The Effect of Soil Properties on Natural Forest Regeneration on Drained Fens

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The objective of this study was to assess the success of natural regeneration in cutovers on drained fens (eutrophic peatland) depending on the soil properties and the depth to the water table in the forests of Biržai and Panevežys state forest enterprises in Lithuania. The assessments were carried out in 100-300 *m* long transects allocated perpendicularly to the drainage ditches. A total of 131 water wells were drilled to measure the depth to the water table and 131 sample plots of 10 × 10 *m* were established. The soil properties were assessed in the soil chemistry laboratory. The results showed that natural forest regeneration on drained cutblocks in fens was affected by the following factors: the depth to the water table ($H_{V.01}$) (measured at the beginning of the growth period), the *pH* level, the potential hydrolytic soil acidity (*HA*), the base saturation and the thickness of the peat layer. Multiple regression analysis was used to assess the dependence of the number of regenerating trees (*N*) on the main factors ($H_{V.01}$ and *HA*): $N = 168059.7 - 3446.5\, H_{V.01} - 35.180\, HA$; ($R^2 = 0.8$, $F = 7.51$, $p < 0.0007$). The maximum critical depth to the water table (allowing sufficient number of regenerating trees) was mainly affected by the subsoil texture of the shallow peat soils (HS_s–*ph*) and was 18.0 ± 3.7 *cm*, 26.5 ± 6.6 *cm*, 26.6 ± 3.9 *cm*, 29.6 ± 6.6 *cm* and 42.2 ± 9.6 *cm* in the soils with subsoil of gravel, sand, sandy loam, light loam and medium loam, respectively. The mean hydrolytic acidity of the soil in the cutblocks with sufficient regeneration was 820.99 ± 56.05 *mekv/kg*, which was significantly lower than in the cutblocks with insufficient forest regeneration ($\Delta HA = 212.29 \pm 94.99$ *mekv/kg*, $t = 2.23$, $p = 0.038$). In conclusion, to improve the natural regeneration of forests in the clear-cuttings on low peatland soils, the soil water regime should be improved by the technical means to maintain the optimum soil moisture (mainly by damming the ditches) and, in soils of very high acidity ($HA > 1100$ *mekv/kg*), alkaline enrichment may be needed.

Key words: cutovers, drainage, natural regeneration, peat soils, water table

Introduction

The cutblocks in drained fens (eutrophic peatland) are defined as clearcut sites on drained forest wetland with the thickness of the peat layer exceeding 30 *cm*. The peat soils are different from the mineral soils in their moisture, nutrient and temperature regime as well as the prevailing vegetation. Therefore, the results of studies carried out on the mineral soils cannot be applied to the sites on peat soils (Saarinen *et al.* 2004). Drainage and clear-cutting in forested wetlands markedly affect the physical, chemical and biological properties of the soils and may result in conditions suitable for natural forest regeneration (Roy 1998, Berry and Jeglum 1988, Braekke 1990, Dube *et al.* 1995, Paavilainen and Päivänen 1995). However, according to Berry and Jeglum (1988), Roy *et al.* (2000), Kairiūkštis (1973) and Zalitis (1996) in the temperate zone, a rise of the water table was observed after clearcuts in forested wetlands. This watering-up may initiate paludification, which may disturb forest regeneration (Paavilainen and Päivänen 1995, Roy *et al.* 2000, Ипатьев *et al.* 1984). Forest drainage, implemented to lower the water table and decrease soil water content to a level that ensures sufficient aeration (Paavilainen and Päivänen 1995) could be used after clear-cutting to alleviate watering-up.

According to Kapustinskaitė (1983), the positive effect of drainage in Black alder (*Alnus glutinosa L.*) wetland dominated by *Cyperaceae* or a similar type of ground vegetation was that over 90% of Black alder trees were regenerating not only on elevated mounds (mounds occupied 18-23% of the total area) but also over the whole area including water-formed depressions. Thus, drainage may improve the commercial value of Black alder stands (Kapustinskaitė 1983, 1988).

According to Podzarov (Поджаров 1988), natural regeneration in Black alder stands on flooded sites (common conditions in Black alder stands in lowlands dominated by *Cyperaceae* or *Dryopteris* ground vegetation) is very scarce even during the years of abundant seed crop. In Byelorussia, drainage of such stands is suggested by establishing a shallow ditch network and allocating the ditches at the intervals of 400-500 m.

However, too intensive drainage treatment (where the intensity of drainage markedly exceeds the optimum drainage standards) may disturb forest regeneration in the forested wetlands. According to Kapustinskaitė (1983), on the intensively drained fens (i.e. in the 65 *m*-wide-belt adjacent to the drainage ditch), marked lowering of the peat layer and opening of the tree roots were observed. This caused drying out of one and two-year-old stump sprouts of Black alder (Kapustinskaitė 1960). In such cases, intensive drainage may disturb the natural regeneration of Black alder, especially if carried out during the second year after the clear-cutting (Kapustinskaitė 1983). In spite of good seed yield (40 million *per ha*), seed germination and seedling survival in dry peat soils are worse than in peat soils on undrained sites (Поджаров 1988). According to Podzarov (Поджаров 1988), the best natural regeneration of Black alder occurred on the sites dominated by the ground vegetation of *Urtica dioica*, where the access surface water occurs not later than in the middle of May. According to Ruseckas (2002), in the undrained Black alder stands of high quality (the site index class is I[a]) dominated by *Urtica dioica* the depth to the water table varies between 0-12 *cm* depending on the water excess in spring. Therefore, the optimum drainage intensity of 7 *cm* (with 50% probability) was developed mainly for the optimisation of the water regime of the undrained high quality Black alder stands. However, forested wetlands are often drained too intensively in Lithuania. If the water table drops down to 60 *cm* in fens, the vegetation common in eutrophic peatland ecotype may change to a less unfavourable valuable type of vegetation (Volskis *et al.* 1999).

Drainage and clear-cutting in forested wetland also affect nutrient balance of the soil. According to Kotrushenko (Котрушенко 1967), Koshelkov (Кошельков 1982), Saarinen (1996), Saarinen and Sarjala (1999), an imbalance of nitrogen and potassium may occur in the soil after drainage and clear-cutting. In drained peatland with a deep peat layer, the shortage of potassium may be the main reason for poor tree growth (Kaunisto and Paavilainen 1988). On such sites, the nutrient balance can be optimised by the means of phosphorus-potassium fertilization (Saarinen and Sarjala 1999).

There are no explicit studies addressing the above-mentioned problems in Lithuania. The objective of this study was to assess success of natural regeneration in cutovers on drained fens (eutrophic peatland) depending on the soil properties and the depth to the water table.

Material and methods

The study was carried out in the forests of Biržai and Panevėžys forest enterprises located in the northern part of the Lithuanian Midland lowland. This climatic zone is distinguishing by the lowest precipitation in the country (the mean annual amount of 650-700 *mm*) and the largest area of forested wetlands (forests on organic soils make up to 28-35%). Over 52% of the forested wetlands were drained in this region. The draining was especially intensive in the fens belonging to *Caricosa* and *Urticosa* forest types (70% of all drained area). These forests were drained not only to improve the wood yield but also to improve their accessibility. Without a proper drainage, it may hardly be possible to build roads on the land depressions with loam or clay subsoil (Pikk and Seemen 2000).

To assess the effect of the water table depth and soil conditions on natural regeneration of forests on fens, 31 drained cutovers were selected in the forests of Biržai and Panevėžys forest enterprises. Only the sites with 30-100 *cm* and thicker peat layer were selected. In addition, the depth to the water table was measured in nine undrained cutblocks and in eight Black alder stands of pre-mature age on undrained sites.

Most of the cutovers (approximately 80%) were drained by the means of the 1.2-1.9 *m* deep ditches established along the forest compartment lines. In such a case, the coefficient of drainage intensity (I_k) reflects the water table depth (H) better (R^2 from the regression of H on I_k is 0.57; $p < 0.05$) than the distance to the nearest ditch (L) (R^2 from the regression of H on L is 0.38). The coefficient of drainage intensity (I_k) was estimated according to the following formula: $I_k = T_1/L_1 + T_2/L_2$, where T_1 and T_2 are the depth of the two adjacent ditches, L_1 and L_2 are the distance to the corresponding ditch.

The mean width and length of the cutblocks were 80-100 *m* and 150-200 *m*, respectively. The longer axis of the cutblocks was positioned towards the North. The cutblocks were left for natural regeneration. The natural regeneration and soil properties were assessed in 31 transects (100 to 300 *m* long) located perpendicularly to the drainage ditch (Figure 1). A total of 131 water wells were drilled to measure the depth to the water table and 131 sample plots of 10 × 10 *m* were established. The water wells were located 20-50 *m* apart form each other depending on the width of the cutover belt and the distance to the nearest ditch. The depth to the water table was assessed on three occasions during one year: in spring (the beginning of the growth period), in July and at the beginning of September.

The correspondence of the depth to the water table to the optimum soil moisture level was assessed according to the hydro-climatic coefficient (k), the

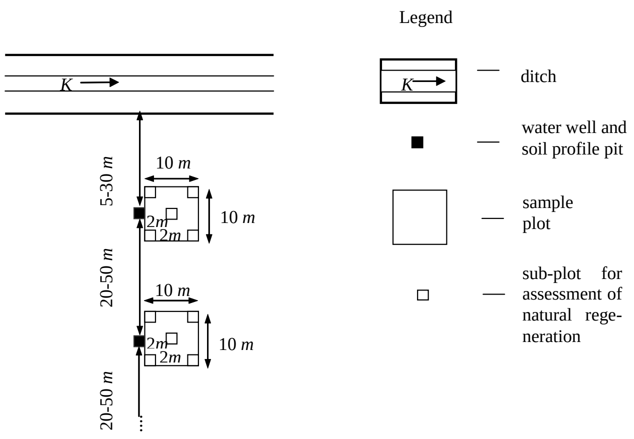

Figure 1. Experimental design showing allocation of sample plots, water wells, soil sampling profiles and sub-plots for assessment of natural regeneration

probability of which considers climatic conditions at the time of assessment and the climatic data over the past 50 years (Ruseckas 1989):

$$k = 0.230P_1 + 0.20P_2 + 0.1(P_3 - 0.15E_0 + 0.05S) \quad (1)$$

where P_1 is the precipitation amount over the winter of the current hydrological year (December, January, February); P_2 is the amount of water in snow and ice layer on the first of March of the current year; P_3 is the precipitation amount over March and April of the current year; E_0 is the sum of daily evaporation values during April of the current year; S is the number of days with permanent snow cover during March of the current year.

The probability (P) of the hydro-climatic coefficient (k) was estimated according to the variation pattern of the hydro-climatic coefficient over the past 50 years:

$$P = 44.67 - 2.9667k; \; (R^2 = 0.977, \; p < 0.05) \quad (2)$$

Sample plots of size 100 m^2 were established close to the water wells. In each sample plot, 5 subplots (size 4 m^2 each) were allocated to assess the number of regenerating young trees.

During the assessment of natural regeneration, the following data were recorded: tree species, age, stocking, the mean height, type of plants (sprouts or seedlings), viability, seedling distribution pattern and position in relation to the site micro-topography. The mean height of each height class was calculated. The viability was assessed according to the following classes: (1) viable, (2) not viable and (3) dead (Regulations on natural and artificial establishment of forest 2003).

According to the number of viable regenerating young trees, the cutblocks were subdivided into the following categories: (1) sites with natural regeneration of sufficient (satisfactory) stocking (the number of viable and evenly distributed young trees of Black alder and birch, Norway spruce and ash, as well as Scots pine was not less than 2200, 2000, 3500 young trees *per ha*, respectively (based on the standards given in the Regulations on natural and artificial establishment of forest (2003)), and (2) sites with natural regeneration of insufficient stocking (the numbers of the regenerating young trees were less than these for the first category indicated above).

To assess the type and the physical properties of the soils, a 1 *m* deep profile pit was dug in each sample plot. Soil sample rods were used to assess soil properties at 2 *m* depth. In the profile pits, the following assessments were made: thickness of the forest litter and the peat layer and the soil samples were taken at the depths of 2-10, 11-20, 21-30, 31-60, 81-100 *cm* for assessment of the degree of peat decomposition and soil texture. The degree of peat decomposition was measured according to the Post scale (Overbeck 1975). The soil texture of the upper 20 *cm* layer of the bedrock was assessed by the pipette method (Buivydaitė and Motuzas 2000) and the soil texture of the deeper bedrock layers - by the Kacinski method (Vaičys et al. 1979).

To assess soil chemical properties in the 17 cutblocks, 50 soil samples were taken from the surface soil layer (0-20 *cm*). In the soil chemistry laboratory, the following soil properties were determined: potential exchangeable soil acidity, potential hydrolytic soil acidity and the amount of bases in the soil. The hydrolytic soil acidity and the amount of bases in the soil were assessed according to Geohler and Drews (1971). The potential exchangeable soil acidity was assessed by using the potenciometric method of *KCl* extractives. The ash content in the peat was assessed according to the standard LST EN 13039.

Results and discussion

The effect of soil acidity on natural regeneration

There was a large variation in the soil chemical properties on drained fens (eutrophic peatlands). In the cutovers with insufficient natural regeneration, the potential exchangeable soil acidity varied from 4.1 to 6.1 and the mean exchangeable soil acidity was 5.10±0.12 (Table 1).

There was no significant difference in exchangeable acidity between the sample plots with sufficient and insufficient natural regeneration (Table 1). However, in the sample plots with sufficient regeneration,

Table 1. Chemical properties of peat soils on drained fens ("a" data for the sample plots with insufficient regeneration, "b" data for the sample plots with sufficient regeneration)

Chemical properties		Mean	Minimum	Maximum	Coefficient of variation
pH_{KCl}	*a*	5.10±0.12	4.10	6.10	12.4
	b	5.54±0.10	4.20	6.00	8.3
	a-b	-0.43±0.16 (t = 2.68, p = 0.0148)			-
Hydrolytic acidity, *mekv/kg*	*a*	1032.78±76.68	382.05	1712.20	37.9
	b	820.49±56.05	532.94	1587.47	30.6
	a-b	212.29±94.99 (t = 2.23, p = 0.038)			-
Amount of basis in the soil, *mekv/kg*	*a*	1566.52±64.68	887.55	2028.50	21.1
	b	1674.26±49.59	1313.25	2178.71	13.2
	a-b	-107.74±81.50 (t = 2.23, p = 0.2025)			-
Base saturation, %	*a*	60.66±2.35	34.14	84.15	19.1
	b	67.36±1.78	45.27	77.03	11.8
	a-b	-6.70±3.25 (t = 2.27, p = 0.037)			-

the values of pH_{KCl} were 5.54 ± 0.10, which is a significantly higher value than in the sample plots with insufficient regeneration (ΔpH_{KCl} = 0.43 ± 0.16, p < 0.05, t = 2.78).

The variation in the exchangeable acidity of the sample plots showed that the number of regenerating young trees was insufficient in most of the plots on the soils with *pH* less than 5.1 (of 14 only in 2 sample plots on the soils of such acidity contained sufficient number of regenerating young trees of dawny birch (*Betula pubescens Ehrh.*)) (Figure 2).

The most favourable conditions for forest regeneration were on the soils with conditionally acidic reaction (*pH* from 5.8 to 5.9) (Figure 2). On the above-mentioned soils, the number of sample plots with sufficient regeneration was three times greater than with insufficient regeneration. Witt (1990) and Carthaigh (1997) obtained similar results, which showed that the tree growth was the greatest on the soils with *pH* values ranging from 5.5 to 6.0. Vaičys *et al.* (1979) reported a slightly larger optimum range of the potential exchangeable acidity (pH_{KCl}) for

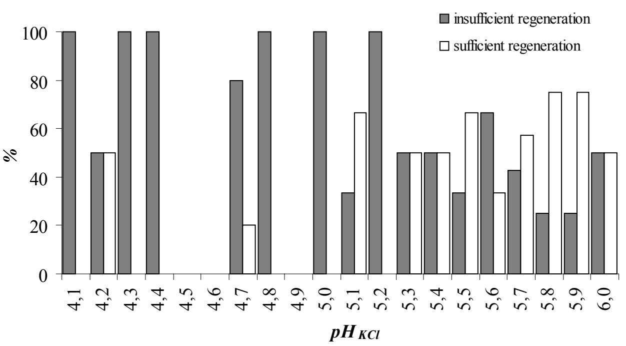

Figure 2. pH_{KCl} contents at the upper soil layer (0-20 *cm*) in the sample plots with sufficient (open bars) and insufficient (filled bars) regeneration

deciduous tree species (within the range of 4.7 to 7.0). We found a significant relationship between the number of viable trees (N) and pH_{KCl} values (r = 0.74, p < 0.05), which confirms the results on the effect of the potential exchangeable acidity on natural regeneration. The regression of the number of viable trees on pH_{KCl} yielded the following equation: $N = 0.1787\ Ln(pH_{KCl}) + 3.8503$, ($R^2$ = 0.543, p < 0.05).

In addition, the suitability of the cutovers in drained forested wetland to natural regeneration was assessed according to potential hydrolytic acidity of the soil, which is always higher than the potential exchangeable soil acidity (Buivydaitė and Motuzas 2000). There was a significant relationship between the number of viable trees (N) and the potential hydrolytic peat soil acidity (R^2 = 0.37, p = 0.036), (Figure 3). This indicates that the potential hydrolytic acidity as well as pH_{KCl} is a suitable index for assessment of suitability of cutovers to natural regeneration in drained forest wetlands.

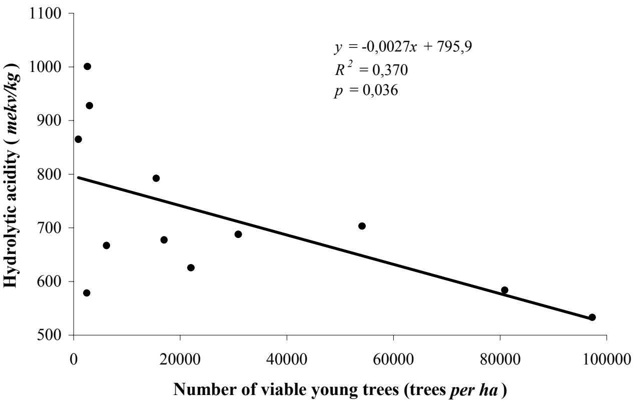

Figure 3. Dependence of the number of viable young trees on the hydrolytic acidity of the upper soil layer (0-20 *cm*)

The effect of soil base saturation on natural regeneration

The soil base saturation is one of the main indicators of soil fertility (Вайчис 1975, Buivydaitė and Motuzas 2000).

The soil base saturation in the sample plots with sufficient regeneration was significantly higher than in the sample plots with insufficient regeneration (Table 1). In the sample plots with soil base saturation of 31-45%, natural regeneration was insufficient (Figure 4). According to Vaičys (Вайчис 1975), such low soil base saturation is common in the intermediate type of peat soils. In the sample plots with soil base saturation of 45.1-60.0%, out of 15 only in 3 sample plots natural regeneration often was insufficient, natural regeneration of dawny birch with occasionally occurring Norway spruce (*Picea abies (L.)*

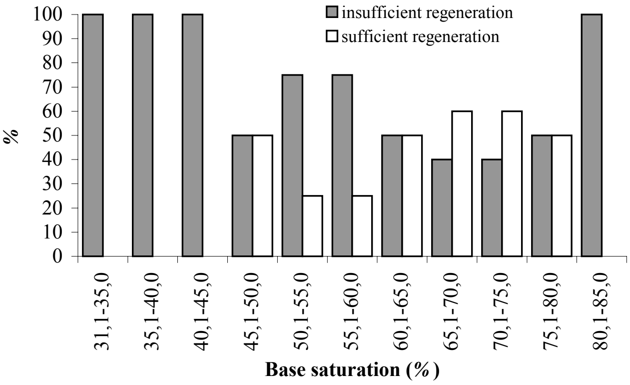

Figure 4. Percentage of the sample plots with sufficient and insufficient natural regeneration in each percentage class of soil base saturation

H. Karst) and Scots pine (*Pinus sylvestris L.*) seedlings was sufficient). In the sample plots with soil base saturation of 60.1-80.0%, natural regeneration of Black and Grey alder (*Alnus incana (L.) Moench*) and European ash (*Fraxinus excelsior L.*) was abundant. In the soils with base saturation of 65.1 to 80.0%, the plots with sufficient natural regeneration occurred 1.4 times more than plots with insufficient regeneration. Thus, the most favourable conditions for natural regeneration occur on sites with soil base saturation ranging from 65 to 80%. Therefore, in the cutovers in fens with the soil base saturation of less than 45% and potential soil acidity *HA* > 1100 *mekv/kg*, alkaline enrichment is recommended. Many studies indicate that alkaline enrichment positively affects the growth of deciduous and Norway spruce trees (Сабо 1980, Паавилайнен 1983, Корчагина, Ионин 1984, Ипатьев 1990).

The effect of water table depth on natural regeneration

As the water table depth is closely connected with the climatic conditions, it may be useful to review the climatic data over the study period. The spring of 2003 was dry (in 2003 the hydro-climatic coefficient reached 68.8% of the long-term mean value). The spring of 2004 was of medium humidity (the hydro-climatic coefficient was close to the long-term mean value). During the period of active growth (from May to August) in 2003 and 2004, the precipitation amount was 295 *mm* and 353 *mm*, respectively. These values were reaching 80 and 96% of the long-term mean values.

On undrained sites, at the beginning of the growth period in 2003 and 2004, the water table was 5 ± 2 *cm* and 12 ± 4 *cm* above the surface, respectively (these values were from 5 to 10 *cm* higher than in pre-mature Black alder stands on drained out sites). This data correspond to the reports from some studies, where a rise of water table from 7 to 17 *cm* was observed after the clear-cutting (Roy 1998, Roy *et al.* 2000, Ипатьев 1990). On drained cutovers with peat soils, the depth to the water table at the beginning of the growth period ($H_{V.01}$) was dependent on the drainage intensity (I_k) (Figure 5). In the spring of 2004 with an average humidity, the depth to the water table was 5-45 *cm*, which is from 17 to 57 *cm* deeper than in the premature Black alder stands on undrained sites. At the beginning of the growth period, the mean depth to the water table was 27.4 ± 2.1 *cm* and 45.1 ± 2.6 *cm* below the surface, in the cutblocks with sufficient and insufficient regeneration, respectively (Table 2). This indicates, some of the sites were drained out too intensively: in the plots with insufficient regeneration the water table was for 17.8 ± 3.3 *cm* (t = 5.34, p < 0.0001) deeper than in the plots with sufficient regeneration.

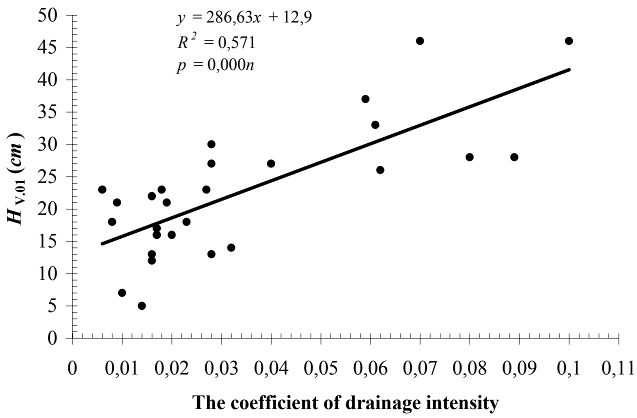

Figure 5. The dependence of the depth to water table at the start of growth period ($H_{V.01}$) on the coefficient of drainage intensity (I_k) (data from 2004)

The variation coefficient for the mean water table depth was very high on all sites regardless of the regeneration success (V = 48.5-59.9%) (Table 2). To investigate the cause of such a large variation, the effects of other factors influencing soil moisture were studied. Soil moisture and forest regeneration success are affected not only by the depth to the water table (Hillman 1992) but also on the subsoil texture (Ruseckas 2002).

The assessments of the effect of soil texture on the depth to the water table showed that in the cutblocks with sufficient regeneration and coarse subsoil texture (gravel, sand, sandy loam), the depth to the water table was for 15.9 ± 3.7 *cm* (p = 0.0001) less than in the cutblocks with insufficient regener-

Table 2. Mean depth to water table at the beginning of the growth period on shallow peat soils (HS_s-*ph*) depending on the subsoil texture

Subsoil texture	Plots with insufficient regeneration						Plots with sufficient regeneration						Difference			
	M, cm	*m,* (±) *cm*	*Min, cm*	*Max, cm*	*N*	*V*	M_S, *cm*	*m,* (±) *cm*	*Min, cm*	*Max, cm*	*N*	*V*	*M-*M_S, *cm*	$m_{(M-Ms)}$ (±) *cm*	*t*	*p*
Gravel	**53.7**	9.8	16	125	11	60.3	**18.0**	3.7	13	29	4	41.3	**35.7**	10.5	3.42	0.0418
Sand	**38.3**	3.6	11	95	30	51.7	**26.5**	2.7	9	46	19	62.3	**11.8**	4.5	2.62	0.0193
Sandy loam	**37.9**	3.6	18	57	12	32.8	**26.6**	3.9	3	46	13	52.5	**(11.3)**	5.3	2.14	0.0556
Mean for peatland with coarse-textured subsoil	**41.4**	3.1	11	125	53	53.6	**25.5**	2.1	3	46	36	57.2	**15.9**	3.7	4.31	0.0001
Light loam	**49.3**	7.8	12	62	6	38.8	**29.6**	6.6	5	65	8	63.3	**(19.7)**	10.2	1.92	0.1129
Medium loam	**54.8**	9.2	28	68	4	33.7	**42.2**	9.4	18	65	5	49.8	**(12.6)**	13.2	0.95	0.4122
Mean for peatland with medium textured subsoil	**51.5**	4.7	12	68	10	35.0	**34.5**	4.5	5	65	13	57.5	**17.0**	6.5	2.61	0.0290
Mean for peatland with heavy textured subsoil	**65.5**	5.0	52	80	7	18.1	**19.5**	3.6	13	28	4	37.1	**46.0**	6.1	7.8	0.0044
Mean for peatland	**45.1**	2.6	11	125	70	48.5	**27.4**	2.1	3	65	53	59.9	**17.8**	3.3	5.34	0.0001

M – mean, *m* – standard error, *Min* – minimum value, *Max* – maximum value, *N* – number of sample plots, *V* – coefficient of variation, *t* – Student t-test value, *p* – probability the t-test value. Where the difference between the sites with sufficient and insufficient regeneration was not significant, the difference values were included in the parenthesis.

ation. In the cutovers with water table depth greater than 50 *cm*, natural regeneration was very poor. This indicates that, in the cutovers with sand, sandy loam or gravel subsoil, lowering down the water table below the optimum drainage level is unprofitable and may also negatively affect natural regeneration (according to Ruseckas (Русецкас 1989), Smoliak (Смоляк 1969) and Meshechok (1969) the optimum drainage level for the growth of deciduous forests in fens is 7-21 *cm*, 10-15 *cm* and 30 *cm*, respectively). In agreement to this, Volskis *et al.* (1999) concluded that too intensive drainage in fens may lead to a lower commercial value of the forests.

Similar results were obtained on shallow peat soils on medium loam subsoil: in the plots with sufficient and insufficient regeneration, depth to the water table was 34.5 ± 4.5 *cm* and 51.0 ± 4.7 *cm*, respectively (the difference was 17.0 ± 6.5, p = 0.034). If at the beginning of the growth period water table in such soils is below the depth of 70 *cm*, natural regeneration totally fails and if water table is at the depth of 1-10 *cm*, natural regeneration is almost 100% successful (Figure 6). Thus, the critical water table depth, below which natural regeneration is at risk, depends on the subsoil texture of the shallow peat soils (Table 2).

In conclusion, shallow peatland sites with subsoil of more heavy texture are less sensitive to negative effects of too intensive drainage. To obtain successful natural regeneration in fens, lowering down the water table below the optimum level is not recommended on shallow peat soils with sandy as well as loam subsoil.

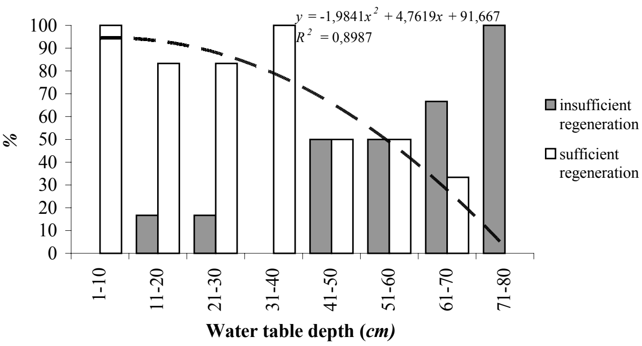

Figure 6. Percentage of the sample plots with sufficient and insufficient natural regeneration in each class of water table depth at the beginning of the growth period in the soils with loam subsoil

Relationships among the properties affecting natural regeneration

The above given results indicated that the following factors have an important effect on natural regeneration of forests on fens: the depth to the water table at the beginning of the growth period, the *pH* of the peat soil, the potential hydrolytic soil acidity and the base saturation in the peat soil. Most of these factors were correlated with each other (Table 3). For instance, the correlation coefficients between the base saturation of the upper peat layer (0-20 *cm*) and the potential hydrolytic acidity, pH_{KCl}, the base sum, the thickness of the peat layer, the amount of silt/clay fraction particles in subsoil were – 0.85, 0.79, 0.50, 0.55, 0.43 (p < 0.05), respectively (Table 3).

Table 3. Correlation coefficients among the soil properties affecting the natural regeneration of forest

Indices	$H_{V.01}$	D_h	F_m	pH_{KCl}	HA	sb	BS
D_h	-0.540	–	–	–	–	–	–
F_m	-0.275	0.770	–	–	–	–	–
pH_{KCl}	-0.595	0.387	0.202	–	–	–	–
HA	0.760	-0.448	-0.280	-0.826	–	–	–
sb	-0.139	0.320	0.363	0.221	0.030	–	–
BS	-0.750	0.545	0.433	0.793	-0.848	0.497	–
N	-0.353	0.280	-0.094	0.415	-0.608	0.002	0.538

$H_{V.01}$ – the depth to water table at the start of growth period (*cm*), D_h – thickness of the peat layer (*cm*), F_m – amount of silt and clay fraction particles (< 0.01 *mm*) in the subsoil (*%*), pH_{KCl} – the potential exchangeable soil acidity (*mekv/kg*), *HA* – the potential hydrolytic acidity of the peat soil (*mekv/kg*), *sb* – sum of basis (*mekv/kg*), *BS* – the base saturation of the peat soil (*%*), *N* – number of viable regenerating young trees (young trees *per ha*).

The multiple stepwise regression analysis (excluding the correlated variables), showed that natural regeneration of forest in fens are mainly affected by the following main components: the depth to the water table at the beginning of the growth period ($H_{V.01}$) and the peat hydrolytic acidity (*HA*). The multiple regression equation was the following:

$$N = 168059.7 - 3446.5H_{V.01} - 35.180HA \quad (3)$$
$$R^2 = 0.814,\ F = 7.51,\ p < 0.0007$$

where *N* is the number of viable trees *per ha*.

This equation confirms the hypothesis that the depth to the water table and hydrolytic soil acidity are the main factors affecting natural regeneration of forests on cutovers on fens. Therefore, to improve the natural regeneration of forests on such cutovers, the water regime of the upper soil layers should be optimised by regulating water flow in drainage ditches and the soils of very high acidity should be enriched with alkaline.

Conclusions

1. Natural regeneration of forest in cutovers on drained fens (eutrophic peatlands) is affected by the following factors: the depth to the water table at the beginning of the growth period ($H_{V.01}$), the *pH* of the peat soil, the potential hydrolytic acidity of peat soil (*HA*), the base saturation of the peat soil and the thickness of the peat layer. As determined by the multiple regression analysis, the depth to the water table at the beginning of the growth period and the potential hydrolytic acidity of the peat soil had the strongest effect (equation No. 3).

2. The critical water table depth, below which natural regeneration is at risk, depends on the subsoil texture of the shallow peat soils (HS_s-*ph*). In the peat soils with gravel, sand, sandy loam, light loam and medium loam subsoil, this critical water table depth was 18.0 ± 3.7 *cm*, 26.5 ± 2.7 *cm*, 26.6 ± 3.9 *cm*, 29.6 ± 6.6 *cm*, 42.2 ± 9.4 *cm*, respectively.

3. In the plots with sufficient regeneration, the mean potential hydrolytic soil acidity was equal to 820.49 ± 56.05 *mekv/kg*, which is markedly lower value than in the plots with insufficient regeneration (ΔHA=212.29 ± 94.99 *mekv/kg*; t = 2.23; p = 0.039).

4. To obtain successful natural regeneration of forests in cutovers on drained fens (eutrophic peatlands), the water regime should be optimised by technical means to maintain the optimum soil moisture level (in many cases by damming the drainage ditches) and the soils of very high acidity (HA > 1100 *mekv/kg*) should be enriched with alkaline.

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ВЛИЯНИЕ ПОЧВЕННЫХ УСЛОВИЙ НА ЕСТЕСТВЕННОЕ ВОЗОБНОВЛЕНИЕ ЛЕСА НА ВЫРУБКАХ ОСУШЕННЫХ НИЗИННЫХ БОЛОТ

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Резюме

Динамика естественного возобновления древесных пород на вырубках с болотными почвами низинного типа в зависимости от их агрохимических свойств и стояния уровня грунтовых вод была изучена в Биржайском и Паневежском лесхозах Литвы. Для этой цели, перпендикулярно осям канав, была устроена 31 трансекта 100-300 *м* длины. В трансектах для наблюдения за уровнем грунтовых вод, был оборудован 131 колодец. Возле каждого колодца для изучения растительности, была устроена пробная площадь 10x10 м. Химические анализы почвы были проведены в центральной лаборатории агрохимических исследований Литвы.

Выявлено, что на естественное возобновление древесных пород на вырубках с болотными почвами низинного типа влияет целый ряд почвеных факторов, это высота уровня грунтовых вод на начало вегетационного периода ($H_{V.01}$), глубина торфа, обменная (*pH*) и гидролитическая кислотность торфа *(HA),* насыщенность почвы основаниями. Влияние основных факторов (величин $H_{V.01}$, *HA*) на количество (*N*) всходов и подроста основных древесных пород на вырубках описано уравнением множественной линейной регрессии ($N \square 168059{,}7 \square 3446{,}5 H_{V.01} \square 35{,}180 HA$ ($R^2 \square 0{,}814$; $F \square 7{,}51$; $p \square 0{,}0007$)).

Выявлено, что критическая максимальная глубина стояния уровня грунтовых вод, при которой формируются молодняки леса достаточной густоты, зависит от грануллометрического состава подстилающей породы и в маломощных торфяных почвах (HS_s-*ph*) с подпочвой из гравия составляет 18,0±3,7 *см*, с подпочвой из супеска – 26,6±3,9 *см*, с подпочвой из легкого суглинка – 29,6±6,6 *см*, с подпочвой из среднего суглинка – 42,2±9,6 *см*.

Замечено, что на вырубках, на которых формируются молодняки леса достаточной густоты, гидролизная кислотность почв *(HA)* существенно меньше (ΔHA = 212,29 ± 94,99 *мэкв/кг*; t = 2,23; p = 0,038), чем на вырубках, на которых формируются неполноценные (недостаточной густоты) молодняки леса, и составляет в среднем 820,49±56,05 *мэкв/кг*. Сделан вывод, что для благополучного естественного возобновления осушенных вырубок с болотными почвами низинного типа следует на болотах уровень почвенно-грунтовых вод отрегулировать гидротехническими средствами до нормы осушения (в большинстве случаев для этой цели следует поднять уровень воды в канавах), а очень кислые почвы *(HA >1100 мэкв/кг)* известковать.

Ключевые слова: естественное возобновление леса, вырубки, болотные почвы, грунтовые воды, осушение