research aim was to determine the productivity and CO_2 removals in a hybrid aspen (*Populus tremula* L. x *P.tremuloides* Michx.) plantation during the 5 years rotation period after managing the plantation as an agroforestry system together with perennial crops – reed canary grass (*Phalaris arundinacea* L.), festulolium (x *Festulolium pabulare*) and fodder galega (*Galega orientalis* Lam.), as intercrop, and fertilized with biogas production residues (30 $tonnes_{DM}\cdot ha^{-1}$), wastewater sludge (10 $tonnes_{DM}\cdot ha^{-1}$) and wood ash (6 $tonnes_{DM}\cdot ha^{-1}$). The research was done within the scope of the European Regional Development fund projects No 2013/0049/2DP/2.1.1.1.0/13/APIA/VIAA/031 & 2010/0268/2DP/2.1.1.1.0/10/APIA/VIAA/118.

Materials and methods

Study site

The research was carried out in the central part of Latvia. The experimental plot (lat: 56.6919, lon: 25.1370) was established on agricultural land in the spring of 2011. The experimental plantation of hybrid aspen (*Populus tremula* L.× *P. tremuloides* Michx.) cultivated in the agroforestry system is a part of the large scale multifunctional plantation of different short rotation energy crops and deciduous trees with the total area of 16 ha. The soil type in the experimental plot is *Luvic Stagnic Phaeozem* (*Hypoalbic*) and *Mollic Stagnosol* (*Ruptic, Calcaric, Endosiltic*) according to FAO (2006) with dominant loam (at 0–20 cm depth) and sandy loam (at 20–80 cm depth). The plantation was fenced in the autumn, 2012. The mean annual air temperature in the time period between 2011 and 2015 ranged from 6.1 to 7.7 ºC at the study site, the annual rainfall ranged from 653 to 856 mm.

Design and planting material

Hybrid aspen (*Populus tremula* L.× *P. tremuloides* Michx.) seedlings were planted in the agroforestry system, the planting material was produced by the JST "Latvia State forest" in Latvia. The average distance between the trees was 2.5 x 5.0 m and 2.0 x 2.0 m. Between the trees (distance between rows 5 m) 2 legume and 2 perennial grass cultivars were sown for seed production: fodder galega (*Galega orientalis* Lam.) 'Gale', poor-alkoloid lupine (*Lupinus polyphyllus* L.) 'Valfrids', reed canary grass (RCG) (*Phalaris arundinacea* L.) 'Bamse' and festulolium (x *Festulolium pabulare*) 'Felina'. The grasses and the legumes were sown in 2.5 m wide bands and the size of a single plot was 60 m^2. A free space of 1.25 m between trees and grasses was provided. The grasses and legumes were sown without a cover crop using narrow row spacing for RCG and festulolium, and broad row spacing (36 cm) for galega and lupine.

Treatments

Four replications of 4 different fertilisation subplots – control (no fertilisation), wastewater sludge, wood ash and digestate (fermentation residues from biogas production) were used, the size of each plots was – 30 x 24 m. First quality class wastewater sludge (according to the regulations of the Cabinet of Ministers of the Republic of Latvia No. 362, applied amount 10 $tonnes_{DM}\cdot ha^{-1}$) from Ltd. 'Aizkraukles ūdens' (Aizkraukle Water) and stabilized wood ash from the boiler house in Sigulda (applied amount 6 $tonnes_{DM}\cdot ha^{-1}$) were spread mechanically before planting of hybrid aspen and sowing of legumes and perennial grasses. Digestate (dose 30 $tonnes\cdot ha^{-1}$) from the methane reactor in Vecauce municipality was applied immediately after planting of hybrid aspen. Threshold values of the heavy metal content and precautionary limits were not exceeded in the fertilised soils according to the regulation on soil and ground quality (regulations of the Cabinet of Ministers of the Republic of Latvia No. 804).

Measurements of trees

During the study the height, diameters at breast height (DBH) and biomass of aspen clones No 4 and No 28 was measured. Biomass equations were elaborated using 10 representative trees per clone. Sample trees were selected by considering the average tree height evenly along the plantation. The moisture content was determined by weighing naturally wet biomass of wood samples and again after drying the samples till constant weight at 105 ºC temperature. Carbon content in biomass (trunk and branches) was determined using equations developed by Muiznieks and Liepins (2016) for hybrid aspen [17]. In order to determine average carbon stock in trees the quotients were recalculated using the proportion of trunk and branches. Estimated carbon content in biomass is 511.33 g $C \cdot kg^{-1}$. Using the default methods provided in the IPCC Guidelines for National Greenhouse Gas Inventories (2006) the amount of CO_2 removed by the plantation was calculated.

Sampling and analyses of soil

Soil was sampled in each sample plot in 3 repetitions in 2011 (before planting of hybrid aspen seedlings, but after fertilization) and in 2015 (after 5 growing seasons). Soils were sampled at 0-20 cm, 20-40 cm, 40-60 cm and 60-80 cm depth using undisturbed soil sample probes (steel cylinder with a 100 cm³ volume). The soil samples were prepared and analyzed in the Forest environment laboratory of the LSFRI Silava according to standard methods approved by the ICP forest monitoring programme. The soil samples were prepared for analyses according to the LVS ISO 11464 (2005) standard. Fine earth fraction of soil ($D < 2$ mm) was used for chemical analysis. The following parameters were determined in the soil samples: bulk density according to LVS ISO 11272:1998, total C content using elementary analysis according to LVS ISO 10694 (2006), carbonate content using Eijkelkamp calcimeter according to ISO 10693. Soil organic carbon stock (SOCS) was calculated according to Eq. (1) [18].

$$SOCS = SOC \cdot SBD \cdot H \cdot \left(1 - P_{2mm}\right) \cdot 100^{-1}, \tag{1}$$

where $SOCS$ – soil organic carbon stock per unit area, kg m^{-2};
SOC – organic carbon content in soil, g kg^{-1};
SBD - soil bulk density, g cm^{-3};
H – thickness of the soil layer, cm;
P_{2mm} – volume fraction of > 2 mm particles in the soil (assumed to be zero as the value is negligible in most soils), %.

SOCS was calculated in 4 layers – at 0-20 cm, 20-40 cm, 40-60 cm and 60-80 cm depth. Similarly, cumulative organic C stock in soils was calculated for 4 layers – at 0-20 cm, 0-40 cm, 0-60 cm and 0-80 cm depth. We analyzed significance of differences between *SOCS* in 2011 and 2015 based on the assumption that in 5 growing seasons after establishment of the plantation soil bulk density has not been changed. We made this assumption to avoid the impact of soil expansion on *SOCS* at monitored soil layer.

Statistical analysis

Parametric statistical methods were used to analyse the tree biomass data (number of total tree biomass measurements – 712; number of total clone No 4 biomass measurements – 394), normal distribution was tested using package Car (function qqPlot) in program R. Statistical differences in biomass of the trees under different treatments were compared by the *T*-test. Nonparametric statistical methods were used to analyse the data of the soil properties. Statistical differences in soil bulk density, *SOC* and *SOCS* between treatments and hybrid aspen planting designs were analyzed with Wilcoxon rank sum test with continuity correction and Tukey's honestly significant difference (HSD) test. Also we used Wilcoxon signed rank test with continuity correction to assess the significance of the land use change on the monitored soil parameters. We used a 95 % confidence level in all analyses. Data analysis was conducted in program R (R Core Team, 2015) for Linux.

Results and discussion

Biomass of trees under different treatment and agroforestry system with intercrop

The study approved the hypothesis proved in previous studies that hybrid aspen clone No 4 is significantly more productive than clone No 28 [19]. Consequently, the clone had the most significant impact on the productivity of the plantation – yield of clone No 4 was by 33 % higher in comparison to clone No 28 in control plots, thereby the following data on biomass and other parameters represent this, more productive, clone (Table 1). The significant impact on tree growth was demonstrated by fertilization with biogas production residues or wastewater sludge, by 0.3-4.2 tonnes higher fresh biomass yield in comparison to control without fertilizer and intercrop (3.1 tonnes of fresh biomass).

Table 1

Biomass, C and energy stock produced in hybrid aspen agroforestry system with perennial grasses and legume galega (during 5 years rotation period, clone No 4)

Fertilizer	Intercrop	Survival, %	Naturally wet wood biomass at real survival, tonnes·ha^{-1}	Naturally wet wood biomass at converted 100% survival, tonnes·ha^{-1}	Obtainable amount of heat, MWh·ha^{-1}	Absolutely dry wood biomass at real survival, tonnes·ha^{-1}	Absolutely dry wood biomass at converted 100% survival, tonnes·ha^{-1}	Stocked CO_2, tonnes·ha^{-1}
Digestate	Festulolium	96 (*n* = 26)	6.0 ± 0.9	6.2	16.0	3.2	3.4	6.4
	Fodder galega	85 (*n* = 23)	12.7 ± 2.7*	14.9	38.6	6.9	8.1	15.2
	Control	89 (*n* = 24)	6.5 ± 1.4	7.3	18.9	3.5	3.9	7.3
	Reed canary grass	96 (*n* = 26)	15.7 ± 1.8*	16.4	42.4	8.5	8.8	16.5
Sludge	Festulolium	81 (*n* = 22)	6.6 ± 1.6	8.2	20.8	3.5	4.4	8.2
	Fodder galega	81 (*n* = 22)	7.4 ± 1.8	9.2	23.4	4.0	4.9	9.2
	Control	93 (*n* = 25)	6.4 ± 1.2	6.9	17.5	3.4	3.7	6.9
	Reed canary grass	96 (*n* = 26)	15.7 ± 1.8*	16.4	41.7	8.4	8.7	16.3
Ash	Festulolium	81 (*n* = 22)	3.1 ± 1.0	3.8	9.4	1.6	2.0	3.7
	Fodder galega	89 (*n* = 24)	7.1 ± 1.4*	7.9	19.5	3.7	4.1	7.7
	Control	81 (*n* = 22)	2.7 ± 0.9	3.4	8.4	1.4	1.8	3.4
	Reed canary grass	96 (*n* = 26)	10.7 ± 1.4*	11.2	27.6	5.6	5.8	10.9
Control	Festulolium	89 (*n* = 20)	2.3 ± 0.9*	2.6	6.3	1.2	1.4	2.6
	Fodder galega	74 (*n* = 20)	5.0 ± 1.6*	6.8	16.5	2.6	3.5	6.6
	Control	81 (*n* = 22)	2.5 ± 0.8	3.1	7.5	1.3	1.6	3.0
	Reed canary grass	82 (*n* = 44)	5.2 ± 0.7*	6.4	15.6	2.7	3.3	6.2

** Significant differences from control within treatment (within one fertilization type); compared naturally wet wood biomass only.*

n – number of tree biomass measurements within fertilisation and intercrop subplot.

In all plots intercrop stimulated growth of trees. Fodder galega and red canary grass intercrop demonstrated the biggest impact on tree growth, by 3.3 and 3.7 tonnes, respectively, more fresh biomass on unfertilized plots in comparison to control plots. The most productive combination was fertilization with wastewater sludge or biogas production residues in combination with reed canary grass (*Phalaris arundinacea* L.) intercrop – 16.4 tonnes of fresh above ground biomass in 5 years rotation (42 MWh of primary energy per hectare). At the end of the fifth year after planting the above ground biomass of trees in the wastewater sludge or biogas production residues fertilized plots was 8.5 $\text{tonnes}_{DM}\cdot ha^{-1}$ corresponding to 16.5 tonnes·ha^{-1} of CO_2 removals.

Organic carbon stock in soil

The changes of *SOCS* after afforestation of cropland have been widely investigated across the globe, but less is known about the variations in *SOCS* after establishment of fertilized short rotation plantations cultivated as an agroforestry system [20]. *SOCS* is the function from soil bulk density and *SOC* in different soil layers [18]. The mean soil bulk density and *SOC* in soil are summarized in Table 2.

Table 2

Soil bulk density and SOC by planting design and treatments

Parameter	Year	Planting design: 2.0 x 2.0 m					Planting design: 2.5 x 5.0 m				
		control	digestate	sludge	wood ash	mean	control	digestate	sludge	wood ash	mean
Soil layer: 0-20 cm											
Bulk density, kg·m^{-3}	2011	1578 ± 153	1585 ± 56	1534 ± 91	1640 ± 78	1584 ± 46	1547 ± 91	1524 ± 82	1241 ± 72	1520 ± 82	1458 ± 49
	2015	1395 ± 98	1323 ± 89	1442 ± 61	1489 ± 108	1412 ± 43*	1362 ± 62	1293 ± 25	1305 ± 68	1439 ± 92	1350 ± 33*
SOC, g kg^{-1}	2011	22.1 ± 6.1	19.8 ± 3.6	18.6 ± 0.5	18.7 ± 6.1	19.8 ± 2.1	28.4 ± 4.3	24.1 ± 1.6	28.1 ± 3.7	23.0 ± 4.2	25.9 ± 1.7**
	2015	21.5 ± 5.3	21.5 ± 5.9	17.2 ± 0.5	17.3 ± 5.9	19.4 ± 2.3	27.3 ± 3.0	23.4 ± 1.3	28.4 ± 6.7	19.6 ± 4.3	24.7 ± 2.1**
Soil layer: 20-40 cm											
Bulk density, kg·m^{-3}	2011	1510.0 ± 67.6	1505.3 ± 33.7	1582.0 ± 141.7	1559.5 ± 91.9	1539 ± 42	1507.5 ± 80.9	1597.3 ± 71.3	1628.0 ± 70.4	1665.8 ± 61.5	1600 ± 35
	2015	1388.6 ± 114.0	1293.8 ± 59.6	1468.7 ± 44.1	1460.7 ± 53.2	1403 ± 37*	1327.1 ± 85.4	1295.3 ± 44.7	1334.5 ± 71.4	1415.0 ± 63.2	1343 ± 32*
SOC, g·kg^{-1}	2011	16.5 ± 7.8	20.0 ± 4.1	13.4 ± 0.9	14.6 ± 5.6	16.1 ± 2.4	24.1 ± 7.3	17.6 ± 3.3	24.6 ± 5.7	23.4 ± 3.9	22.4 ± 2.5**
	2015	21.0 ± 6.4	19.1 ± 5.1	17.0 ± 2.4	13.3 ± 3.9	17.6 ± 2.2	20.8 ± 6.3	22.1 ± 1.1	21.8 ± 4.5	18.2 ± 5.4	20.7 ± 2.2
Soil layer: 40-60 cm											
Bulk density, kg·m^{-3}	2011	1628.3 ± 83.8	1675.3 ± 129.8	1744.8 ± 92.6	1692.5 ± 95.0	1685 ± 47	1787.5 ± 30.6	1693.0 ± 186.1	1750.8 ± 60.4	1727.5 ± 40.9	1740 ± 46
	2015	1513.0 ± 159.2	1576.0 ± 138.5	1671.3 ± 85.1	1660.3 ± 91.7	1605 ± 57*	1788.8 ± 58.9	1700.6 ± 110.1	1548.2 ± 175.0	1691.5 ± 61.8	1682 ± 55
SOC, g·kg^{-1}	2011	12.8 ± 10.3	8.3 ± 3.8	3.6 ± 0.3	2.7 ± 0.4	6.8 ± 2.7	3.1 ± 0.3	5.5 ± 1.3	11.9 ± 9.9	6.9 ± 3.7	6.9 ± 2.5
	2015	8.0 ± 5.9	6.5 ± 3.9	1.2 ± 0.6	3.3 ± 2.3	4.8 ± 1.8*	0.9 ± 0.3	2.1 ± 0.9	13.3 ± 12.5	0.9 ± 0.4	4.3 ± 3.1*
Soil layer: 60-80 cm											
Bulk density, kg·m^{-3}	2011	1785.5 ± 22.9	1741.0 ± 88.3	1823.3 ± 55.2	1784.0 ± 24.9	1783 ± 26	1849.8 ± 40.9	1874.5 ± 34.6	1833.8 ± 26.2	1779.3 ± 62.5	1834 ± 21
	2015	1749.8 ± 70.6	1605.7 ± 121.6	1758.3 ± 83.3	1731.0 ± 80.1	1711 ± 44	1715.5 ± 23.9	1748.4 ± 72.5	1711.2 ± 47.9	1700.7 ± 60.8	1719 ± 25*
SOC, g·kg^{-1}	2011	14.1 ± 11.8	2.7 ± 0.7	2.8 ± 1.1	2.0 ± 0.6	5.4 ± 2.9	3.2 ± 1.3	1.4 ± 0.6	1.9 ± 0.8	1.7 ± 0.4	2.0 ± 0.4
	2015	0.9 ± 0.3	2.7 ± 1.5	0.2 ± 0.1	3.8 ± 2.9	1.9 ± 0.8	0.5 ± 0.2	1.1 ± 0.5	0.9 ± 0.5	0.3 ± 0.1	0.7 ± 0.2*

** Significant differences between years within treatment or within planting desing if mean values of different treatments compered.*

*** Significant differences between planting desing within a year if mean values of different treatments compered.*

mean - planting design mean including control and all fertilized subplots within a year; number of replications within planting design - 16 (4 replications of 4 different fertilisation subplots).

Soil bulk density is an important physical parameter affecting the soil nutrient storage, water-holding capacity and gas penetration [21; 22]. In this study no statistically significant differences in soil bulk density were found between the treatments and control as well as between different planting designs, both in 2011 and 2015, but, as expected, we found significant differences ($p < 0.05$) in soil bulk density between different soil layers for the most of treatments – soil bulk density increases with increasing of the soil depth. Although there is a trend to decrease soil bulk density after establishment of plantation, especially in the upper soil layers (from 1521 ± 35 kg·m^{-3} in 2011 to 1381 ±27 kg·m^{-3} in 2015 at 0-20 cm depth and from 1569 ±28 kg·m^{-3} in 2011 to 1373 ± 25 kg·m^{-3} in 2015 at 20-40 cm depth), statistically significant differences in soil bulk density between years (2011 and 2015) within treatment were not detected, but, nevertheless, we found significant impact ($p < 0.050$) of establishment of hybrid aspen plantation on agricultural land on mean soil bulk density at 0-40 cm depth if the data from all treatments within the planting design were combined (Table 1). This suggests that while tree growth loosens up the top-soil to make it lighter and more permeable, it has little effect on deep soil layers. This might happen because the most of returned litter is deposited at the surface and the most of the fine roots and soil plant/animal residues occur in the shallow 0–60 cm soil layer, effectively loosening up the top-soil [22; 23]. However, the most significant factor loosening soil is repeating freezing and un-feezing cycles during winter that affect the topsoil layers to a higher extent.

We did not find significant impact of establishment of hybrid aspen plantation, fertilization and planting design of hybrid aspen on *SOC* in soil at 0-40 cm depth during 5 growing seasons after establishment of the plantation, but, within planting design the mean *SOC* at 40-60 cm depth was significantly smaller in 2015 in comparison to 2011. This is consistent with other observations, where soil organic carbon storage generally decreases during the first few years after afforestation [24; 25]. As expected, we found significant differences ($p < 0.050$) in *SOC* content between different soil layers within the same year in the most of treatments. Moreover, there was a significant variation of *SOC* content in soil within monitored soil layer. *SOC* content at 0-20 cm depth ranged from 8.3 $g \cdot kg^{-1}$ to 38.3 $g \cdot kg^{-1}$ in 2011 and from 6.1 $g \cdot kg^{-1}$ to 47.0 $g \cdot kg^{-1}$ in 2015, but in the deepest monitored soil layer (60-80 cm) – from 0.06 $g\ kg^{-1}$ to 6.7 $g \cdot kg^{-1}$ in 2011 and from < 0.01 $g \cdot kg^{-1}$ to 12.4 $g \cdot kg^{-1}$ in 2015.

The mean cumulative *SOCS* in different soil layers is shown in Figure 1. The results suggest that there was no significant impact of treatment or planting design on SOCS during 5 growing seasons after establishment of the plantation. We found significant differences in *SOCS* at 0-20 cm depth between planting designs of the hybrid aspen in 2015 ($p = 0.043$), but this difference in *SOCS* was significant ($p = 0.021$) also before establishment of the plantation. The mean *SOCS* at 0-20 cm depth was 6.8 ± 0.4 $kg \cdot m^{-2}$ in 2011 and 5.9 ± 0.4 $kg \cdot m^{-2}$ in 2015, but at 0-80 cm depth – 16.2 ± 1.2 $kg\ m^{-2}$ in 2011 and 12.5 ± 0.8 $kg \cdot m^{-2}$ in 2015. These results relate to the fact that the study area is located on carbon rich agricultural land, because the mean organic carbon stock in soil is higher than the mean *SOCS* at 0-20 cm depth in cropland (5.46 ±0.58 $kg\ m^{-2}$) and grassland (5.82 ± 0.86 $kg \cdot m^{-2}$) in Latvia [26]. The largest part (85 %) of OC stored in soils was found at 0-40 cm depth, but 47 % of the OC is stored in the upper monitored soil layer (0–20 cm). Batjes (1996) studied relative distribution of organic C as a function of depth and found that on average 39-70 % of the total OC in the upper 100 cm of mineral soil is stored in the upper 30 cm deep layer, and 58-81 % – in the upper 50 cm layer [27].

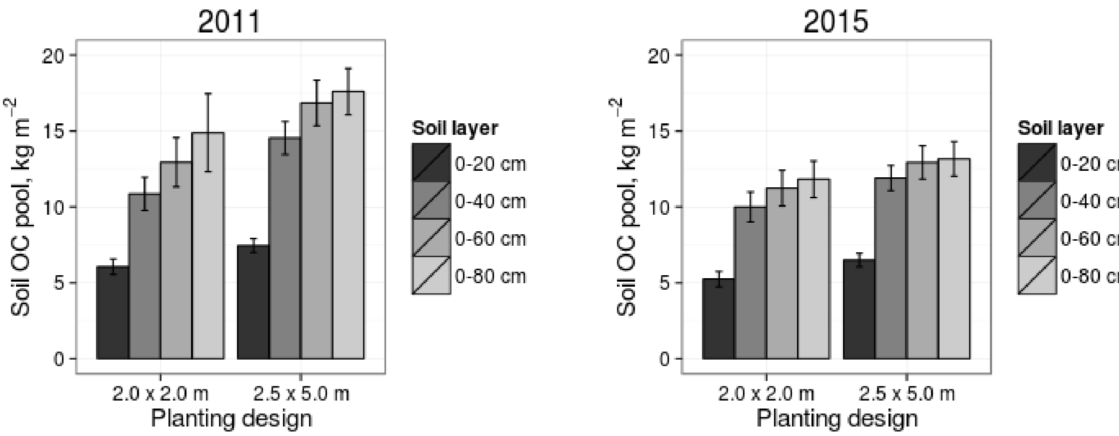

Fig. 1. **Mean soil OC stock in different soil layers**

It is well known that integrating of trees and bushes into agricultural landscapes is important in the climate change mitigation targets; moreover, accumulation of OC mostly occurs in the surface 0-20 cm soil layer [14; 20]. The results of our study indicate that there are no significant differences in OC stock at 0-40 cm soil layer between 2011 (before planting of hybrid aspen) and 2015 (after 5 growing seasons), but, contrary to expectations, significantly smaller OC stock was found in 2015 in comparison to 2011 at 40-60 cm depth ($p = 0.020$ in plots with 2.0 x 2.0 m planting design and $p = 0.006$ in plots with 2.5 x 5.0 m planting design) and at 60-80 cm depth ($p = 0.009$ in plots with 2.5 x 5.0 m planting design). Dixon (1995) has mentioned that some agroforestry systems can be CO_2 sinks and temporarily store C, while other systems are probably sources of GHG (e.g., CH_4) [7]. In previous studies, we found that the soil in the research object is not homogeneous due to the recent re-cultivation of the topsoil: about 20 years ago the levelling of the field was performed and peat was worked in, which is proved by a peat layer visible in some places of the soil profile [28]. Reduced compaction of soil can also lead to better aeration and decomposition of organic substances in soil. Consequently, no difference or even decrease in *SOCS* in fertilized plantations of hybrid aspen can be explained by mineralization of peat worked in 20 years ago. The evaluation period should be extended to at least 2 rotations and soil density should be considered in evaluation of *SOCS* changes, respectively, instead of certain soil layer (volumetric units) soil mass should be compared.

Conclusions

1. Fertilization with wastewater sludge and biogas production residues significantly improves productivity of hybrid aspen (*Populus tremuloides* Michx. × *Populus tremula* L.); in combination with reed canary grass (*Phalaris arundinacea* L.) intercrop these fertilizers secure production of 16.4 tonnes of fresh above ground biomass during 5 years corresponding to 42 MWh of primary energy per hectare or 16.5 tonnes $CO_2 \cdot ha^{-1}$ removed in above ground biomass (8.5 $tonnes_{DM} \cdot ha^{-1}$).
2. Soil bulk density and *SOCS* in soil are decreased reaching significant levels during the 5 year long growing period; while these results are preliminary and should be validated during longer time period.
3. In spite of reduction of *SOCS* fertilized plantations of hybrid aspen in the trails are carbon sinks securing considerable removals of CO_2 from atmosphere. The reasons of reduction of *SOCS* can be improved aeration of soils due to reduction of soil compaction and mineralization of peat worked in 20 years ago. This hypothesis should be evaluated in further studies, especially in conjunction with measurements of methane (CH_4) and nitrous oxide (N_2O) emissions.

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