Effect of Green Waste Compost Application on Afforestation Success

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Abstract

The impact of soil amelioration with green waste compost in the afforestation of depleted peat fields and sand pits was studied. Drilled planting holes (50 cm deep, 20 cm in diameter, 15.7 litres in volume) were filled with fertile compost soil. Containerized yearling seedlings of *Alnus glutinosa* (L.) Gaertn., *Betula pendula* Roth and *Populus tremula* (L.) × *P. tremuloides* Mischx. or bare-rooted ones of *Alnus incana* (L.) Moench were planted into the compost-filled planting holes (test seedlings) and control seedlings into untreated soil. The test growth period lasted for three consecutive growing seasons in 2012–2014.

Compost increased significantly the total three-year height growth of the test seedlings compared to the control ones on the depleted peat mine test site in all four species studied. A significant increase in the total three-year height growth of the test seedlings compared to control ones was also observed in black alder on the sandy loam and sand test sites. A high mortality rate was observed on the sand test site among control seedlings of black alder and among silver birch and hybrid aspen, both test and control seedlings. An irrigation test on sandy loam test site (2014) gave significantly improved height growth to the tested black alder seedlings.

Keywords: green waste compost; compost application; planting seedlings; planting site; height growth; soil aeration; water retention.

Introduction

In Estonia, the renewable energy sectors are priority areas for ensuring sustainable development (Wilkins et al. 1998). The reforestation of depleted peat and sand mining areas is often complicated due to the unfavourable physical, chemical and biological properties of soils. On peatlands, nutrient deficiencies or imbalances, low aeration and excess water content can restrict the growth of seedlings (Pearson et al. 2011). In depleted sand mines (sand pits), lack of water and nutrients are limiting factors for afforestation. The topsoil may easily desiccate during warm and windy periods, and planted tree seedlings face the risk of unsuccessful growth (Castro et al. 2005, Close et al. 2005).

There are several methods that enable better water retention in sand soil. For example, inserting approximately 1 cm thick manure-based organic layers 45-60 cm deep into the sand can accumulate rainwater on the organic barriers and enable cereal plants (rye and wheat) to produce double grain yield compared to test sites, where the same amount of manure was mixed into the upper 25 cm of sand (Egerszegi 1964). Underground water percolation barriers are made from sheet plastic (Smucker 2012) or a layer of asphalt a few millimetres thick (Saxena et al. 1969, Palta and Blake 1974). Hydrogel superabsorbent materials are used for improving sandy soils water retention properties (Singh et al. 2011, Shahid et al. 2012). Different mulching solutions using plastic, ridges and furrows for preventing water evaporation with a combination of rainwater collecting abilities are also tested (Wang et al. 2009, 2011). Usage of the water retention ability of modified clay was analysed by Zhang and Wang in 2013. Usage of Biochar as a water retention medium in soil was tested in sandy loam soils (Ulyett et al. 2014). In the case of low water retention ability only in the upper layer of soil, conducting plant root growth through the dry upper soil layer to deeper moist layers levels has been successful by using artificial wick-roots (Jarvis et al. 2012).

Watering planted forest trees to ensure adequate root development and initial growth is suggested by Goor and Barney (1968). The root systems of plants are able to perform water redistribution in soil upwards, downwards and horizontally using hydraulic redistribution. Hydraulic redistribution is described by several authors as a passive water movement through roots from moister soil areas or layers to roots and exiting roots in soil in areas with lower water potential (Caldwell et al. 1998, Schulze et al. 1998, Brooks et al. 2002, Liste and White 2008).

The mechanism anticipated to support further tree growth is expected to work as follows: if the roots extend into the surrounding soil with the help of nutrients achieved from the extended substrate supply, the bacterial and mycorrhizal fungi communities that exist in the applied compost will spread out into the surrounding nutrient-poor soil along the growing roots. The bacterial and mycorrhizal fungi communities use tree root exudates to survive. Several authors (Uroz et al. 2009, Calvaruso et al. 2010, Zhang et al. 2014) have found that the bacterial communities inhabiting the areas around the tree roots and using root exudates for nutrition can decompose soil minerals making soil more versatile and more suitable for further growth of the same trees. Decomposition of soil mineral particles is also performed by mycorrhizas (Hagerberg et al. 2003, Yuan et al. 2004, Schöll et al. 2008). In addition to bacterial and mycorrhizal fungi communities around the roots, root exudates also cause mineral decomposition of the surrounding poor soil components into the forms with higher assimilability for the same trees by themselves (Dakora and Phillips 2002).

All selected four tree species: grey alder (*Alnus incana* (L.) Moench), black alder (*Alnus glutinosa* (L.) Gaertn.), silver birch (*Betula pendula* Roth) and hybrid aspen (*Populus tremula* (L.) x *P. tremuloides* Mischx.) are able to regenerate from roots or stumps after cutting (Uri et al 2010). Alder species are pioneer species having ability to accommodate nitrogen-fixing bacterial communities (*Frankia alni*) in root nodules (Claessens et al. 2010).

Though afforestation can be supported with mineral fertilizers, wood or peat ash (Pärn et al. 2009, Kikamägi et al. 2013), the substances would not help mitigate problems with low aeration of the soil and too low or too high moisture. The aim of the current study was to test if these problems could be overcome by local enhancement of growth conditions around the roots of tree seedlings, using nutrient rich and air permeable green waste compost with a good water holding capacity during afforestation. Drilling planting holes and filling them with compost is expected to mitigate the problems with low soil aeration in peat and too low or too high moisture level and lack of some nutrients in all target soils. The hypothesis tested in the current work was that locally enhanced soil conditions around the roots of the planted tree seedlings may enable faster development of the seedlings in poor soil.

Materials and Methods

General description of the test sites

Three test sites within 40 km of Tartu (coordinates: 58°23’ N; 26°43’ E; elevation: 30-60 m above sea level) were studied (Figure 1).

The **peat test site** was located on a depleted peat field that was used 15 years ago for producing peat for energy (cutover peatland area). The test site was adjoined by a 60 cm deep ditch from the west, an area with 6 m tall trees from the north and east and an open treeless area in the south. The depth of peat was 74 cm on average. The peat layer was underlaid with clay. The level of groundwater varied during the test period from 40 to 70 cm depending on the rainwater. All the seedlings were planted on 30 May, 2012.

The **sand and sandy loam test sites** were located on the flattened areas of sand pits with open treeless spots in the south. Groundwaters were several meters deep in both cases. All the seedlings were planted on the sandy loam test site on 30 April, 2012 and on the sand test site on 30 May, 2012.

According to data of the weather stations nearest to the test sites, precipitation in millimetres and effective heat (average day temperature over +5°C) sums during the 2012-2014 vegetation periods are presented in Table 1. These data are provided to indicate the climatic background since plants growth rate depends on solar heat and water received from atmospheric precipitation.

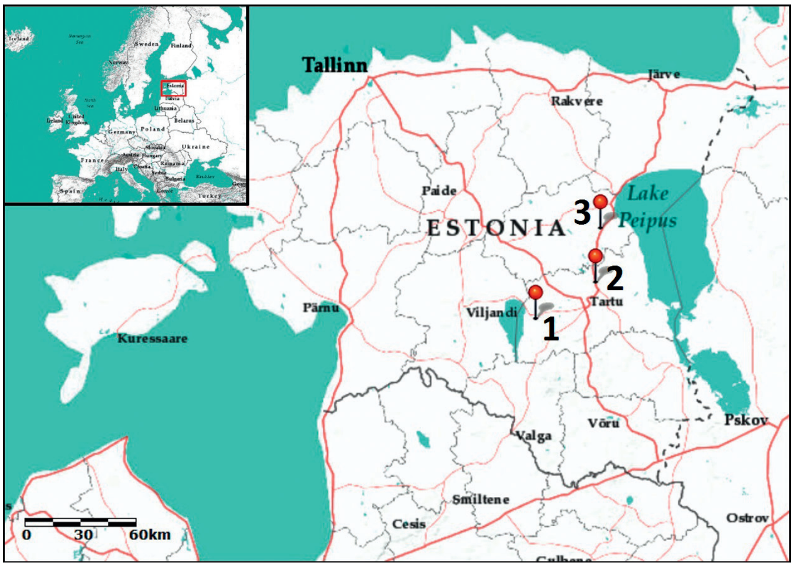


Figure 1. Location of the test sites (1 – peat, 2 – sand, 3 – sandy loam) for assessment of the effect of compost application on the height growth of forest tree seedlings on soils of various types

Table 1. Precipitation in millimetres and effective heat (over +5°C) sum in degrees C on the test sites from 01 April to 31 October during the three-year test period

Soil	Peat		Sandy loam		Sand	
Year	Precipitation, mm	Effective heat sum, deg. C	Precipitation, mm	Effective heat sum, deg. C	Precipitation, mm	Effective heat sum, deg. C
2012	524	1606	503	1478	510	1571
2013	311	1754	403	1662	345	1802
2014	444	1659	448	1337	476	1723

Planting holes and compost

The planting holes were made with soil auger "Stihl BT 121". In order to ensure maximum volume of compost available per plant, the biggest available 20 cm in diameter soil drill was used to drill 50 cm deep planting holes. The volume of each drilled hole was 15.7 litres. Deep planting holes were chosen because earlier tests with containerized seedlings have shown a positive correlation between increased container depth and seedling growth (Close et al. 2005, Chirino et al. 2008). Growing seedlings in deeper containers increases the number of primary roots and improves the plant root system architecture (Nelson 1996). The relatively large planting hole filled with compost was expected to minimize the seedlings transplanting stress by holding water, air and nutrients, as well as enabling the seedlings to form their own root structure as freely as possible. The planting holes were filled with green waste compost and compacted lightly.

Green waste compost used in the tests (its properties are given in Table 2) was produced from only plant-origin residues in the Tartu Tree Nursery. The raw materials of the compost were weeds, grass clippings and peat formerly used for growing forest-tree seedlings in seedbeds. This compost was produced by piling the components and mixing already matured compost into the piles during several years. Plant pathogens in the compost were not investigated.

Moisture and nutrient content in soils and compost

The volumetric water content (VWC) of the soil was measured with a Fieldscout TDR 300 (time domain reflectometry) soil moisture meter using 200 mm measuring rods. Volumetric water content values were measured in 04 October 2012 at the end of growing season to show the difference in VWC between compost additions and test site soils without having transpiration influence from the seedlings. For comparison, the VWC values were measured in the middle of growing season on 22 June 2013 to have a full transpiration impact from the seedlings on water content in soil under compost application and in the original soil. Both measurements were made two days after a moderate rainfall (Table 3).

In Table 2 the values of soil parameters were determined from soil samples as follows: pH_{KCl} (pH was determined in KCl solution), total nitrogen (N) by Kjeldahl method, available phosphorus (P) content, potassium (K) and calcium (Ca) by flame photometry (Helrich 1990), magnesium (Mg) by flow injection analysis (Page et al, 1982) and the soil organic matter content by the method of loss on ignition (Schulte 1995).

On three test sites studied, soils were deficient in several nutrients (Table 2). The planting holes were drilled into the soil and filled with compost (in the Table 2). The N, P, K, Ca and Mg contents in the green waste compost were considered to be high or average for plant growth (Pihelgas 1983, Kevvai 1996, Loide 2008). The concentrations of P and K in the test sites soils are generally considered to be low or very low. A very high nitrogen and very low phosphorus content in peat is common. In this particular peat, the calcium and magnesium contents were also very high, which sets off this peat from the majority of peats.

Planting of seedlings

Twenty black alder (*Alnus glutinosa* (L.) Gaertn.) and grey alder (*Alnus incana* (L.) Moench) seedlings (10 test and 10 control seedlings) were planted on the **peat and sand test sites**. Also, 10 silver birches (*Betula pendula* Roth) and 10 hybrid aspens (*Populus tremula* (L.)×*P. tremuloides* Mischx.) were planted, with 5 test and 5 con-

Table 2. Results of chemical analysis of compost used for filling planting holes and soils from the test sites (soil layer 0-15 cm)

	pH_{KCL}	N, %	P, mg kg^{-1}	K, mg kg^{-1}	Ca, mg kg^{-1}	Mg, mg kg^{-1}	Organic matter, %
Compost	6.72	0.470	325.63	401.32	3622.80	505.87	14.63
Peat	5.39	2.33	0.185	24.62	15307.00	1651.83	70.00
Sand	8.67	0.005	4.31	9.94	1975.10	24.70	0.25
Sandy loam	6.25	0.029	39.10	36.80	338.87	48.69	0.73

trol seedlings planted alternately (60 seedlings in total per test site, 30 test and 30 control seedlings alternately). On the **sandy loam test site**, the number of each species of the seedlings was doubled (120 seedlings in total, 60 test and 60 control seedlings alternately). The distances between the seedlings were 2 m on all sites.

All black alder and silver birch seedlings were grown in containers with dimensions 60×60×80 mm; the hybrid aspen seedlings in containers with 60×80×80 mm. The grey alder seedlings were bare-rooted (grown in nursery). All these seedlings were one year old.

The test seedlings were planted into the centres of the compost fillings of the planting holes. Three litres of water was poured to each planted seedling in each compost soil filling during planting because the compost was too dry for planting. The same number of **control seedlings** were planted directly into the original soil of the test plots (peat, sand and sandy loam). Also, the control seedlings were irrigated with 3 litres of water to provide equal treatment (except control seedlings on peat because the peat was soaked wet at the time of planting). No extra irrigation was carried out after the planting day on any of the test sites.

Irrigation test series on sandy loam

To test the seedlings growth response to higher soil water content on sandy loam, three groups of 12 one year old black alder seedlings were planted on 27 April, 2014. The seedlings of two groups were planted into 1 m deep and 10 cm in diameter holes with compost fillings (with a volume of 7.9 litres). The third (control) group of 12 seedlings was planted into untreated sandy loam soil. For one of the groups with compost fillings, an automatic drip irrigation system was installed (model Irrigatia SOL C-24) that supplied 1 litre of water per seedling per day.

Measurements of height growth

The seedlings growth was monitored by measuring their height with a measuring tape with 1 mm accuracy. The height measurements were made after each vegetation period from 2012 to 2014. All the seedlings with animal browsing damage were excluded from the data. Also, all negative annual height growths were excluded from the height growth analysis.

Statistical analysis

Statistical analyses were performed with the MS Excel 2013 software. Two sample *t*-tests with assuming unequal variances were used to test the effect of added compost on height growth. All statistical tests were considered significant at the level $p < 0.05$.

Results

Moisture content in soil

Supplied compost in **peat** may provide better aeration compared to the surrounding dense peat layers. Based on volumetric water content (VWC) measurements, the compost around the test plant roots was significantly drier on average than around the control plants roots when measured after the vegetation period (2012) and in the middle of the vegetation period (2013). Undisturbed peat measured in 1 m distance from the control seedlings contained more water in both cases (Table 3).

The VWC trend was changing on the **sandy loam** being higher after and lower during the vegetation period in compost around the test seedlings.

Improvement of the water retention ability of the compost was detected on the **sand** test site both during and after the vegetation period.

Height growth

Black alder seedlings gave significantly higher growth compared to control seedlings through three-year growth test on all test sites. It is important to note that due to a high number of dieback of the shoots of untreated seedlings on **sand** the number of test seedlings with positive height growth was too small to be analysed during the second and third year.

On the peat test site almost all the test seedlings of all species studied showed significantly higher height growth

Table 3. Average volumetric water contents in soils (%) measured two days after rain

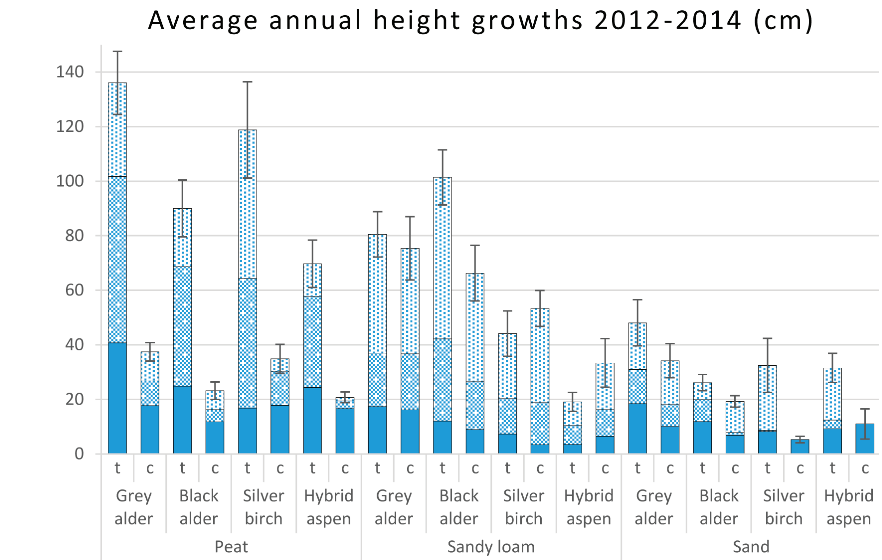
	Peat test site			Sandy loam test site			Sand test site		
Measure- ment location / measure- ment time	Compost around test seedling	Soil around control seedling	Soil without seedling	Compost around test seedling	Soil around control seedling	Soil without seedling	Compost around test seedling	Soil around control seedling	Soil without seedling
After vegetation period	27	39	43	23	18	20	18	8	8
In the middle of vegetation period	14	28	34	8	9	11	5	3	3

compared to the control seedlings every year except silver birch during the first year (Figure 2).

An additional positive effect of compost was also observed on the peat test site. The compost seemed to protect newly planted seedlings from frost heaving. All the seedlings in compost soil were well rooted and stood firmly in the ground, whereas four control seedlings out of 30 were lifted by frost heaving after the first winter after planting. The number of observations is small to draw a conclusion but the result can be considered as an indication.

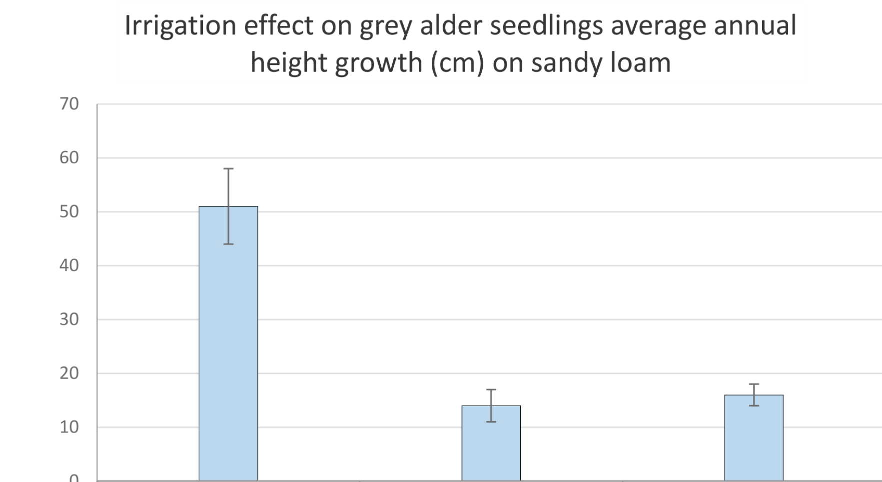
Effect of irrigation

The results of the irrigation test during the 2014 growing season showed a statistically significant difference in height growth between irrigated seedlings grown in compost compared to non-irrigated seedlings in compost and the seedlings in untreated soil (Figure 3).



	Peat								Sandy loam								Sand							
	Grey alder		Black alder		Silver birch		Hybrid aspen		Grey alder		Black alder		Silver birch		Hybrid aspen		Grey alder		Black alder		Silver birch		Hybrid aspen	
	t	c	t	c	t	c	t	c	t	c	t	c	t	c	t	c	t	c	t	c	t	c	t	c
Number	9	7	10	4	5	3	5	1	20	17	20	19	4	3	5	5	8	6	5	1	2	0	4	0
SE	12	3	10	3	18	5	9	2	8	12	10	10	8	7	3	9	8	6	3	2	10	1	5	6
Σ 3 years	136	37	90	23	119	35	70	21	80	75	101	66	44	53	19	33	48	34	26	19	32	5	32	11
2014	34	11	21	7	54	5	12	1	43	39	59	40	24	35	9	17	17	16	6	11	24	0	19	0
2013	61	9	44	4	48	13	33	3	20	21	30	18	13	15	7	10	13	8	8	1	1	0	3	0
2012	41	18	25	12	17	18	24	17	17	16	12	9	7	3	3	7	18	10	12	7	8	5	9	11

Figure 2. Comparison of the height growth (cm) of test seedlings "**t**" (with compost application) and control seedlings "**c**" (planted without treatment) belonging to four tree species under study on three test sites with **peat**, **sandy loam** and **sand** soils, respectively.
SE is the standard errors of 3-year cumulative height growths (cm), error bars on graph represent standard errors.
Number is the number of seedlings that gave positive height growth on the third growth year.
Σ 3 years is the resultant height growth during three consecutive years (2012-2014)



	Compost + irrigation	Compost	Untreated
Growth	51	14	16
SE	7	3	2
Number	12	12	12

Figure 3. Average annual height growth (cm) of one-year old grey alder seedlings during irrigation test on sandy loam test site in 2014
Growth is the height growth (cm);
SE is the standard error of height growth (cm), error bars on graph represent standard errors;
Number is the number of seedlings

Growth success ratio

The seedling response to the compost fillings can be expressed as a percentage of seedlings with positive height growths. Test seedlings had the following positive height growths: 97 % cases on peat, 89 % on sandy loam and 70 % on sand compared to control seedlings (52 %, 81 % and 37 %, respectively).

Discussion and Conclusions

On the **peat** test site, the compost added into planting holes was more aerated than the surrounding peat and enabled higher root activity that resulted in faster growth of the test seedlings. The surrounding peat had a higher water content compared to the compost-filled planting holes and acted as a water reserve always available for the roots grown out from the compost. In addition, the high growth of the test seedlings was probably supported by a very high level of nitrogen in the surrounding peat. The practical absence of phosphorous in the peat was compensated by its abundance in the compost. The height growth of the test seedlings was higher during the second growing season, when there was a comparatively low amount of precipitation and relatively high effective temperatures (Table 1). Higher growth of test seedlings with compost addition corresponds to the results of another peatland afforestation test with sewage sediment compost, where compost was spread uniformly over the test area and mixed with peat soil (Pikka 2005). Growth test on peat substrate with added sewage sludge compost and wood ash showed improved growth of willows (Lazdina et al. 2011), which is in accordance with the results of current work.

On the **sand** test site, the addition of compost increased significantly only the height growth of the black alder seedlings during the first two years and silver birch seedlings during the first growing year. Improved height growth can be attributed to better water retention ability and fertility of compost. Similar improvements of water holding capacity in sand soils are achieved with addition of modified clay (Zhang and Wang 2013) or rainwater collecting solutions that use plastic film and changed surface profile (Wang et al. 2009, 2011). Despite better water holding capacity compared to the surrounding sand, the amount of rainwater that accumulated into the compost-filled planting holes was not sufficient to provide a constantly available supply for the test seedlings. Severe drying of the shoot tops (dieback) occurred among the control seedlings of black alder, silver birch and hybrid aspen during the second growing season, when precipitation was comparatively low and effective temperatures were high. Dieback continued during the third growing season despite milder growing conditions. Higher nutrient content in the compost compared to the surrounding sand was expected to accelerate the treated seedlings growth during the period of water availability compared to seedlings without treatment. No significant differences in height growths were observed between grey alder test and control seedlings, however, both had constant and steady growth through three years.

On the **sandy loam** test site, the higher nutrient content in the compost was expected to give a significant effect on the height growth of the test seedlings of all tree species compared to control seedlings. However, the expected trend appeared only with black alder seedlings. The result corresponds to the tests performed with added biochar (Ulyett et al. 2014) or superabsorbent (Singh et al. 2011, Shahid et al. 2012), where the added substances improved water retaining capacity of sandy loam. The suspected water shortages in compost between rainfalls were expected to be the reason for only modest growth improvement with test seedlings in compost fillings. The conducted additional irrigation test (see “Effect of irrigation”) seems to avoid a soil water deficit on the test site. However, the current test does not explain the roughly doubled height growth of both test and control seedlings during the third year, despite the precipitation rate being roughly similar and the effective heat sum being smaller than during the previous years.

The study showed the differences in seedlings height growth on test sites and between tree species. All the test seedlings (except silver birch during the first year) gave significantly higher three-year height growth on the peat test site. This result corresponds to the results of the studies (Pärn et al. 2009, Kikamägi et al. 2013) that described improved height growth of silver birch and black alder in response to ash addition. Also, statistically significant differences in height growth between the irrigated seedlings grown in compost compared to non-irrigated seedlings in compost and the seedlings in untreated soil were measured. It confirms the statement that after planting, watering of forest tree seedlings results in their better establishment (Goor and Barney 1968). The hypothesis was confirmed showing that added compost caused significantly improved height growth of some tree species seedlings on some soil types, hence enhanced the growth conditions locally.

Recommendations for future testing

This work was expected to detect which species on which soils can benefit from compost amendment. The number of seedlings used in the tests was rather small and the results of this experiment will be a good starting point for further testing with a larger number of seedlings focusing on species and soils selected based on the results of the current work. Drilling planting holes and filling them with compost can be mechanized and automatized or even robotized to some extent in levelled areas like depleted peat fields and sand. In the case of deep planting holes, root activity should be supported with artificial aeration by embedding perforated plastic pipes into planting holes. In further tests, other kinds of compost can be used, for example, compost of city sewage sediments, which may reduce the price of current afforestation method and help reuse sewage waste. The sewage compost cannot be used for agricultural purposes: it may contain an excess amount of chemical contaminants that can be assimilated by food crops (Lillenberg et al. 2010, Nei et al. 2011). However, sewage compost is rich in minerals, enabling long-lasting supply for the fast growth of plants. Chemical contaminants are expected to be consumed from compost by forest tree plants and accumulated in their timber, enabling to draw pollutants out from circulation (López et al. 2014). The amount of compost needed in the form of the fillings in the planting holes is remarkably smaller and is expected to pose a smaller threat to groundwater through leaching components compared to the method covering the soil with a sewage sediment compost layer for afforestation (Pikka 2005). Automated irrigation systems could be used in a further test on the sand and sandy loam test plots to investigate whether irrigation can increase the effect of compost application on root vertical growth down to more moist soil layers. In sand areas, adding plastic film reservoirs at the bottom of planting holes (filled with porous material like surrounding sand to maintain shape) must be tested for water retaining ability and for plant growth reaction. The plastic water reservoirs under plants may be equipped with filling pipes for adding water during longer dry periods and for water level monitoring. Additional rainwater collection solution consisting in funnel-like sheet-plastic surrounding planted seedlings inside the upper soil layer can be tested together with the reservoirs. Also, a technically easier method of filling the planting holes with liquefied compost (mixed with water) can be tested based on the results of the current work.

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