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Nutrient Status of Tree Seedlings in a Site Recovering from a Landslide

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Abstract: The aim of the study was to investigate the effect of soil recovery after a landslide on the nutritional status of a young generation of Silver fir (*Abies alba* Mill.) and Silver birch (*Betula pendula* Roth.) trees. The study was carried out on the site of a landslide that took place in 2010 in the Gorlice Forest District (Southern Poland). Basic soil properties, macro, and microelements content and enzymatic activity were determined in the soil samples that were collected from across the landslide area, from locations distributed by a grid 10 × 10 m (18 points). Plant material samples, collected to indicate nutritional status, were also taken from each point. Results demonstrate that the nutritional status of emerging regeneration depends on soil acidification and soil organic matter content. The pH of the soils on the landslide determines the intensity of nutrient uptake by the young seedlings. The nutrition of young trees varied across the landslide zone, differing in terms of the soil's organic matter content and its chemical properties. In comparison to the depletion zone, the accumulation zone proved to be substantially richer in soil organic matter, resulting in higher soil biochemical activity. The study demonstrates that Silver birch (*Betula pendula* Roth.) is improving nutrient cycling in areas disturbed by landslide.

Keywords: enzyme activity; forest ecosystem; silver fir; silver birch; soil organic matter

1. Introduction

Plants take up most of the essential macro and microelements from the soil. The nutritional status of trees then depends not only on the total mineral content in soil but also on a number of factors that determine the assimilation of nutrition by higher plants. Such factors are the activity of soil microorganisms and their enzymes, the contents of the organic matter, moisture, and soil structure, which determines proper aeration and root development [1,2]. These factors are usually strongly related to each other.

Landslide is a term used to describe the phenomena of rocky masses becoming dislocated from the ground to be displaced along a slope. Soil cover on a landslide is subject to strong transformations if not complete destruction and the soil properties are often drastically altered. Landslides are particular in that the uneven distribution of organic matter and associated nutrients across the zone makes for unequal soil fertility [3]. Landslides zones rich in organic matter as a source of nutrients promote colonization by vegetation [4]. Adams and Sidle's [5] observations note a depletion zone in landslides that is characterized by relatively low nitrogen availability. Following a landslide, the composition of the organic matter, structure, texture, and microbiological activity of the soil is often substantially different [6–8]. Landslides have received substantial research attention, particularly investigating the effects on vegetation [9–13]. Spatially heterogeneous removal of substrate on landslide is responsible for a variety of plant successional trajectories [9]. The appearance of plants on a landslide depends on the availability of suitable germination sites, soil stability and presence of organic matter and nutrients. Invasive species frequently thrive on highly disturbed surfaces such as landslide [10]. For example, studies indicate that they are conducive to the development of a number of species, particularly pioneer and fast-growing species sown by wind and birds. This may be for the reason that, they are characterized by diverse microhabitats that create the conditions for numerous tree and shrub species to emerge [8,14], and diverse vegetation is associated with soil recovery [13–15].

Soil enzymatic activity is a parameter used to monitor soil changes [16–18]; it reflects soil quality as it is closely related to important soil parameters such as soil organic matter, soil physical properties, and microbiological activity [19–21], which are all substantially affected by landslides [14]. Measuring effects on soil enzymatic activity is key to understanding how to manage land for microbial biodiversity and activity, and consequently, for enhanced enzymatic activity [22,23]. For example, Błońska et al. [16] found evidence that fir stands were capable of stimulating enzyme activity, particularly β-glucosidase activity. However, a simultaneous interaction of mycorrhizal fungi in the roots of fir stands should be considered. Similarly, Gawęda et al. [24] confirmed the beneficial effect of birch stand regeneration on the dehydrogenase activity of post-agricultural land.

To date, previous studies have focused on determining areas predisposed to landslides and as yet there are no studies investigating the rate of soil cover recovery and its association with vegetation. Understanding how plants colonize a landslide can improve the effectiveness of long-term restoring soil cover stability in a landslide. Assessment of regenerating landslide vegetation is key to developing reconstruction strategies in disturbed areas. Estimation of the condition of regenerating vegetation, including the new generation of trees, will indirectly assess the stability of the ecosystems and the risk of disturbance. Our research covered tree species with a different spectrum of ecological requirements. We compare deciduous species of early stages of succession and the shade-resistant coniferous species, characterized by slow growth. The aim of the present study is to investigate the effect of soil recovery on a landslide on the nutritional status of a young generation of trees. We expect that the accumulation zone, a part of the landslide comparatively rich in organic matter, will demonstrate increased nutrition in the new generation of trees. We also expect that the young generation of birch and fir will react differently to properties in the recovering soil.

2. Materials and Methods

2.1. Study Area and Soil Sampling

The research was conducted on a landslide that took place in 2010 in the Gorlice Forest District (Southern Poland). Information on the landslide was obtained from the Polish Institute of Geology in which a landslide inventory is maintained under the System for Landslide Mitigation. The landslide was located at an altitude 530–620 m a.s.l, sample plots occupied area with magura tertiary sandstones and schists and dystric cambisols prevailed in the test area [25]. Prior to the landslide, Silver fir (*Abies alba* Mill.) was the dominant species in the study area. Following the landslide, birch and fir appeared spontaneously as a natural regeneration. The study area is characterized by the following climate conditions: the average annual rainfall is 880 mm, the average annual temperature is 7.0 °C, the length of the growing season is 205 days. According to the area's morphology, the landslide was divided into two zones: a depletion zone (0.1 ha) and an accumulation zone (0.1 ha). Soil samples were collected on a 10 × 10 m grid that covered the landslide area (60 × 30 m) yielding a total of 18 sampling points (Figure 1). Soil samples for laboratory analysis were collected from the surface mineral horizons, this was from a depth of 0–15 cm after removing the organic layers. Each soil sample was a mixture of 5 subsamples that had been taken from one grid point from 1 m^2. Plant material from each of the grid points was collected for laboratory analyses. The analyses included Silver fir (*Abies alba* Mill.) needles and Silver birch (*Betula pendula* Roth.) leaves. Young trees collected for analysis were 4–5 years old and five trees from each species were collected from each point. Plant material (seedlings of birch and fir) was dried, birch leaves, and fir needles were then separated from the remaining parts of the trees.

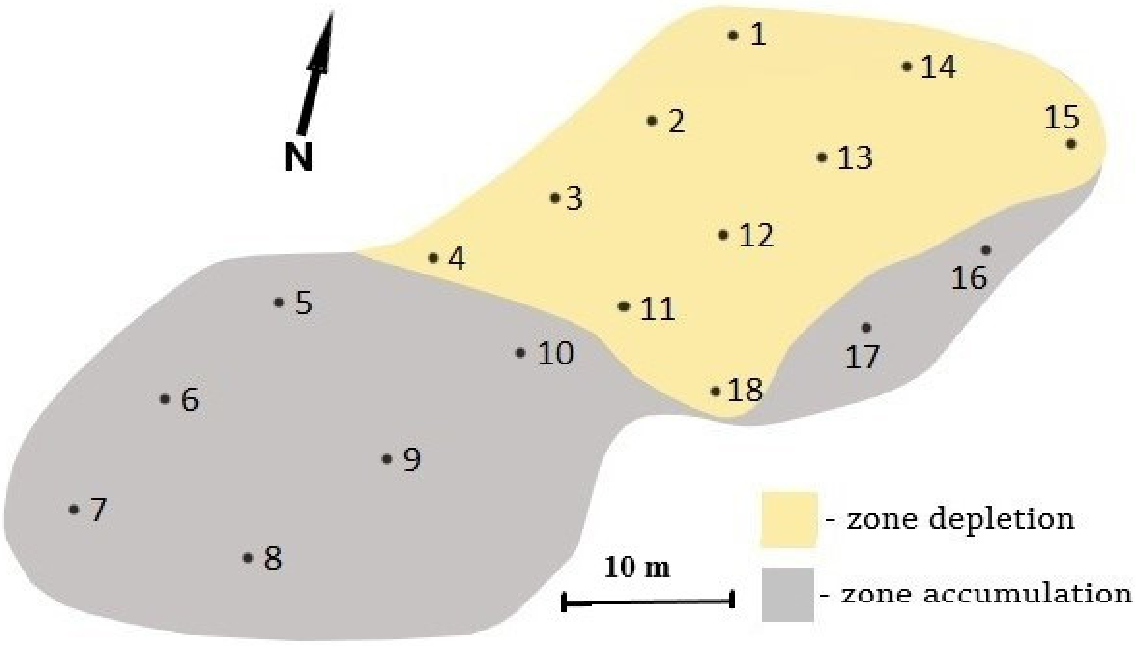

Figure 1. Soil sampling scheme on the landslide area.

2.2. Laboratory Analysis

In the soil samples, particle-size distribution was determined using laser diffraction (Analysette 22, Fritsch, Idar-Oberstein, Germany), pH was analyzed in distilled water using the potentiometric method, and the content of total nitrogen (N) and organic carbon (C_t) content were measured using LECO CNS True Mac Analyzer (Leco, St. Joseph, MI, USA), including calculation of the C/N ratio. Exchangeable calcium, potassium, magnesium, and sodium were determined after extraction in 1M ammonium acetate by an ICP (ICP-OES Thermo iCAP 6500 DUO, Thermo Fisher Scientific, Cambridge, UK). Exchangeable acidity was determined by the Sokołow method, and hydrolytic acidity was determined by the Kappen method. In samples with natural moisture, the forms of mineral nitrogen NH_4-N and NO_3-N in 2M KCl soil extracts by FIAstar 5000 were determined.

To obtain an indication of enzymatic activity, fresh samples of natural moisture were filtered through a sieve (ø 2 mm) and stored at 4 °C until analysis. Enzyme activity was measured using fluorogenically labelled substrates [26,27]; six fluorogenic enzyme substrates based on 4-methylumbelliferone (MUB) were used: MUB-β-D-cellobioside for β-D-cellobiosidase (CB), MUB-β-D-xylopyranoside for xylanase (XYL), MUB-*N*-acetyl-β-D-glucosaminide for *N*-acetyl-β-D-glucosaminidase (NAG), MUB-β-D-glucopyranoside for β-glucosidase (BG), MUB-phosphate for phosphatase (PH) and MUB-sulfate potassium salt for arylsulphatase (SP) [28]. 2.75 g of soil was mixed with a 92 mL universal buffer (pH 6.0). Soil suspension was then pipetted into wells on a microwell plate that contained the substrate and modified universal buffer. Fluorescence was measured by incubations of soil suspension (for 1.5 h at 35 °C) in 96-well microplates (Puregrade, Germany), and analyzed immediately on a multi-detection plate reader (SpectroMax) with excitation at 355 nm and emission at 460 nm wavelength.

In the leaves and needles samples, the concentration of macro and microelements was determined by an ICP (ICP-OES Thermo iCAP 6500 DUO, Thermo Fisher Scientific, Cambridge, UK). Dried samples of leaves and needles were mineralized in a mixture of HNO_3 and $HClO_4$ (3:1). Carbon (C) and nitrogen (N) in the litter were measured with an elemental analyzer (LECO CNS TrueMac Analyzer (Leco, St. Joseph, MI, USA)).

2.3. Statistical Analysis

The distribution was checked for normality. U Mann–Whitney test was used to evaluate the differences between the mean values of properties. Pearson correlation coefficients for the content of selected elements in the leaves and needles of seedlings and soil characteristics were calculated. A general linear model (GLM) was used to investigate the effect of localization on landslide and tree species on nutritional status of young trees. The classification and regression tree (C&RT) approach was applied to estimate the influence of soil properties on nitrogen content in the leaves and needles of seedlings. Differences with $p < 0.05$ were considered statistically significant. All analyses were performed using Statistica 12 software (StatSoft 2012).

3. Results

The area of the landslide under study revealed substantially diverse soil properties across the zone. The depletion zone was characterized by significantly less organic matter content than the accumulation zone; on average, samples from the depletion zone were characterized by 9.2 g·kg^{-1} Corg. and 0.7 g·kg^{-1} N, while samples from the accumulation zone contained 19.1 and 1.4 g·kg^{-1} C and N, respectively (Table 1). No significant differences were found between pH levels, acidity, or the content of macro and microelements between depletion and accumulation zones (Tables 1 and 2). The depletion zone was characterized by single points with a slightly higher pH, alkaline cation content, and lower acidity. Accumulation zone soil samples were characterized by a higher content of total phosphorus (242.5 mg·kg^{-1}) and mineral forms of nitrogen, ammonium (N-NH_4 1.51 mg·kg^{-1}) and nitrate (N-NO_3 24.33 mg·kg^{-1}), while the mean content of phosphorus and mineral forms of nitrogen were significantly lower in depletion zone soil samples (182.4, 0.94 and 12.48 mg·kg^{-1}, respectively; Tables 2 and 3). Additionally, accumulation zone soil samples had a significantly higher activity of enzymes (CB, BG, NAG, PH; Table 3). However, it should be noted that there was no such distinction observed in the case of xylanase (XYL) and arylsulphatase (SP) activity (Table 3).

Table 1. Basic properties of soil of depletion and accumulation zone.

	pH H_2O	pH KCl	Hh	He	C	N	C/N	Sand	Silt	Clay
			cmol (+)·kg^{-1}		%				%	
Zone of depletion	5.12 ±0.74 ^{a}	3.87 ±0.40 ^{a}	7.26 ±3.62 ^{a}	6.86 ±4.60 ^{a}	0.92 ±0.20 ^{b}	0.07 ±0.01 ^{b}	14.20 ±2.34 ^{a}	16.1 ±6.2 ^{a}	69.4 ±3.7 ^{a}	14.5 ±3.8 ^{a}
Zone of accumulation	4.72 ±0.88 ^{a}	3.83 ±0.82 ^{a}	10.30 ±3.92 ^{a}	8.79 ±3.81 ^{a}	1.91 ±0.49 ^{a}	0.14 ±0.03 ^{a}	14.08 ±1.22 ^{a}	20.5 ±11.1 ^{a}	67.3 ±6.8 ^{a}	12.1 ±4.8 ^{a}

Mean ± standard deviation; Hh—hydrolytic acidity; He—exchangeable acidity; small letters in the upper index of the mean values mean significant differences between zones of landslide.

Table 2. Macro and microelements content in soil of depletion and accumulation zone.

	Al	Ca	Mg	K	Na	P	Cu	Mn	Ni	Zn
	mg·kg^{-1}									
Zone of depletion	24886.5 ±5340.5 ^{a}	1377.3 ±899.2 ^{a}	3706.9 ±1110.8 ^{a}	8033.6 ±2893.6 ^{a}	310.2 ±46.6 ^{a}	182.4 ±65.4 ^{b}	12.5 ±6.2 ^{a}	568.8 ±233.1 ^{a}	24.9 ±12.5 ^{a}	43.0 ±11.5 ^{a}
Zone of accumulation	24170.9 ±7445.8 ^{a}	1151.3 ±1195.5 ^{a}	3414.9 ±1743.4 ^{a}	7593.8 ±4547.4 ^{a}	312.7 ±95.2 ^{a}	242.5 ±40.4 ^{a}	11.5 ±8.17 ^{a}	705.7 ±503.5 ^{a}	25.1 ±24.3 ^{a}	43.4 ±14.9 ^{a}

Mean ± standard deviation; small letters in the upper index of the mean values mean significant differences between zones of landslide.

Table 3. Enzyme activity and mineral form of nitrogen of soil of depletion and accumulation zone.

	CB	BG	XYL	NAG	SP	PH	N-NH$_4$	N-NO$_3$
	nmol MUB·g^{-1}d.s.·h^{-1}						mg·kg^{-1}	
Zone of depletion	21.62 ±9.95 ^{b}	83.11 ±51.54 ^{b}	24.28 ±19.23 ^{a}	56.11 ±31.20 ^{b}	4.51 ±3.84 ^{a}	310.76 ±141.47 ^{b}	0.94 ±0.13 ^{b}	12.48 ±4.19 ^{b}
Zone of accumulation	45.85 ±10.74 ^{a}	169.62 ±48.65 ^{a}	33.34 ±30.04 ^{a}	253.98 ±72.45 ^{a}	7.66 ±7.77 ^{a}	686.35 ±294.69 ^{a}	1.51 ±0.32 ^{a}	24.33 ±3.84 ^{a}

Mean ± standard deviation; CB—β-D-cellobiosidase, BG—β-glucosidase, NAG—N-acetyl-β-D-glucosaminidase, XYL—xylanase, SP—arylsulphatase, PH—phosphatase; small letters in the upper index of the mean values mean significant differences between zones of landslide; d.s.—dry soil.

The nutritional status of young trees of both species varied between the designated landslide zones. Birch leaves growing in the depletion zone revealed an average nitrogen content of 2.27% d.m., while those in the accumulation zone contained significantly more nitrogen (2.74% d.m.; Table 4). The nitrogen content in fir needles growing in both landslide zones reached 1.10 and 1.40% d.m., respectively, which was less than that observed in birch leaves (Table 4). Regarding other macroelements, no significant differences between species growing in both zones were found (Table 4). Samples of the leaves of birches and needles of firs taken from depletion zone points with high soil pH, high Ca, Mg, silt and clay contents and low acidity, showed higher Ca and Mg and reduced concentrations of aluminium (Table 5).

Table 4. Macronutrients in the leaves of birch and needles of fir growing in different landslide zones.

Zone	Species	C	N	C/N	Ca	Mg	K	Na	Al
		%			mg·kg^{-1} d.m.				
Zone of depletion	Birch	44.43 ±4.54 ^{a}	2.27 ±0.17 ^{b}	19.60 ±1.53 ^{a}	3546.2 ±718.8 ^{a}	2159.2 ±606.4 ^{a}	7494.1 ±968.5 ^{a}	117.2 ±18.8 ^{a}	1993.9 ±1703.4 ^{a}
	Fir	46.43 ±1.45 ^{a}	1.10 ±0.26 ^{b}	44.58 ±11.53 ^{a}	5992.9 ±968.8 ^{a}	791.6 ±382.2 ^{a}	6266.6 ±1141.2 ^{a}	88.2 ±25.2 ^{a}	1453.9 ±1620.0 ^{a}
Zone of accumulation	Birch	43.86 ±3.88 ^{a}	2.74 ±0.47 ^{a}	16.25 ±1.78 ^{b}	3171.1 ±555.5 ^{a}	1918.3 ±358.0 ^{a}	7755.3 ±1005.3 ^{a}	132.1 ±32.8 ^{a}	2122.3 ±1627.0 ^{a}
	Fir	45.76 ±1.28 ^{a}	1.40 ±0.24 ^{a}	33.66 ±6.33 ^{b}	5895.6 ±1355.0 ^{a}	659.2 ±251.7 ^{a}	5466.0 ±921.3 ^{a}	70.4 ±18.3 ^{a}	1248.2 ±777.9 ^{a}

Mean ± standard deviation; small letters in the upper index of the mean values mean significant differences between zones of landslide; d.m.—dry mass.

Classification and regression tree charts were developed to identify the properties that most determine the N supply of trees. In the case of birch, it is the soil's nitrate nitrogen (N-NO$_3$) content followed by soil pH (Figure 2). The highest nitrogen content in birch leaves was found at the content of N-NO$_3$ above 24 mg·kg^{-1} and the lowest at N-NO$_3$ below 8.5 mg·kg^{-1}. In the range of 8.5–24 mg·kg^{-1} N-NO$_3$, soil pH is an important factor in the supply of birch leaves N. The best nitrogen supply in the mentioned range of nitrate nitrogen content was found in the pH range 4.16–6.22. In the case of fir, the most important characteristic was soil acidity, followed by nitrate nitrogen content and soil pH (Figure 3).

Significant differences in Cu content in birch leaves were found between the landslide zones. Birch growing in the accumulation zone were characterized by significantly higher Cu content compared to in the depletion zone (19.21 and 16.60 mg·kg^{-1}, respectively; Table 5). Birch leaves showed a significantly higher content of N (about 2 times higher than fir needles), Mg (about 3 times higher) and P (about 1.7 times higher). Moreover, higher contents of Na and Al was found in birch leaves (although these were not significant), and in the case of microelements, a significantly higher content of Co, Mn and particularly Zn (about 4 times higher). Fir needles were characterized only by a significantly higher calcium content in relation to that recorded in birch leaves (Tables 4 and 5). The strong influence of landslide zone and tree species on the nutritional status of a new generation of tree was confirmed by GLM analysis (Tables 6 and 7). The location on the landslide determines the nutrition of the seedlings with nitrogen, and the difference in nutritional status is apparent between the studied species of trees. Interestingly, high pH and low acidity was also associated with increased phosphorus in seedlings of both species; this was confirmed with strong correlations between macroelements in the leaves and needles and soil characteristics at the test points (Table 8).

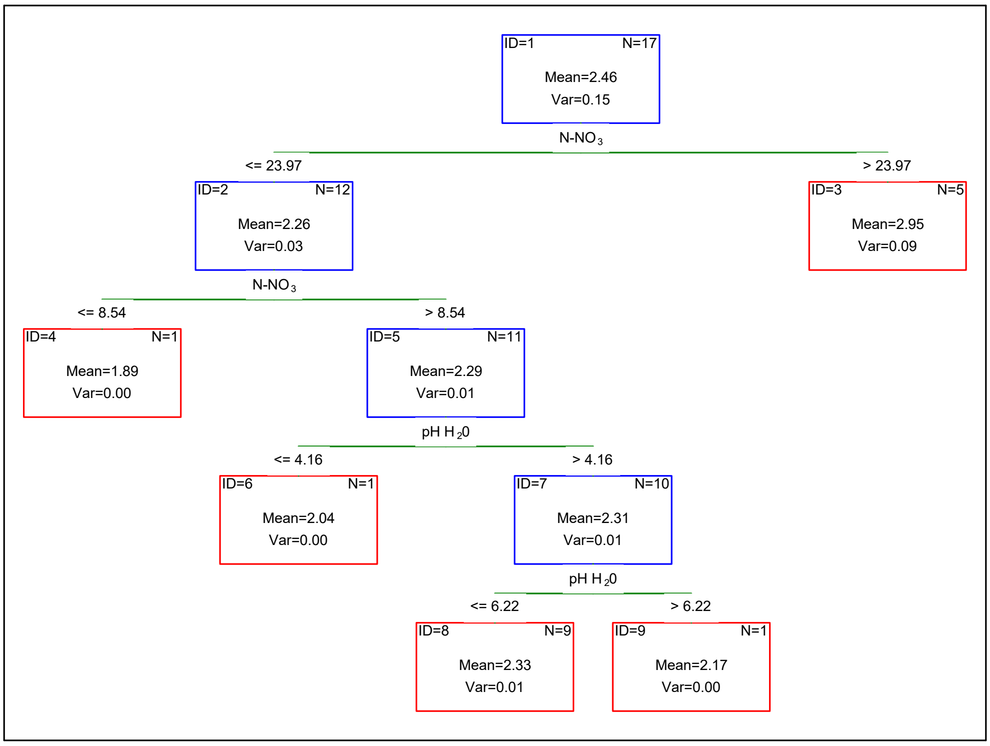

Figure 2. The regression tree (C&RT) for nitrogen content in birch leaves.

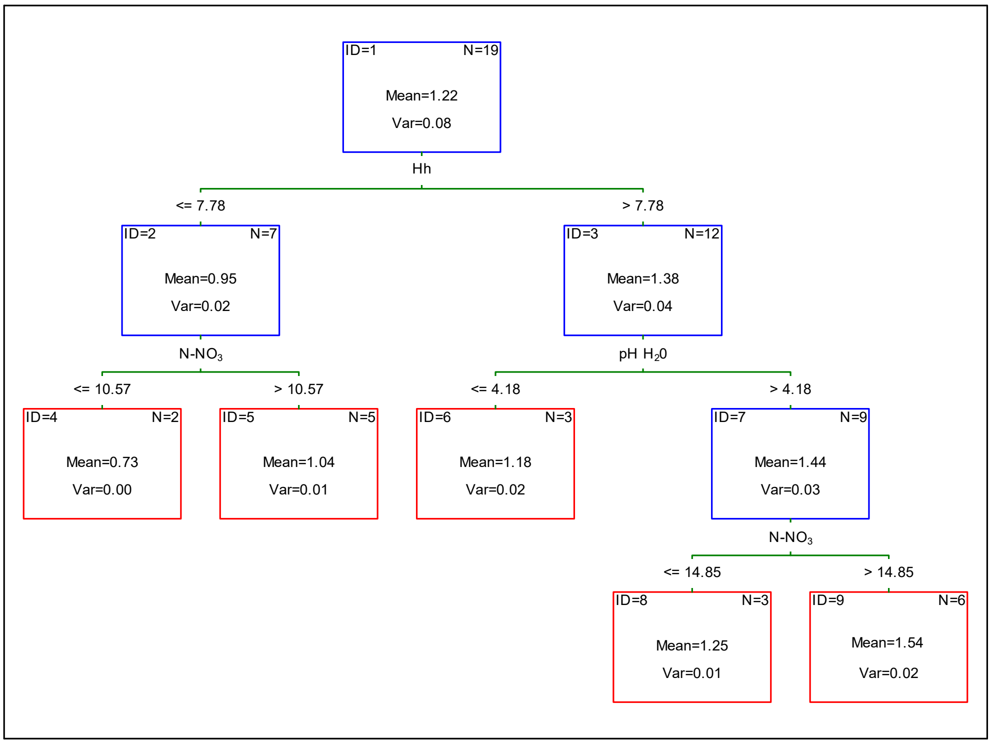

Figure 3. The regression tree (C&RT) for nitrogen content in fir needles.

Table 5. Macro and micronutrients in the leaves of birch and needles of fir growing in different landslide zones.

Zone	Species	Ca/Al	Mg/Al	Ca/Mg	P	Cu	Co	Mn	Ni	Zn
					mg·kg^{-1}					
Zone of depletion	Birch	3.56 ± 4.14 [a]	2.13 ± 2.65 [a]	1.72 ± 0.44 [a]	2051.6 ± 515.2 [a]	16.60 ± 1.53 [b]	2.10 ± 1.53 [a]	1668.4 ± 411.8 [a]	11.26 ± 4.22 [a]	120.13 ± 22.73 [a]
	Fir	6.01 ± 2.26 [a]	0.69 ± 0.22 [a]	8.45 ± 2.29 [a]	1150.0 ± 474.7 [a]	16.39 ± 5.94 [a]	0.83 ± 0.74 [a]	1302.5 ± 519.6 [a]	12.81 ± 4.93 [a]	29.39 ± 8.06 [a]
Zone of accumulation	Birch	2.73 ± 2.09 [a]	1.56 ± 1.20 [a]	1.68 ± 0.34 [a]	1879.3 ± 288.7 [a]	19.21 ± 2.90 [a]	1.89 ± 1.19 [a]	1786.9 ± 132.1 [a]	11.64 ± 6.65 [a]	137.71 ± 35.08 [a]
	Fir	6.25 ± 3.31 [a]	0.66 ± 0.34 [a]	9.57 ± 2.79 [a]	1120.8 ± 387.0 [a]	12.11 ± 9.39 [a]	0.60 ± 0.28 [a]	1439.4 ± 650.0 [a]	12.12 ± 8.10 [a]	34.78 ± 6.98 [a]

Mean ± standard deviation; small letters in the upper index of the mean values mean significant differences between zones of landslide.

Table 6. Results of general linear model (GLM) analysis for macronutrients, including the zone of landslide and tree species.

	C		N		C/N		Ca		Mg		K		Na		Al	
	F	p	F	p	F	p	F	p	F	p	F	p	F	p	F	p
Zone of landslide	0.33	0.568	15.19	**0.000**	8.89	**0.006**	0.53	0.471	1.58	0.218	0.60	0.445	0.03	0.855	0.01	0.941
Tree species	3.29	0.079	160.64	**0.000**	78.40	**0.000**	63.74	0.000	78.32	**0.000**	25.48	**0.000**	30.81	**0.000**	1.90	0.178
Zone of landslide × Tree species	0.00	0.964	0.76	0.389	2.50	0.124	0.18	0.671	0.13	0.717	2.32	0.138	3.99	0.054	0.11	0.747

Significance effect ($p < 0.05$) are shown in bold.

Table 7. Results of general linear model (GLM) analysis for ratio of nutrients and nutrients, including the zone of landslide and tree species.

	Ca/Al		Mg/Al		Ca/Mg		P		Cu		Co		Mn		Ni		Zn	
	F	p	F	p	F	p	F	p	F	p	F	p	F	p	F	p	F	p
Zone of landslide	0.08	0.784	0.34	0.566	0.75	0.394	0.45	0.507	0.19	0.670	0.37	0.548	0.45	0.508	0.01	0.940	2.70	0.111
Tree species	7.81	**0.009**	4.96	**0.033**	136.39	**0.000**	30.61	**0.000**	3.52	0.070	12.36	**0.001**	3.51	0.071	0.25	0.623	191.76	**0.000**
Zone of landslide × Tree species	0.25	0.620	0.27	0.608	0.85	0.363	0.23	0.637	3.13	0.087	0.00	0.987	0.00	0.962	0.07	0.794	0.76	0.390

Significance effect ($p < 0.05$) are shown in bold.

Table 8. Correlations between the content of selected macroelements in the leaves and needles of seedlings and soil characteristics.

	N_{birch}	N_{fir}	P_{birch}	P_{fir}	K_{birch}	K_{fir}	Mg_{birch}	Mg_{fir}	Ca_{birch}	Ca_{fir}	Ca/Al_{birch}	Ca/Al_{fir}
pH H_2O	0.151	−0.504 *	0.512 *	0.622 *	0.408	0.400	0.702 *	0.637 *	0.661 *	0.598 *	0.567 *	−0.118
pH KCl	0.362	−0.315	0.439	0.646 *	0.279	0.327	0.504 *	0.463	0.428	0.640 *	0.430	0.070
Hh	−0.000	0.584 *	−0.483 *	−0.550 *	−0.336	−0.398	−0.766 *	−0.653 *	−0.678 *	−0.556 *	−0.476	0.265
He	−0.053	0.523 *	−0.462	−0.566 *	−0.394	−0.345	−0.775 *	−0.659 *	−0.682 *	−0.544 *	−0.502 *	0.240
C	0.417	0.498 *	−0.358	−0.301	−0.050	−0.458	−0.457	−0.341	−0.401	−0.287	−0.249	0.200
N	0.445	0.571 *	−0.313	−0.323	−0.046	−0.457	−0.494 *	−0.377	−0.443	−0.307	−0.215	0.245
N-NH_4	0.338	0.521 *	−0.375	−0.320	−0.141	−0.400	−0.505 *	−0.320	−0.482	−0.330	−0.249	0.272
N-NO_3	0.700 *	0.574 *	−0.054	−0.182	0.200	−0.417	−0.450	−0.354	−0.192	−0.189	0.053	0.159
silt	−0.010	−0.465	0.392	0.238	0.510*	0.367	0.494*	0.343	0.486 *	0.192	0.421	−0.147
clay	−0.066	−0.127	0.334	0.421	0.152	0.433	0.271	0.469	0.352	0.365	0.140	−0.359

* $p < 0.05$; Hh—hydrolytic acidity; He—exchangeable acidity.

4. Discussion

The nutritional status of the young generation of trees growing on a landslide was dependent on the soil properties. In the course of this analysis, we identified the soil properties that had the largest impact on the nutritional status of birch and fir trees growing on a landslide. The first group of properties is related to soil acidification. In places with higher soil pH and lower acidity, higher Ca, Mg, and P was found in birch leaves and fir needles. The importance of pH for the availability and plant absorption of macro and microelements, has been well documented [1,29,30]. The uptake of macro- and microelements reaches the highest level from slightly acidic to neutral pH and decreases in both strong acidic and alkaline pH [2,31]. Soils with a strongly acidic pH dominated the landslide. Only at a few points located in the depletion zone of the landslide, a weak acidic pH was found, and the supply of microelements proved to be the best. The formation of places with higher soil pH in the landslide is usually associated with the exposure of deeper, less leached soil horizons with lower acidity [4,5]. The C&RT approach confirms the importance of pH in the nitrogen nutrition of the tested species. In the case of birch and fir, low nitrogen concentration in leaves and needles was noted below 4.2 pH. The second group of properties that appear to be important for the nutritional status of the young generation of trees was soil organic matter and biochemical activity in the soil. This is for the reason that, as microorganisms lead to the decomposition of organic matter, carbon dioxide is produced, it equilibrates with soil water and releases hydrogen ions, affecting soil pH. Through this mechanism, microorganisms affect soil enzyme activities and regulate the speed of organic matter decomposition [32]. Birches and firs were characterized by significantly increased nitrogen supply on landslide sites with greater organic matter content (accumulation zone). The importance of soil organic matter as a source of the basic macroelements, particularly nitrogen, has long been evidenced in the literature [33,34]. Furthermore, organic matter stimulates the activity of microorganisms by being a source of energy for microorganisms and a primary source of nitrogen, carbon, and phosphorus. A close relationship between the content of organic carbon in soils and the activity of enzymes participating in the C, N and P cycle, the decomposition of cellulose and amino acids, was demonstrated in the examined landslide. Sample points with higher biochemical activity were characterized by increased nitrogen, which was taken up by plants. The level of nitrogen supply, particularly for birch trees, depended on the amount of nitrate nitrogen contained in the soil. The relationship between enzyme activity involved in the C, N and P transformations and organic matter, has been repeatedly observed [5,35]. Moreover, in previous studies on the recovery of soil cover following landslides, organic matter has been identified as a key factor determining the rate of soil recovery [5,6,10]. The accumulation zone, in which material had slipped from higher parts of the landslide, was characterized by increased organic matter and greater presence of tree species with greater nitrogen demands. In addition, greater variety of species and with improved nutritional development, were found in sections of the landslide characterized by high soil organic matter [11].

Higher contents of phosphorus were found in young generation trees growing in soil with high pH and simultaneously low levels of organic matter. It should be noted that the phosphorus measured in this study was the total pool of the component, of which only a small part is available for plants [1]. The quantity of phosphorus available for plants depends on the degree of decomposition of soil organic matter, soil microbiological activity and relations with other ions. For example, while aluminium and iron compounds form insoluble phosphates in a strongly acidic pH, in a strongly alkaline environment, phosphorus assimilability may be reduced by calcium excess [36–38]. In the accumulation zone, despite higher levels of total phosphorus and higher biochemical activity that favors the release of phosphorus, a strongly acidic pH and high concentration of aluminium limits its uptake by plants.

During this study, various ecological characteristics of the analyzed species were confirmed. Birch is considered a relatively robust pioneer species with relatively low requirements, only being intolerant to soil phosphorus and nitrogen deficiency [39]. In our study birch accumulated significant amounts of nitrogen, magnesium, phosphorus and zinc, compared to those accumulated by fir. In depletion zone, birch accumulated twice as much nitrogen and phosphorus as well as three times more magnesium compared to fir. In the accumulation zone, as in the depletion zone, birch accumulated twice as much nitrogen and phosphorus as well as three times more magnesium compared to fir. The literature review determined the quantities of macroelements collected by the species under study [40,41]. Fir is a species with a particularly low nitrogen demand (2–5 times lower than species such as pine, spruce, oak and ash). Birch on the other hand, is reported in the literature to provide optimal contents of basic macroelements in leaves, as follows: N 1.9–2.3% dm, P 0.18–0.28% dm, K 0.7–1.6% dm, Mg 0.15–0.25% dm. In the analyzed landslide, birch leaves accumulated P and K in quantities corresponding to the lower limit of the range; magnesium aligned with the range reported in the literature; while nitrogen accumulation exceeded the upper limit of the range determined as the optimum supply of N. The intensive uptake of N and Mg and their return to the soil makes birch trees particularly valuable for accelerating the circulation of these elements, which may be key to soil cover recovery following landslides. This aligns with the findings of previous studies [42] that confirm that large quantities of K, N, Ca, Mg, and P are leached from birch leaves per unit of leaf area. In previous studies, high biomass of birch growing on the landslide was indicated [14]. Birch had six times higher biomass compared to fir of the same age. Considering our results with better nitrogen, magnesium and phosphorus supply of birch and higher birch biomass, it can be assumed that this species will have a more beneficial effect on nutrient circulation in the landslide.

5. Conclusions

The nutritional status of a young generation of trees growing on a landslide will be affected by the properties of the soil, particularly acidification and soil organic matter content. The pH level of recovered landslide soil determines the intensity of nutrient uptake by young seedlings. Nutrition of young trees varies across the landslide as particular zones differ in terms of soil organic matter content and chemical properties. The accumulation zone compared to depletion zone proved to be richer in soil organic matter, resulting in higher soil biochemical activity. For its ability to intensively bioaccumulate nutrients taken from the soil, the findings of this study support birch as a useful species to improve soil nutrient circulation in the landslide area.

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