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THE INFLUENCE OF THE METHOD OF RECLAMATION AND SELECTION OF TREE SPECIES FOR AFFORESTATION ON CHANGES IN LANDSCAPE DEGRADED BY FIRE

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Abstract: The paper analyses the influence of the method of reclamation on changes in the landscape degraded by fire. The analyses involved experimental areas (I, II, III) in which various ways of preparing the soil were used (soil excluded from mechanical cultivation; full mechanical cultivation; ploughing furrows) in cultivations of the Scots pine (*Pinus sylvestris* L.) and the Grey alder (*Alnus incana* (L.) MOENCH). The analyses also included a natural succession (NS) area and a control area (L) marked out in a natural forest complex directly bordering the burned area. The analyses showed that after 12 years of recultivation, the burned landscape was regaining the state of structural and functional biological balance. Cultivation of grey alder substantially stimulated the enzymatic activity of the analyzed soil, thus showing its beneficial influence on the landscape potential and justifying the use of this species as a preceding crop when rehabilitating the burned area. Various ways of preparing the soil had no substantial influence on noticeable, long-term changes in the functioning of the analyzed landscape.

INTRODUCTION

Disturbances in the functioning of landscape resulting from complete forest fires are rapid and frequently irrevocable [9]. One of the main landscape elements which undergoes degradation is the soil [7, 8]. Positive restoration effects of after-fire landscapes can be achieved by soil revitalization and by the application of plantings with species suitable for specific site [12, 15].

The basis of the functioning of the landscape is the continuity of matter circulation and energy flow between individual elements of the landscape [6]. Soil microorganisms belong to the most active landscape components which determine its quality and the activity of enzymes secreted into the soil environment provides a good indicator of their metabolic potentials. Enzymatic processes reflect disturbances in the matter circulation and energy flow by landscape elements caused by environmental stress factors [5].

The objective of the performed experiments was to assess the influence of the method of restoration and tree species selection for afforestation on the transformations of the landscape degraded by a forest fire on the basis of selected soil parameters determining processes of energy flow and matter circulation in a landscape system.

OBJECT AND METHODOLOGY

The performed investigations were carried out on a fire site situated in the north-central part of the Noteć Primeval Forest, in the region of the Potrzebowice Forest District (52°53'N, 16°10'E) on podzolic soils (Podzols) under different types of reclamation programs. The reclamation operations were performed by the Department of Soil Siviculture of the Poznań Agricultural University [4]. The experimental surface of 7.5 ha was established in 1994, two years after a Scots pine stand approximately 60 years of age was completely burned down. The dimensions of plots, henceforth referred to as 'experimental plots', were as follows: 25 x 20 m (50 m^2). The investigations comprised the surface of natural succession (NS) as well as surfaces on which three extremely different methods of soil preparation (I, II and III) were employed in plantations with Scots pine – *Pinus sylvestris* L. (S) and Grey alder – *Alnus incana* (L.) MOENCH – (O). The plantings were carried out using two-year old seedlings [4]. The soil on the experimental plot I was excluded from mechanical cultivation and its preparation was limited to digging a hole with a spade in which the seedling was placed. This method enabled leaving the organic-mineral horizon intact. In the case of the experimental plot II, full mechanical tillage was performed carrying out shallow ploughing to the depth of 30 cm using a disk plough. Consequently, the residues of the soil organic horizon were removed completely and they were uniformly mixed with the mineral layer. On the experimental plot III, furrows were ploughed every 1.5 m with of a forest LPZ-75 plough equipped with 2 mouldboards and their bottoms were additionally loosened to the depth of 40 cm using a subsoiler. Seedlings were planted in the belts prepared in the above-described way. The organic horizon was completely removed from the area of furrows and, following the turning over of the ploughed furrow-slice, it was left between rows earthed up with part of the mineral soil. The succession plot (NS) and control area (L) were established on an un-cleaned clear-cut area situated at the distance of approximately 70 m from the forest fragment which survived the forest fire. The residues which were left after clear cutting were neither removed nor cut. No artificial regeneration was carried out on this plot so that all plants growing there were the result of spontaneous plant succession in the region of the forest fire.

The investigations on selected plots were conducted in 2004–2006. The presented paper discusses research results obtained following 12 years of reclamation operations on the forest fire site.

In June 2006, soil samples were collected from the depth of 0–10 cm and 10–20 cm from five points on each of the selected experimental plots and selected physical, chemical and biochemical properties were determined in each of them in five replications. Identical soil samples were collected from the natural forest complex unaffected by the forest fire situated in direct neighborhood of the forest fire site and which acted as the control plot (L). The following parameters were determined in soil samples with disturbed and intact structure: texture composition using Bouyoucos method in Prószyński's modification, specific density by pycnometric method [17], bulk density using Nitzsch's vessels of 100 cm^3 volume, soil porosity calculated on the basis of density assays, soil moisture content by drier-gravimetric method, pH in 1 mol·dm^{-3} KCl, organic carbon and total nitrogen using Vario Max analyzer as well as ammonium nitrogen and nitrate nitrogen [ISO 14255]. The biochemical analyses comprised the following determinations: the activity of dehydrogenases with a TTC (triphenyl tetrasolium chloride) substrate [20], acid phosphatase (Pac) and alkaline phosphatase (Pal) [19], urease [21] and protease [11]. The activity of dehydrogenases was given in cm^3 H_2 necessary to reduce TTC to TFP (triphenyl phormosan); of phosphatases – in mmols of p-nitrophenol (PNP) produced from sodium 4-nitrophenylphosphate; urease – in mg N-NH_4^+ formed from hydrolyzed urea; protease – in mg tyrosine developed from sodium caseinate.

Statistical analysis was carried out using the Statistica 6.0 PL program.

RESULTS AND DISCUSSION

Different methods of soil preparation, after 12 years of their application on the forest fire site, failed to exhibit an unambiguous effect on the analyzed soil physical properties (Tab. 1). Soils on the examined experimental plots showed almost identical texture (the content of clay fraction ranged from 1–3%) and specific density (2.64–2.65 Mg·m^{-3}). Soil moisture content on the majority of the plots ranged from 0.03–0.04 m^3·m^{-3} to 0.05 m^3·m^{-3} on O II, O III and NS experimental surfaces.

Table 1. Basic physical properties of investigated soils

Plots /*	Depth [cm]	Moisture [m^3·m^{-3}]	Specific density [Mg·m^{-3}]	Bulk density [Mg·m^{-3}]	Porosity [m^3·m^{-3}]
S I	0–10	0.0392	2.64	1.42	0.46
	10–20	0.0376	2.65	1.47	0.44
S II	0–10	0.0331	2.65	1.35	0.49
	10–20	0.0434	2.65	1.45	0.45
S III	0–10	0.0406	2.65	1.14	0.57
	10–20	0.0411	2.65	1.41	0.46
O I	0–10	0.0395	2.65	1.28	0.51
	10–20	0.0354	2.65	1.47	0.44
O II	0–10	0.0359	2.65	1.31	0.50
	10–20	0.0522	2.65	1.37	0.48
O III	0–10	0.0439	2.65	1.32	0.50
	10–20	0.0572	2.65	1.47	0.44
NS	0–10	0.0510	2.64	1.35	0.49
	10–20	0.0575	2.65	1.47	0.44
L	0–10	0.0391	2.64	1.36	0.48
	10–20	0.0311	2.65	1.48	0.44

/*S – *Pinus silvestris*, O – *Alnus incana*,
NS – natural succession, L – control area

Distinct differences were observed only in porosity and, closely connected with it, soil bulk density. In the soil top layer (0–10 cm), porosity and bulk density values ranged from 0.46 m^3·m^{-3} and 1.42 Mg·m^{-3} (S I) to 0.57 m^3·m^{-3} and 1.14 Mg·m^{-3} (S III), respectively. In the subsurface layer (10–20 cm), the values of the parameters were lower and comparable. Plot O II (grey alder plantings) constituted an exception where, following complete mechanical tillage, residues from the organic layer were totally mixed thoroughly with the mineral layer, causing significant homogenization of the 0–20 cm layer and, consequently, leading to high porosity (0.48 $m^3 \cdot m^{-3}$), at 1.37 $Mg \cdot m^{-3}$ density. Such an effect failed to occur on plot S II (Scots pine plantings), though.

The obtained results indicate that a tree species used for plantings was a factor modifying porosity and bulk density. It could have been associated with the individual impact of a tree species on the composition of a microbiological complex settling tree roots and decomposing the plant material. A tree species significantly influences soil soluble C concentration and, as a result, affects soil porosity and bulk density [8, 14]. In alder plantings (O I – O III), the values of soil porosity in the 0–10 cm layer were higher (0.50–0.51 $m^3 \cdot m^{-3}$) than in pine plantings (S I and S II) (0.46–0.49 $m^3 \cdot m^{-3}$). In comparison to leaf fall, needle fall contains less N and more lignin. The coniferous substrate, rich in waxes, resins and lignin, is more resistant to decomposition due to its high initial lignocellulosic index which plays a decisive role in the rate of its microbiological transformation [10]. As to the 0–10 cm layer, the porosity bearing the closest similarity to that of an intact forest habitat (0.46 $m^3 \cdot m^{-3}$), was found in the soils of plot S II and the NS (natural succession) plot, which were totally different with regard to the extent of interference in the soil cover.

A surprisingly low bulk density (1.14 $Mg \cdot m^{-3}$) and the highest porosity were observed in the soil from plot S III (Tab. 1). As regards the pine crops, the soil from plot S III had the highest organic carbon content. However, it was noticeably lower than in the soil in the forest habitat not disturbed by fire (L) (Tab. 2). A positive impact of the reclamation system on transformations in the landscape destroyed by fire can be observed, among others, in soil humus formation. The method of soil preparation is a factor influencing soil biological activity contributing to the improvement and stability of soil colloidal-mineral complex, which, in turn, guarantees a long-term effect of favorable changes in the soil physical condition. Malicki [13] points out that mechanical interference in a soil environment exerts only a slight influence on the development of soil physical properties. This claim is corroborated by numerous reports found in the literature on the subject. Among others, Biskupski and Sienkiewicz [3] showed that methods of soil preparation for sowing highly diverse as to their intensity changed soil density and moisture content only to a limited extent. On the other hand, experiments carried out by Olejarski [15] revealed that the method of soil preparation on fire sites had a significant impact on the development of the physical state, in particular, on the water properties. However, it should be emphasized that Olejarski [15] also presented results of other investigations which showed that, in certain conditions, the method of soil preparation fails to cause tangible, long-term changes in soil physical conditions.

Soils on the fire site were characterized by lower acidity than the soil on the forest site unaffected by the fire (experimental plot L). The above mentioned differences ranged from 0.20 to 0.70 pH unit in 1 $mol \cdot dm^{-3}$ KCl (Tab. 2). On all the examined plots, pH_{KCl} values were lower in the top soil layer (0–10 cm) than in the layer extending from 10 to 20 cm. Differently decomposed forest litter, usually occurring in the form of surface organic layer, favors acidification because it contains non-neutralized humus substances as well as soluble fractions of humic acids. Moreover, nitrification, which is the outcome of enhanced mineralization, is one of the factors which increase the acid load in the surface layers of forest soils. The applied methods of reclamation of the forest fire site failed to exert any practical influence on changes in the reaction of those soils (Tab. 2).

Table 2. pH, content of organic carbon and nitrogen (total N, N-NH_4^+, N-NO_3^-) in soils

Plots	Depth	pH	C	N	C:N	N-NH_4^+	N-NO_3^-
	[cm]	KCl	[g·kg^{-1}]			[mg·kg^{-1}]	
S I	0–10	3.92	12.54c	0.58b	21.6c	30.27b	6.56b
	10–20	4.46	4.67a	0.23a	20.3c	23.94a	4.35a
S II	0–10	3.88	11.70c	0.55b	21.2c	32.83b	5.78b
	10–20	4.44	5.16a	0.25a	20.6c	24.05a	3.49a
S III	0–10	3.82	21.42e	0.90c	23.8d	30.28b	5.12b
	10–20	4.45	6.67b	0.31a	21.5c	23.78a	3.25a
O I	0–10	3.63	23.11f	1.12c	20.6c	47.09c	19.73c
	10–20	4.38	5.87a	0.31a	18.9c	32.86b	8.96b
O II	0–10	3.59	14.29d	1.08c	13.2b	48.72c	20.19c
	10–20	4.41	3.98a	0.40a	9.9a	35.54b	8.89b
O III	0–10	3.73	14.86d	0.82c	19.3c	47.85c	18.92c
	10–20	4.47	5.17a	0.28a	18.4c	32.46b	11.08b
NS	0–10	3.76	19.72e	0.68b	29.0e	35.20b	9.15b
	10–20	4.65	6.31 b	0.28a	22.5d	24.18a	5.45a
L	0–10	3.22	28.83g	1.48d	19.4c	52.35c	20.49c
	10–20	4.03	9.96c	0.54b	18.4 c	36.09b	8.79b

values in the column followed by the same letter are not significant at $p < 0.05$, "t" – test

Following 12 years of reclamation, the content of organic carbon and total nitrogen in soils of the plots affected by the fire was statistically significantly lower by about 20–60% in comparison with the soil from the control plot (Tab. 2). Our earlier investigations [14] carried out after 10 years of reclamation showed that levels of the above-mentioned constituents in soils damaged by the fire were by 50–80% lower than in the unaffected soil in the site directly neighboring with the fire site. The observed increases in levels of organic carbon and total nitrogen in consecutive years of the experiments confirm growing self-regulating capabilities of the landscape damaged by the fire and show that the applied methods of reclamation were effective. The new active humus found in the sterile soils acts as a stimulator of the continuity of processes of matter circulation and energy flow which take place between individual elements of the landscape [2, 6].

In the case of soils situated in the area affected by the fire on plots with the Scots pine plantings, the $C_{org.}$ and total N resources were significantly lower than in the cultivations with Grey alder and on the NS plot (natural succession). Statistically confirmed differences were observed primarily in the top soil layer (Tab. 2). Different methods of soil preparation after 12 years of their application on the fire site failed to show an unequivocal impact on organic carbon and total nitrogen contents in soils. In Scots pine plantings, the highest quantities of $C_{org.}$ and total N were recorded in the soil from the experimental plot III on which furrows were ploughed up, while in the alder plantings – in the soil from plot I (the soil where no mechanical tillage was used).

The quantities of organic carbon and total nitrogen determined in the top layer of the examined soils were several times higher than those found in the 10–20 cm layer (Tab. 2).

The values of the C:N ratio observed in the soils from the plots S III, O II and NS were significantly higher in the 0–10 cm layer than in the 10–20 cm layer. The differences noted on the other plots (S I, S II, O I and O III) were statistically non-significant (Tab. 2). The highest values of the C:N ratio were registered in the soil of the NS plot: 29.0 in the 0–10 cm layer and 22.5 in the 10–20 cm layer while the lowest ones were found in the soil from plot O II: 13.2 in the 0–10 cm layer and 9.9 in the 10–20 cm layer. On the other plots, the values of this parameter reached the same level as those in the soil of the control plot (L) (Tab. 2). Greater fluctuations in the metabolic rate were observed in the alder plantings (C:N ranging from 9.9 to 20.6) than in the pine crops (C:N from 20.3 to 23.8).

The contents of $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ in soils on plots where Grey alder was cultivated were similar to those determined in the control soil (experimental plot L), whereas in soils from the plots with Scots pine planting as well as on the NS (natural succession) plot, they were significantly lower, by approximately 30–40%, than in the control soil (Tab. 2). In alder cultivating, the symbiosis between the tree roots and nitrogen-fixing Actinomycetales contributes to soil enrichment with the available forms of this element and enables nitrogen uptake by a plant.

The above mentioned results indicate that alder plantings exerted a positive impact on the resource-functional (material, storage, transport) potentials of the landscape after the fire which increase the system capability for biotic productivity and realization of abiotic processes [1, 18]. On the other hand, in Scots pine cultivations as well as on the NS plot, the soil still remains an accumulative ecosystem which immobilizes nitrogen, hence in the process of biomass production it will continue to exhibit increased demand for nitrogen. It should further be emphasized that the investigations carried out two years earlier, after 10 years of reclamation operations of the degraded landscape [14], revealed that within the forest fire site, irrespective of the employed regeneration species, quantities of mineral nitrogen ($N\text{-}NH_4^+$ and $N\text{-}NO_3^-$) in soils were by about 70–80% smaller than in the soil of the forest environment unaffected by the fire. In addition, it is worth stressing that the content of these constituents on plots with Grey alder plantings was significantly higher in comparison with Scots pine stands. The above data prove that the destroyed cultural landscape, i.e. the forest fire site before the reclamation process, with the passage of time managed to regain its capacity to counteract changes in its structure and character of functioning of its elements caused by the fire and transformed into a harmonious cultural landscape [16]. Methods of soil preparations employed in the process of the reclamation of the fire site did not influence in a significant manner the content of $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ in the soil. The content of the ammonia form of nitrogen in the examined soils was several times higher than that of the nitrate form (Tab. 2), which was related to the low soil pH limiting nitrification (Tab. 1).

The activity of dehydrogenases, acid phosphatase, alkaline phosphatase and protease in the soils on experimental plots with Grey alder was similar to the level of the activity of these enzymes determined in the soil on the control plot (L), whereas on plots where Scots pine was growing as well as on the NS (natural succession) plot, it was significantly lower, approximately 1.5 to 3.0 times than in the control soil (Tab. 3). In the case of urease, it was found that the activity of this enzyme in soils on all plots affected by the forest fire was identical with that in the control soil which is in keeping with the results reported by Januszek *et al.* [7] and corroborate once more that urease is resistant to external factors and the only factor limiting its activity is substrate (urea) availability. The above data confirms that following 12 years of after-fire reclamation operations of the affected landscape, especially on the experimental plots with alder plantings, it was possible to achieve the condition of relative dynamic biological equilibrium which is essential if the landscape system is to function properly [6]. The observed high relative soil enzymatic activity on plots with alder plantings was accompanied by a significantly higher content of organic carbon and total nitrogen (Tab. 2). These results indicate that alder plantings enhance the reclamation potentials of landscape area, including such partial potentials as: self-regulation and resistance, buffering, environment-forming as well as resource and functional procedures as expressed in the form of, among others, the capacity of the landscape to produce and store energy in the form of organic matter [18].

Table 3. Enzymatic activity of soils (Dh – dehydrogenases in $cm^3\ H_2 \cdot kg^{-1} \cdot d^{-1}$, Pac – acid phosphatase and Pal – alkaline phosphatases in $mmol\ PNP \cdot kg^{-1} \cdot h^{-1}$, U – urease in $mg\ N\text{-}NH_4^+ \cdot kg^{-1} \cdot h^{-1}$, P – protease in $mg\ tyrosine \cdot kg^{-1} \cdot h^{-1}$)

Plots	Depth [cm]	Dh	Pac	Pal	U	P
S I	0–10	2.21c	14.63c	5.42d	2.35b	6.21b
	10–20	1.23a	8.63b	2.95a	0.79a	3.68a
S II	0–10	1.98b	9.56b	4.34c	2.28b	7.53b
	10–20	1.09a	4.47a	2.59a	0.76a	4.08a
S III	0–10	1.22a	9.32b	4.75c	2.72b	8.05b
	10–20	0.89a	6.42a	2.12a	0.84a	5.16a
O I	0–10	3.06d	28.98d	8.39e	2.41b	10.98d
	10–20	1.25a	11.75c	3.78b	0.64a	6.94b
O II	0–10	3.34d	30.12d	8.16e	2.48b	11.27d
	10–20	1.78b	10.88c	3.21b	0.72a	6.36b
O III	0–10	3.12d	29.94d	8.02e	2.54b	11.40d
	10–20	1.64b	12.85c	3.28b	0.78a	6.98b
NS	0–10	2.47c	10.93c	4.98d	2.69b	8.30c
	10–20	1.08a	8.92b	2.72a	0.73a	5.24a
L	0–10	3.29d	29.92d	8.27e	2.52b	11.93d
	10–20	1.95b	12.79c	3.65b	0.79a	6.15b

values in the column followed by the same letter are not significant at $p < 0.05$, "t" – test

No significant effect of the method of soil preparation on its enzymatic activity was noted.

The activity of the examined enzymes in top layers of soils was several times higher than in the 10–20 cm layer (Tab. 3) which is associated with profile humus distribution and declining quantities of the carbon substrates in the soil available for microorganisms and enzymes.

Summing up the obtained results, it can be said that following 12 years of reclamation the examined after-fire landscape is reaching the condition of biological structural and functional equilibrium. At the same time, it should be emphasized that landscape, as an energetically open system where boundary exchange of energy and matter takes place continually, is permanently exposed to the action of natural and anthropogenic factors. What is important from the ecological point of view is the stability and durability of the capability for self-regulation developed in the result of the performed reclamation procedures which characterizes harmonized cultural landscapes. This indicates that it is necessary to continue research on changes of biochemical parameters stimulating processes of matter circulation and energy flows between landscape elements from the point of view of estimation of the long-term effect of reclamation operations on functioning of the examined landscape.

CONCLUSIONS

1. The increasing contents of organic carbon and total nitrogen in the examined soils in consecutive years of investigations confirm the growing self-regulating capability of the landscape damaged by the fire and the effectiveness of the performed reclamation program.
2. The distinct positive impact of the reclamation program on experimental plots with alder plantings justifies the use of this species as the pioneer crop for fire site regeneration.
3. The determined significant increase in the organic carbon content in the soil on experimental plots with Grey alder stimulated favorable changes in the activity of enzymes catalyzing the most important transformations of soil organic matter. This confirms that alder plantings increased the self-regulating, resistance, buffering as well as resource-functional potentials of the examined landscape.
4. Plantings with Grey alder exerted a significant influence on the increase of mineral forms of nitrogen in the soil corroborating their positive impact on the resource-functional potentials of the landscape subjected to the reclamation program.
5. It is evident from the performed investigations that the applied enzymatic tests also signal changes taking place in the landscape system under the influence of the applied tree species which makes complex recognition of the course of the regeneration processes of forest ecosystems damaged by fires possible and can be utilized to develop optimal programs of management of large-area fire sites.
6. Different methods of soil preparation 12 years after their application on the examined fire site failed to exhibit a significant influence on the determined soil properties. This means that the employed methods of soil preparation did not cause tangible, long-term changes in the functioning of the examined landscape.

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WPŁYW METODY REKULTYWACJI I WYBRANYCH GATUNKÓW DRZEW DO ZALESIEŃ NA ZMIANY KRAJOBRAZU ZDEGRADOWANEGO PRZEZ POŻAR

W pracy analizowano wpływ sposobu rekultywacji na przekształcenia krajobrazu zdegradowanego przez pożar. Badaniami objęto powierzchnie doświadczalne, na których zastosowano odmienne sposoby przygotowania gleby (gleba wyłączona z uprawy mechanicznej, pełna uprawa mechaniczna, wyoranie bruzd) w uprawach sosny zwyczajnej (*Pinus silvestris* L.) i olszy szarej (*Alnus incana* (L.) MOENCH) oraz powierzchnię sukcesji naturalnej i powierzchnię kontrolną wytypowaną w naturalnym kompleksie leśnym bezpośrednio sąsiadującym z pożarzyskiem. Badania wykazały, że po 12 latach rekultywacji krajobraz popożarowy uzyskuje stan strukturalnej i funkcjonalnej równowagi biologicznej. Nasadzenia olszą szarą w istotny sposób stymulowały aktywność enzymatyczną badanych gleb, co wskazuje na ich korzystny wpływ na potencjał krajobrazu i uzasadnia stosowanie tego gatunku jako przedplonu przy odnawianiu pożarzyska. Odmienne sposoby przygotowania gleby nie miały istotnego wpływu na uchwytne, długofalowe zmiany funkcjonowania badanego krajobrazu.