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Conversion of an industrial cutaway peatland to a *Betulacea* family tree species plantation

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Abstract. To evaluate the potential of establishing a deciduous tree plantation on an industrial cutaway peatland over an 8 ha large experimental site was established in the central part of Latvia and silver birch (*Betula pendula* Roth) and black alder (*Alnus glutionsa* (L.) Gaertn.) tree species were planted. As it is a harsh and unfavorable environment wood ash, otherwise a waste product, was used as a fertiliser and liming material in three applications (5, 10 and 15 t ha^{-1}). In comparison with control, fertilised soils had higher Ca, Mg, P amounts, whilst the most substantial difference was seen in the amount of K. Application of wood ash also considerably increased soil pH from 3.5 (Control) to 5.9 (15 t ha^{-1}). Even though showing reduced growth in unfertilised soil both alder and birch seedling survival rate was higher than 80%. The highest survival rate for birch was under wood ash treatment, while alder under 10 t ha^{-1} wood ash fertiliser treatment showed the lowest survival rate i.e. 81%. In total, more than 60 naturally occurring vegetation species were observed in the first and the second year of sites establishment after fertilisation. Species as *Betula pendula, Betula pubescens, Populus tremula, Pinus sylvestris*, *Salix* spp. often occurred from natural vegetation regeneration. Already after one year of vegetation succession increase in tree and shrub species cover was observed, suggesting perhaps such areas can be naturally afforested thus creating a more heterogeneous forest stand. In such a way sustaining economic use of land resources after peat extraction while providing other ecosystem services.

Key words: afforestation, drained peatland, wood ash fertilization.

INTRODUCTION

Peatlands are estimated to cover 2.84% of total land area, yet they are important part of carbons cycle storing about one third of world's total soil carbon (Yu et al., 2010; Xu et al., 2018). In many countries peat is also an important resource extracted for fuel or horticulture (Karofeld et al., 2017). Peat extraction process greatly changes the ecosystem. Prior the extraction hydrological conditions in the peatland are altered by drainage and melioration system establishment that can further result in leaching of nutrients (Laiho & Laine, 1995; Leupold 2004). Extraction process itself causes major changes, from removing the existing vegetation, that in turn causes increase in greenhouse gas emissions, elevated fire risks, erosion and degradation of biodiversity, to increased peat density due to the pressure of heavy machinery, that further changes regulatory functions of the peatland (Wichtmann et al., 2016; Leifeld & Menichetti

2018). In Latvia, after the extraction it is required by law to mitigate the inflicted and prevent further environmental damage by undertaking some form of restoration or reclamation measures (Karofeld et al., 2017). Restoring the cutaway area to a peatland is the most suitable option for maintaining biotope diversity. Due to technical or economic limitations it is not always possible to restore the field to similar conditions prior the peat extraction, mainly due to ongoing peat extraction (Joosten et al., 2015). In such cases an alternative can be to extend the use of the peatland for economical purposes by growing plants, simultaneously providing ecosystem services and increasing carbon sink. Afforestation is one of the economically and environmentally justified recultivation options (Laasasenaho et al., 2017). We evaluate the possibility to utilize cutaway peatlands to grow deciduous tree species. Silver birch and black alder were selected as typical economically important deciduous tree species for Latvia that are tolerant to fluctuating hydrological conditions (Bebre & Lazdiņa, 2017). Silver birch is naturally occurring in peatlands and black alder is water demanding species that is adapted to anaerobic soil conditions, thus showing potential to successfully grow in peatland soils (Claessens et al., 2010). Due to nitrogen fixing properties of black alder, it is also suited to serve as nurse plant for other tree species (Mangalis, 2004).

There are challenges that need to be addressed in order to successfully afforest a cutaway peatland. Low pH and limited mineral element availability is characteristic to peatlands (Lazdiņa et al., 2011). This in turn leads to nutrient deficiency and reduced biomass production of planted trees. It can become apparent shortly after planting or in long term, when trees have depleted the reserves that were originally present in peat (Black et al., 2017). To ameliorate these harsh conditions, wood ash can be used as liming material and fertiliser (Demeyer et al., 2001; Jacobson, et al., 2004; Augusto et al., 2008; Libiete et al., 2016). Woody biomass is important source of energy in most Northern countries, including Latvia. Wood chip use has been increasing in Latvia, thus providing waste product – wood ash in large quantities as potential resource (CSB, 2018). Wood ash has positive effect on mineralization processes in organic soil and contains bioavailable macro and micro nutrients crucial for tree development that are often lacking in peatland soil, such as K, P, Ca, Mn and Mg. However, N evaporates during incineration process and it might be necessary to add it as additional fertiliser, since it is often not present in adequate amount in bioavailable form in peat soil (Saarsalmi et al., 2012; Brais et al., 2015). Studies have shown positive effect of wood ash on tree growth in especially unfavorable conditions (Huotari et al., 2008; Moilanen et al., 2013; Lazdina et al. 2017; Ots et al. 2017), yet some studies find only short-term positive effect (Brais et al., 2015). In this study we look at impact of wood ash in different application dosages on early growth and survival of silver birch and black alder saplings as well as treatment effect on natural afforestation process. Natural afforestation and regrowth of vegetation is relatively slow in most cutaway peatland sites, but can be promoted by fertilising. Vegetation cover plays an important role in mitigating erosion and leaching of nutrients (Huotari et al., 2011). Often overlooked is the fact, that vegetation can store more C than young trees (Huotari et al., 2009). We looked at species composition of naturally occurring vegetation, especially trees and shrubs, in first and second vegetation season after site establishment and fertilisation.

The objective of this study was to evaluate survival and growth of birch and alder tree species and natural vegetation regeneration in a cutaway peatland, as well as to determine whether fertilising such area with wood ash is beneficial.

MATERIALS AND METHODS

Study site

Study site is located in central Latvia (N 56°.43'.41.35'' E 23°.34'.39.61'') in a cutaway peatland where active peat extraction is still happening in other parts of the peatland. Total study site area is 8 ha and it can be considered as marginal land due to unfavorable soil structure. Peat layer after extraction was left 50 cm or thicker.

Prior the establishment of the plantations, study site was cleaned of covering vegetation, mostly trees and reeds. To stabilize hydrological conditions, contour ditches were cleaned and the peat acquired in the process was dispersed across study site. Reeds had to be cut each year, due to competitiveness with planted trees.

Study design

Wood ash was wetted, dispersed and mixed in to the top layer of peat. Based on other study results three doses of wood ash (5, 10 and 15 t ha^{-1}) were chosen and applied in three repetitions (blocks) (Ernfors et al., 2010; Huatori et al., 2011; Lazdiņa et al., 2013; Huatori et al., 2015; Ots et al., 2017). Three repetitions with no treatment was set as control (Fig. 1). Wood ash on a dry mass basis consisted of 24.7 potassium (K), 18.2 magnesium (Mg), 120.4 calcium (Ca), 6.6 phosphorus (P) g kg^{-1}.

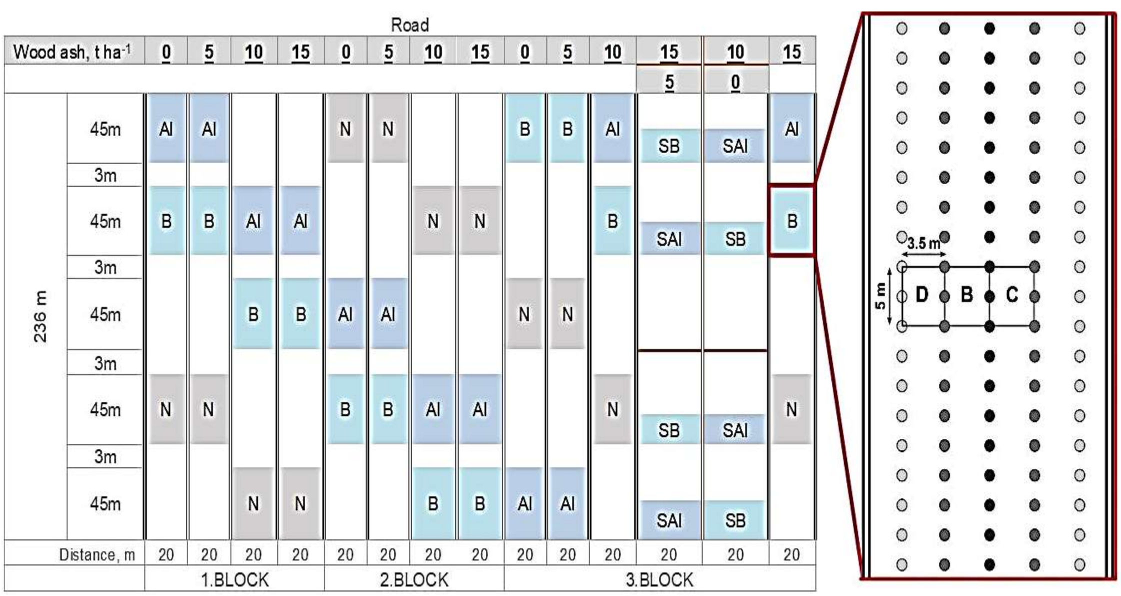

Figure 1. Design of the study site (left) and design of plot (right) with sub-plots (D – near contour ditch, B – in between, C – in the centre of the plot). Al – black alder; B – silver birch; N – natural regeneration; SAl – sown black alder; SB – sown silver birch. 0, 5, 10 and 15 – dosage of wood ash applied (t ha^{-1}). Dots represent individual trees and double lines represent contour ditches.

In spring of 2017 silver birch and black alder (288 per plot or if drainage system is not accounted for 1,142 trees per ha) containerized seedlings were planted in 40 x 45 m large plots between the contour ditches. A distance of 2.5 m was left from the ditch and trees were planted in 5 rows with 3.5 m distance between the rows and 2.5 m between the trees. In addition, twelve plots were left unplanted for natural regeneration.

To estimate the viability of regeneration by sowing, in the spring of 2018 black alder and silver birch were sown in 4 plots each. Three unchilled seeds per planting spot were chosen for black alder and five seeds for silver birch and manually sown in the top 1 cm of the soil.

Soil analysis and chemical properties

To better describe the conditions in the experimental field and to be able to draw broader conclusions from the results, soil samples were collected at the beginning of the second growing season. Three soil samples per wood ash treatment were collected from the centre of the plot from the top 10 cm soil layer. Samples were analysed according to Bardule and co-workers (2013) described methodology.

Data collection

Survival and height of planted trees was measured at the end of 2017 and 2018 year in each plot and each row from 6th to 14th tree (in total 1,080 trees were surveyed).

Vegetation cover was evaluated at the end of the summer of 2017 and 2018. Vegetation composition was determined within each plot in three sub-plots 5 x 3.5 m each, 108 sub-plots in total (Fig. 1). Naturally occurring herbaceous, moss and woody species were noted as present or absent, since relative cover per species (with occasional exceptions) was below 10 percent of the sub-plot area. In each plot one sub-plot was located near contour ditch (D), one in between (B) and one in the centre of the plot (C). Species affiliation to perennials, annuals or biennials as well as weeds, woody species and monocotyledon was noted. Due to unfavorable growing conditions, some plants were lacking the typical characteristics for the species and were identified only to subspecies level.

Data analysis

R version 3.5.1 (R Core Team, 2018) was used for statistical analyses. Generalized linear models (binomial and Poisson) were used to evaluate species richness and planted tree survival difference between treatments and control and species richness differences depending on sub-plot location in relation to contour ditch.

For the *analysis of variance (ANOVA)* height was set as the numeric variable and tree species, wood ash dose and location was used as factors. Afterwards package 'car' (Fox & Weisberg, 2011) function Anova with type 'III' was used to account for the unbalanced design. Tukey's HSD test used for pairwise comparison. Damaged trees were not included in the analysis.

RESULTS AND DISCUSSION

Soil chemical properties

Fertilisation with wood ash impacted pH and the amount of all of the measured nutrients (see Table 1). After wood ash application on a cutaway peatland similar changes in soil pH (Moilanen et al. 2012) and K concentration (Kikamägi et al., 2013), Ca an Mg concentration (Mandre et al., 2010) and in the top layer have been observed.

Table 1. Chemical properties and available nutrients of soil with a different dose of wood ash, ± standard deviation

Wood ash dose, t ha^{-1}	pH_{CaCl2}	C_{total}, g kg^{-1}	N_{total}, g kg^{-1}	P, g kg^{-1}	HNO^3 method of extraction K, g kg^{-1}	Mg, g kg^{-1}	Ca, $g^{-1}g$
0	3.52 ± 0.02	554.6 ± 10.7	16.2 ± 2.2	0.24 ± 0.01	0.07 ± 0.01	1.0 ± 0.18	11.1 ± 0.3
5	4.15 ± 0.06	530.4 ± 8.3	13.4 ± 0.7	0.26 ± 0.01	0.33 ± 0.01	1.45 ± 0.04	13.5 ± 0.4
10	4.83 ± 0.06	529.8 ± 8.7	13.7 ± 2.0	0.45 ± 0.10	0.69 ± 0.13	2.07 ± 0.18	18.7 ± 2.0
15	5.87 ± 0.07	483.0 ± 8.4	12.1 ± 0.4	0.79 ±0.07	1.70 ± 0.20	2.81 ± 0.13	24.9 ±1.2

Tree survival

Germination of sown birch or alder seeds was not observed. Perhaps due to the high temperature and severe drought during the summer.

The average survival for both planted tree species in all of the experimental plots was above 74% (see Table 2). It would seem that in general birch seedlings survived better, but it did not gain enough statistical significance in the binomial regression model to be proven. Nevertheless, the survival of both species was high. No clear pattern for both species and wood ash fertiliser dose or location was observed. Only for birch seedlings the survival on average was higher in fertilised soil. While alder seedlings had on average higher survival rate in the plots located in the centre of the plot.

Table 2. Planted tree survival depending on wood ash treatment (0, 5, 10 and 15 t ha^{-1}) and location (D – near contour ditch; B – in between; C – in the centre of the plot)

Wood ash dose, ha^{-1}	0			5			10			15		
Location	D	B	C	D	B	C	D	B	C	D	B	C
alder	88.9	86.8	92.9	77.8	79.6	92.6	79.6	77.8	85.2	85.2	87	85.2
average		89.5			83.3			80.9*			85.8	
birch	87	88.9	74.1	94.4	100	96.3	94.4	98.1	96.3	96.3	96.3	96.3
average		83.3			96.9*			96.3*			96.3*	

* – result significantly differ from the control plots (0 t ha^{-1} dose of wood ash).

Planed tree height

As can be seen in Fig. 2 after two growing seasons both black alder and silver birch seedling had higher growth rate when wood ash was used as fertiliser in a drained and cutaway peatland. The significant effect of wood ash application can already be seen after the first growing season (see 2017 season in Table 3). However, the overall trend is not identical for both species. *Tukey's HSD test* confirmed that birch tree seedlings have significantly higher average height with increased wood ash dose after second growing season. Interestingly it has been previously stated that the pH does not impact the total amount of produced biomass for birch on a cut away peat soil (Hytönen, 2005). While no significant difference between height of alder tree seedlings in plots with 5, 10 and 15 t ha^{-1} dose of fertiliser was found. Thus suggesting to avoid increased fertilisation in alder plantations on cutaway peatlands to reduce the amount of leached nutrients at least for the first growing seasons (Piirainen et al., 2013; Maresca et al., 2019).

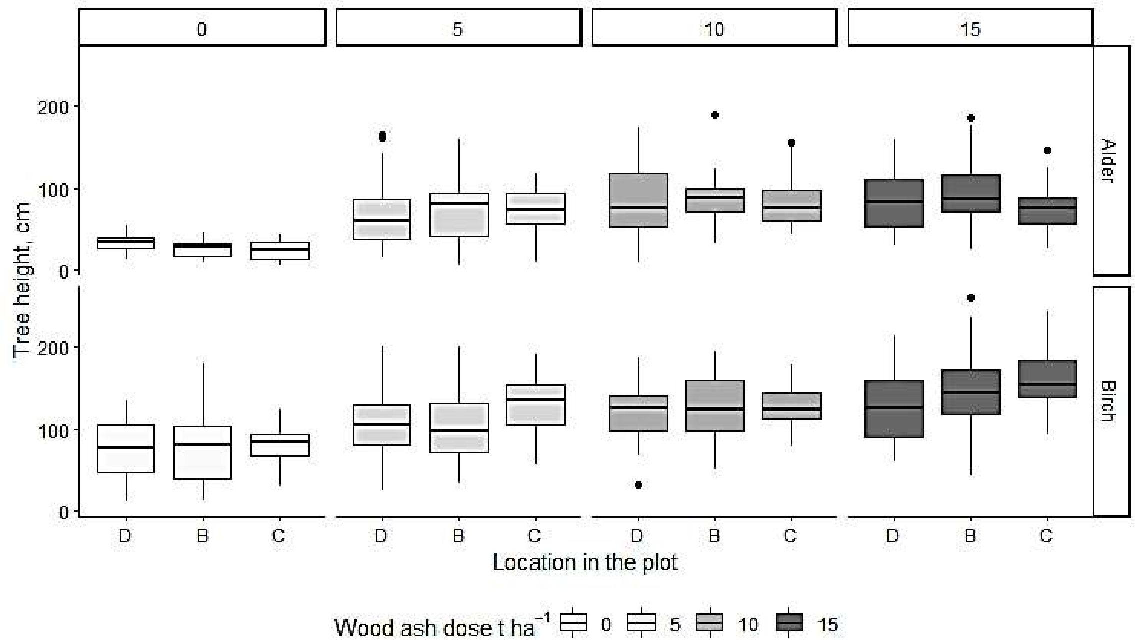

Figure 2. Boxplot graphs showing the tree height after second vegetation season of alder (*Alnus glutinosa*) and birch (*Betula pendula*) tree species located near contour ditch (D), in between (B) and in the centre of the plot (C) with different dose of wood ash fertiliser in the soil (0, 5, 10 and 15 ha^{-1}). Points show outliers, vertical lines – either the minimum or maximum x value plus 1.5*interquartile range (upper) or minus 1.5*interquartile range (lower), lover hinge – 25% quantile, upper hinge – 75% quantile, vertical line in the middle – median.

Containerized seedlings from a nursery have a small amount of substrate around their root system. Thus, when planted, some nutrients are provided. Perhaps due to nutrient availability from the container and soil mineralization process, larger impact of wood ash fertilisation is seen after the second year of establishment. When nutrients of the container have been used up and seedlings have formed greater root systems. Furthermore, it has to been observed that in some cases after few years the effect of fertilisation may diminish and due to lack of nutrients cause tree species dieback (Black et al., 2017). In such cases re-fertilization may be useful.

Table 3. Analysis of variance of tree height for two tree species grown in plots with four wood ash doses in three locations after first growing season of year 2017 and the second (year 2018)

Source of variation	df	SS		F		P	
Year		2017	2018	2017	2018	2017	2018
tree species	1	65,458	95,394	253.5	77.12	***	***
wood ash dose	3	4,849	222,902	6.3	**60.07**	***	***
location	2	134	6,915	0.3	**2.80**	0.7	0.06
tree species by wood ash dose interaction	3	2,749	14,669	3.54	3.95	*	**

*** – $P \leq 0.001$; ** – $P \leq 0.01$; * – $P \leq 0.05$; df – degrees of freedom; SS – sum of squares.

Vegetation cover

Total of 62 species of plants were present at the study site sub-plots (Annex 1). Species distribution and richness was not dependent on planted tree species (birch, alder or none), therefore plot species were excluded from the model. However, planted tree species, birch and alder, could have effect in long-term, due to characteristics of leaf litter, foliage and the shading effect on understory vegetation (Augusto et al., 2003).

Perennial weeds, especially weeds common after disturbances, were the most prevalent plants in both of the study years. Such weed species can also be found in peatlands, that have been used as agricultural land prior restoration (Hausman et al., 2007). The change in species composition in two years is rather small and decrease in annual and biannual species can be expected in later years (Salonen, 1990). However, most species have spread across more sub-plots, especially tree and shrub species and weeds. Monocotyledons showed decrease in species richness, but not in overall presence in sub-plots. The biggest decrease of presence in sub-plots was observed for species such as *Arabidopsis thaliana*, *Juncus articulatus*, *Chamaenerion angustifoliu*m and the biggest increase in presence was observed for *Salix caprea*, *Populus tremula*, *Calamagrostis spp.*, *Erigeron canadensi*s and *Pinus sylvestris*. Compared to control, all treatments had a significant ($P < 0.05$) positive effect on species richness already in the first year after application (Table 4). This shows the potential use of wood ash not just as a fertiliser and liming material for target species, but as an amendment to accelerate natural regeneration as well. Natural vegetation regeneration is particularly important in the first years of establishment to avoid nutrient leaching from fertilized peat soil since part of them are taken up by plants (Huotari et al., 2011). In the second year, interaction between treatment and location in relation to contour ditch become significant, possibly due to extreme weather conditions (hot and dry) of particular summer. Vegetation sub-plots located closer to contour ditches showed higher species richness than the sub-plots located closer to centre of the plots. Such association was present already in the first year of the study and was slightly less prominent in second year. This finding could be connected to hydrological conditions as well as other factors – micro-patterns of dispersion of wood ash, seed dispersal ways and plant propagation mechanisms.

Table 4. Species present in sub-plots depending on sub-plot location (D – near contour ditch, B – in between, C – in the centre of the plot) and treatment (0, 5, 10 and 15 t ha^{-1})

Wood ash dose, t ha^{-1}	0			5			10			15		
Location	D	B	C	D	B	C	D	B	C	D	B	C
2018	27	17	13	27	28	26	33	30	25	29	28	24
total species		28			31*			38*			33*	
2017	19	8	11	27	23	20	26	22	23	31	25	25
total species		24			32*			32*			34*	

* – result significantly differ from the control plots (0 t ha^{-1} dose of wood ash).

Seven tree and shrub species were observed to naturally regenerate in cutaway peatland within two years. These species are *Pinus sylvestris*, *Populus tremula*, *Salix caprea* and other *Salix spp.*, *Betula pendula*, *B. pubescens* and in separate cases individual *Picea abies* sprouts. In plots treated with wood ash *Populus tremul*a and *Salix* species showed significantly ($P < 0.05$) better regeneration than in control plots. Other woody species did not show significant association between treatment and presence.

From species present in the study site, *Typha latifolia* and *T. angustifolia*, *Silene vulgaris*, *Juncus effusus*, *J. articulatus*, *Equisetum arvense*, *Cirsium arvense* as well as *Pinus sylvestris* and some *Salix* species are plants known to be used in phytoremediation (Valujeva et al., 2015). Given the wood ash fertiliser, these plants (*Salix* species, *Typha latifolia* and *Silene vulgaris* in particular) with some management could be used to mitigate the environmental impact of heavy metals present in ash (Augusto et al., 2008; Huotari et al., 2011; Ingerslev et al., 2014).

Species typical to *Sphagnosa*, *Caricoso-phragmitosa*, *Dryopteriosa-caricosa*, *Filipendulosa* as well as *oxalidosa turf. mel.*, *Myrtillosa turf. mel*., *Vacciniosa turf. mel*. and *Callunosa turf. mel*. forest types can be found in the study site (forest types according to Bušs, 1976). But there is no prevalence of species typical to any specific forest type in either of the years. Only small portion of the species present two years after disturbance are typical peatland plants, probably not only because of changes in hydrological and soil properties, but also due to loss of large portion of seed bank caused by the removal of top-soil (Hedberg, et al., 2014).

CONCLUSIONS

Fertilisation with wood ash improved both the survival and the growth of birch tree seedlings in the first two growing seasons, but with increased dose only the growth rate improved. In comparison alder seedlings exhibited a different pattern, where the application of fertiliser improved the growth rate, but the survival rate was decreased. Suggesting that other factors as location (thus possibly hydrological conditions or physical peat properties) could be of more importance.

No added benefit of applying larger doses than 5 t ha^{-1} wood ash in alder plantation was detected thus for environmental concerns it may be suggested to limit fertilization at least in the first growing seasons.

Regeneration of vegetation was more rapid in plots treated with wood ash. However, the difference between treatment dosages was rather small, suggesting, that 5 to 10 t ha^{-1} application of wood ash is sufficient to promote natural regeneration in first two years after disturbance.

Wood ash treatment had a significant positive effect on natural regeneration of *Populus tremula* and *Salix* pioneer tree species, but did not have an effect on tree species more typical to peatlands (birch and pine).

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Annex 1. Species present in study site (x – presence) in 2017 and 2018 at 0, 5, 10 and 15 t ha^{-1} wood ash. *P* – perennial; A – annual; B – biannual; W – weed species; m – monocotyledons; WS – woody species

Wood ash dose, t ha^{-1}	**0**		**5**		10		15					
Growing season	1.	2.	1.	2	1.	2.	1.	2.	Type	*W*	*M*	*WS*
Agrostis tenuis	x		x		x		x		P	*x*	*x*	
Arabidopsis thaliana	x		x		x	x	x		A	*x*		
Arctium spp.							x		B	*x*		
Arctium tomentosum				x					B	*x*		
Betula pendula	x	x	x	x	x	x	x	x	P			*x*
Betula pubescens	x	x	x	x	x	x	x	x	P			*x*
Bidens tripartita			x	x		x			A	*x*		
Brassica spp.	x		x	x	x	x	x	x				
Calamagrostis spp.	x	x	x	x	x	x	x	x	P	*x*	*x*	
Carex cespitosa					x				P		*x*	
Carex spp.	x	x	x	x	x	x	x	x	P		*x*	
Cerastium holosteoides					x				P	*x*		
Chamaenerion angustifolium	x		x		x	x	x	x	P	*x*		
Chenopodium spp.							x			*x*		
Cirsium arvense	x	x	x	x	x	x	x	x	P	*x*		
Crepis spp.		x					x					
Echinochloa crusgalli						x	x	x	A	*x*		
Epilobium spp.	x	x	x	x	x	x	x	x	P	*x*		
Equisetum arvense	x		x						P			
Equisetum sylvaticum		x							P			
Erigeron canadensis				x	x	x		x	A	*x*		
Eriophorum vaginatum			x					x	P			
Eupatorium cannabinum		x	x	x	x	x	x	x	P			
Fragaria vesca					x	x			P			
Hieracium spp.					x		x		P	*x*		
Hieracium x floribundum		x		x					P	*x*		
Juncus articulatus	x	x	x	x	x	x	x	x	P	*x*	*x*	
Juncus effusus		x	x	x		x	x	x	P	*x*	*x*	
Juncus tenuis	x		x	x	x	x	x		P	*x*	*x*	
Lamium spp.			x			x		x		*x*		
Linaria vulgaris						x			P	*x*		
Lycopus europaeus	x	x		x		x			P	*x*		
Matricaria perforata			x	x					A	*x*		
Mycelis muralis					x		x		A			
Phragmites australis	x	x	x	x	x	x	x	x	P		*x*	
Picea abies					x	x			P			*x*
Picris hieracioides	x		x		x	x	x	x	B/P	*x*		
Pinus sylvestris	x	x	x	x	x	x	x	x	P			*x*
Plantago lanceolata								x	P	*x*		
Plantago major			x				x	x	P	*x*		
Polygonum persicaria	x	x	x	x	x	x	x	x	A	*x*		
Polygonum spp.							x			*x*		
Polytrichum spp.	x		x		x				P			
Populus tremula	x	x	x	x	x	x	x	x	P			*x*
Rubus idaeus	x	x	x	x	x	x			P			*x*
Rumex acetosella				x		x			P	*x*		
Salix caprea		x	x	x		x		x	P			*x*

Annex 1 (continued)

Salix spp.	x	x	x	x	x	x	x	x	P			*x*
Scirpus sylvaticus			x		x		x		P	*x*	*x*	
Senecio vulgaris		x		x		x		x	A/B	*x*		
Silene vulgaris			x						P	*x*		
Solidago canadensis						x		x	P	*x*		
Solidago spp.							x		P	*x*		
Sonchus arvensis		x		x		x		x	P	*x*		
Sonchus asper					x				A	*x*		
Stellaria spp.		x		x		x	x	x				
Taraxacum officinale	x	x	x	x	x	x	x	x	P	*x*		
Tussilago farfara	x	x	x	x	x	x	x	x	P	*x*		
Typha angustifolia					x				P		*x*	
Typha latifolia		x				x			P		*x*	
Urtica dioica							x	x	P	*x*		
Viola arvensis					x				A	*x*		