Int. J. Environ. Res., 6(3):703-710, Summer 2012
ISSN: 1735-6865

Effect of European Black Alder Monocultures on The Characteristics of Reclaimed Mine Soil

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Received 15 Aug. 2011; Revised 15 Jan. 2012; Accepted 25 Jan. 2012

ABSTRACT: The effect of European black alder (*Alnus glutinosa* L.) on the contents of carbon and nitrogen, exchangeable base cations, and plant available forms of phosphorus in the reclaimed mine soils formed by waste deposition from opencast lignite mines was researched in central Serbia. It was concluded that the greatest part of dead organic residues reaching the soil under European black alder monocultures was liable to rapid decomposition into end products. This was the consequence of a narrow C/N ratio in the European black alder litterfall which amounted on average to 12.77 in the study monocultures. Only a small part of organic residues was transformed into humus. On that account, European black alder monocultures did not have a major impact on the accumulation of organic carbon and total nitrogen in the soil. The content of carbon in the surface layers accounted for 1.55-1.57%, and the content of nitrogen to 0.085-0.132%. Fast mineralisation of organic matter, and thus also of the organic forms of nitrogen, resulted in the surplus of soil nitrates, which were liable to washing through the soil. Nitrate movement resulted in the soil leaching and the movement of base cations, primarily calcium, to the deeper layers of the solum. The total soil phosphorus content was low, and also the level of plant available forms. A significant portion of total phosphorus in the surface layers of the reclaimed mine soils was composed of its organic forms.

Key words: European black alder, Reclaimed mine soil, Litterfall, Soil properties, Serbia

INTRODUCTION

Mine waste deposition from opencast lignite mines results in the formation of soils of low production capacity. They are often unsuitable for the establishment of plantations of valuable forest species because they do not contain sufficient supplies of nutrients in plant available forms. Mine soils generated by mine spoil deposition from opencast lignite mines in the Kolubarski Basin (central Serbia) are characterised by deep solum. Physical and chemical, as well as microbiological properties of these mine soils were researched by numerous authors (Stojanović *et al.,* 1977; Antonović *et al.,* 1978; Antonović *et al.,* 1984; Veselinović *et al.,* 1984; Rasulić, 1997; Šmit & Miletić, 1997; Dražić, 1997; Miletić, 2004; Miletić & Radulović, 2005; Miletić *et al.,* 2011). All the authors report that the main problems are unfavourable chemical characteristics of the generated anthropogenic soils, primarily the complete absence of humus and organic matter, and consequently the complete absence of organic nitrogen, from which the plant available forms are released by mineralisation. Different studies have discussed several parameters that affect the soil quality (Gousterova *et al.,* 2011; Ahmad and Jawed, 2011; Yu *et al.,* 2011; Ying *et al.,* 2011; Bhakta and Munekage, 2011; Rafati *et al.,* 2011). For the majority of oligotrophic forest species, low supplies of readily available forms of phosphorus and potassium are minor problem, because these elements are present in available forms, and under the effect of agents of mineral decomposition in the top soil, the non-available forms are transformed into plant available forms.

European black alder is a species capable of symbiotic nitrogen fixation (Akkermans & Van Dijk., 1976; Blom *et al.,* 1981) so its nutrition in mine soils is not a major problem. On reclaimed mine soil in the Kolubarski Basin, European black alder was characterised by very fast growth and good wood volume yield, which was in some cases higher than that of black poplar (Šmit & Veselinović, 1997). The subject of this research was the impact of European black alder monocultures on the characteristics of reclaimed mine soils and the possibility of their

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implementation as pre-culture aiming at the establishment of plantations of the species with higher nutritive requirements.

MATHERIALS & METHODS

To assess the effect of European black alder monocultures on mine soil characteristics, three sample plots were established on the reclaimed lignite mine soil in central Serbia. The altitude of all the sample plots ranges from 185 to 207 m. Sample plots 1 and 2 are located on a flattened terrain without any aspect, and sample plot 3 is located on the slope of 5° and its aspect is north-west.

According to the data of the nearest weather station Baroševac (Table 1), mean annual air temperature in the area is 11.8°C, and 18.3°C during the vegetation period. The coldest month is January with mean monthly temperature 0.7°C, and the warmest month is July with mean monthly temperature 21.7°C. The average sum of monthly precipitation is 576.4 mm, of which the greatest part amounting to 355.1 mm occurs during the growing season.

Litterfall collectors were placed in each sample plot in early spring before the beginning of vegetation growth. Litterfall was collected at monthly intervals till the end of February of the following year. In this way, the mass of litterfall reaching the soil surface over a year was determined. The analyses of the collected organic material included the quantities of ash and organic matter, total nitrogen and total carbon by Anstett method modified by Ponomaryeva and Nikolajeva (Ponomarieva & Plotnikova, 1975), total phosphorus (colorimetrically), total potassium (flame-photometrically), total calcium and magnesium (complexometrically).

One soil profile was opened in each sample plot and soil samples were taken for laboratory analyses. The samples were taken from the following layers: 0-2 cm, 2-7 cm, 7-17 cm and 17-100 cm. The criteria for the the selection of soil layers for sampling were as follows: soil layer 0-2 cm showed the morphological signs of the formation of humus horizon; soil layer 2-7 cm contained the roots of native herbaceous plants, whose individual roots in some cases reached the depth of 17 cm; the deepest layer 17-100 cm contained only the roots of European black alder, and there were no roots of native species.

The following properties were determined in the soil samples: active and substitution acidity potentiometrically, exchangeable cations and cation exchange capacity by Bover et Atens method (Džamić *et al.,* 1996), total phosphorus by Ginzburg *et al.,* method (Džamić *et al.,* 1996), content of organic phosphorus by Legg and Black method (Olsen & Dean, 1965), available forms of phosphorus and potassium by Al-method (Džamić *et al.,* 1996), content of total humus by Turin's method modified by Simakova (Džamić *et al.,* 1996), group fraction composition of humus by Ponomaryeva's method (only in the surface soil layers 0–2 cm and 2–7 cm) (Škorić & Racz, 1966), and the content of total nitrogen by Kjeldahl's method (Džamić *et al.,* 1996).

The abundance of the main physiological groups of soil microorganisms in organic litter horizon was determined in the spring, summer and autumn periods, i.e.: number of ammonifyers on meat-peptonic agar, total

Table 1. Temperature and precipitation at the weather station "Baroševac"

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I-XII	IV-IX
Temperature (ºC)														
Average	0.7	2.3	7.2	11.7	17.2	20.1	21.7	21.1	17.9	12.1	6.0	2.8	11.8	18.3
min	-3.3	-2.8	1.7	9.2	14.1	17.9	19.8	18.3	13.8	8.9	1.9	-1.4	10.6	16.9
max	5.1	7.7	10.6	15.9	19.7	22.4	25.6	23.4	22.4	15.2	8.2	6.3	13.0	19.9
Precipitation (mm)														
Average	32.1	33.9	32.1	43.2	70.0	81.1	60.5	62.5	37.5	46.3	45.7	31.6	576.4	355.1
min	0.0	1.0	0.0	16.1	26.1	34.1	9.6	15.5	0.0	12.5	0.0	0.0	444.0	243.0
max	95.4	82.2	112.8	101.2	164.7	125.3	193.0	229.8	70.9	107.5	100.6	72.1	749.0	439.0

number of mineralogenic microorganisms on the soil agar, number of oligonitrophiles on Eshbi agar, total number of fungi on Chapek's agar, number of actinomycettes on Krasilnikov's agar (Šourkova *et al.,* 2005).

The effect of forest plantations on mine soils was determined by the comparison of mine soil surface layers, which were under the highest effect of organic matter, with the deeper layers in which this effect was minor.

RESULTS & DISCUSSION

Litterfall represents the most important source of organic carbon input to the forest floor (Nordén, 1994). Litterfall input to the soil surface under European black alder plantations was high on all three sample plots. Also, the variability of litterfall masses on sample plots was high. The measured litterfall mass under alder monocultures ranged from 1775.50 to 22704.5 kg of oven dry organic matter per hectare (Table 2). The characteristic of litterfall in all three sample plots was a high content of nitrogen and a very narrow C/N ratio. C/N ratio in the foliage of broadleaf species in the temperate zone is on average 25, and C/P ratio is 310 (Vitousek *et al.,* 1988). C/N ratio in European black alder litterfall in the study plantations was twice narrower and C/P ratio was approximately the same or somewhat narrower compared to the average for the foliage of broadleaf species in the temperate zone. In addition to nitrogen and phosphorus, tEuropean black alder litterfall also contained significant quantities of potassium, calcium and magnesium. The amount of phosphorus in alder litterfall was low, and C/P ratio was somewhat narrower compared to the average for broadleaf foliage in the temperate zone.

Under European black alder monocultures, litterfall was the main source of organic matter in the organic litter horizon. The organic litter horizon was the deepest in autumn, after the leaf fall phenophase. European black alder litterfall was characterised by a narrow C/N ratio. The narrow C/N ratio is a precondition for the fast decomposition of organic matter (Ohta & Kumada, 1978). For that reason, from the spring of the following year, when favourable temperature conditions are established, organic litter was liable to very fast mineralisation. During the vegetation growth period, the greatest part of organic litter was mineralised. In the autumn, at the beginning of the leaf fall phenophase, organic litter was not continuous and mostly consisted of plant material produced by other, native species. It also contained some coarse wood residues and a considerably lower proportion of alder foliage.

Vegetation type and litter quality seem to be of higher importance for soil microbial activity than substrate quality on the reclaimed spoil heaps. (Šourkova, *et al.,* 2005). In the study European black alder plantations in the spring period, the number of ammonifying microorganisms in organic litter was notably higher than the number of other physiological groups of saprophytic microorganisms (Table 3). It was followed by the physiological group of mineralogenic microorganisms on the soil agar, and by oligonitrophilic microorganisms.

During the spring, the dominant part of organic litter was alder foliage, together with other organic residues. During the winter, litter was not subject to major changes, because biochemical processes were slowed down thanks to low temperatures. Organic litter is still rich in proteins, which is the basic energy material for the richest physiological group of microorganisms - ammonificators, and it is not a favourable material for oligonitrophiles which are the smallest group.

In spring, the observed number of fungi in organic litter under European black alder plantations was slightly higher than that on actinomycettes. The number of fungi and actinomycettes decreased in summer because of intensive organic litter desiccation. The reduction in the number of actinomycettes was considerably greater than the reduction in the number of fungi.

In summer, the abundance of ammonifying and mineralogenic microorganisms in organic litter also

Table 2. Characteristics of European black alder litterfall

Sample plot	Litterfall mass	Organic matter	Ash	N	C	C/N	K	P	C/P	Ca	Mg
	Kg/ha	%	%	%	%		%	%		%	%
1	1775.5	89.90	10.10	2.66	31.15	11.72	2.128	0.084	370.83	2.171	0.524
2	2612.5	91.04	8.96	2.14	29.34	13.74	2.991	0.096	305.63	1.943	0.698
3	2704.5	90.58	9.42	2.53	32.48	12.84	2.809	0.081	400.99	2.161	0.501

Table 3. Seasonal dynamics of the abundance of soil microorganisms in organic litter under European black alder plantation (1000 microorganisms /1g air dry organic litter)

	Ammonifyers (1)	Mineralogenics (2)	Oligonitrophiles (3)	Fungi (4)	Actinomycettes (5)
Spring	2468.4	647.4	447.7	211.8	190.8
Summer	83.3	8.3	1166.7	175.0	18.6
Autumn	4771.7	13420.5	8526.0	842.1	135.1
Average	2441.2	4692.1	3380.1	409.6	114.8

1. Number of ammonifying microorganisms on meat-peptone agar
2. Total number of microorganisms on soil agar
3. Number of oligonitrophilic microorganisms on Eshbi agar
4. Total number of fungi on Chapek's agar
5. Actinomycettes on synthetic agar

decreased. This was partly the consequence of low moisture content in the soil and organic litter, and partly also the result of lower quantities of protein nitrogen, which was decomposed already in the spring period. The reduced number of ammonifying microorganisms, which use proteins as energy material, caused the reduced production of mineral forms of nitrogen in organic litter. This resulted in the decrease in mineralogenic microorganisms which develop on soil agar and which use mineral forms of nitrogen. In summer, the dominant parts of organic litter were the organic matter produced by other, native species, and coarse wood fragments. Alder foliage remains mostly consisted of conducting and mechanical tissues which contained low quantities of nitrogen. The consequence of the changed composition of organic litter was a highly elevated number of oligonitrophilic microorganisms. Because of oligonitrophile activity, which use atmospheric nitrogen for their nutrition, C/N ratio in organic litter was narrowed, because their dying led to the input of organic matter rich in nitrogen. In autumn, the soil and organic litter moisture was higher, and fresh litterfall was produced, i.e. fresh energy material for saprophytic microorganisms. This resulted in a great increase in the abundance of all the observed physiological groups of saprophytic microorganisms. The dominant physiological group consisted of mineralogenic microorganisms which prevailed both over ammonifyers and oligonitrophiles. The C/N ratio is one of the most effective indices of the decomposition and humification of organic matter (Ohta & Kumada, 1978), The narrow C/N ratio is a precondition for the fast decomposition of organic matter. Narrow C/N ratio in the litterfall under alder monocultures caused the greatest part of carbon to be converted into CO_2 by oxidative processes, as the end product of organic matter decomposition. Only a small part of dead organic residues reaching the soil under European black alder plantations was transformed into humus (Table 4). In contrast to organic matter in the dead organic residues which is subject to rapid decomposition, humus is a far more stable organic matter in the processes of biochemical decomposition. Because of the decomposition of alder dead organic residues into end products, there was no intensive accumulation of organic carbon and nitrogen under European black alder plantations, although their input to the soil via litterfall was high. On the study areas, the quantities of both carbon and nitrogen were exceptionally low, even in the surface soil layer 0-2 cm immediately below the organic litter. Biological accumulation of nitrogen in the soil occurs in humus substances, as the ripe humus pre-stage is formed by the synthesis of amino acids and hinones (Kononova, 1963). Amino acids are formed as intermediate products of protein decomposition, and hinones are intermediate products of the decomposition of organic compounds which do not contain nitrogen. They are nitrogen and carbon components of humus. Humic acids are formed by further polymerisation of humus pre-stages (Kononova, 1963). The decomposition of organic remains under European black alder plantations did not produce sufficient supplies of carbon components for the synthesis of humus substances, whereas there was a surplus of nitrogen components.

In the humus group fraction composition, fulvic acids prevail over humic acids (Table 5). The most abundant humic acids is fraction 1 (free humic acids), which is poorly bound with the mineral component and which is therefore more liable to biochemical degradation than other fractions. Fraction 2 (grey humic acids), bound with calcium, and also fraction 3,

Table 4. Content of organic carbon and nitrogen in soil under European black alder plantations

Sample plot	Depth	C - organic	Humus	N	C/N
	cm	%	%	%	
1	0-2	1.57	2.70	0.099	10.6
	2-7	0.91	1.57	0.071	10.2
	7-17	0.18	0.31	0.068	10.6
	17-100	0.07	0.12	0.089	5.4
2	0-2	1.56	2.69	0.085	8.0
	2-7	0.26	0.45	0.045	5.1
	7-17	0.15	0.26	0.033	10.0
	17-100	0.18	0.31	0.014	3.0
3	0-2	1.55	2.66	0.132	11.9
	2-7	1.19	2.04	0.043	14.5
	7-17	0.38	0.66	0.025	6.4
	17-100	0.37	0.64	0.036	23.1

bound with clay, are far less abundant. The most represented fulvic acid fraction was free fulvic acid fraction 1, poorly bound with the mineral component. The percentage of fulvic acid fractions 2, 3 and 4, bound with clay and stabile sesquioxides, was somewhat lower. Of all humus fractions, the lowest level was reached by the aggressive fulvic acid fraction 1a, which is characteristic of the soil under acidifying species.

Table 5. Group fraction composition of humus in the soils under European black alder plantations

SP	Depth.	C total	Humic acids fractions 1	2	3	ΣC ha	Fulvic acids fractions 1a	1	2	3	4	ΣC fa	ΣCha + ΣC fa	Insoluble residue	Cha/fa	Degree of decom-position
	cm	%	%	%	%	%	%	%	%	%	%	%	%	%		
1	0–2	1.57	0.09	0.03	0.04	0.16	0.07	0.19	0.14	0.11	0.13	0.63	0.79	0.77	0.25	0.50
		100	5.73	1.91	2.55	10.19	4.46	12.10	8.92	7.01	8.28	40.13	50.32	49.04		
	2–7	0.91	0.04	0.07	0.04	0.15	0.03	0.12	0.16	0.13	0.02	0.46	0.61	0.30	0.33	0.67
		100	4.40	7.69	4.40	16.48	3.30	13.19	17.58	14.29	2.20	50.55	67.03	32.97		
2	0–2	1.56	0.09	0.07	0.02	0.18	0.05	0.19	0.09	0.11	0.14	0.58	0.76	0.80	0.31	0.49
		100	5.77	4.49	1.28	11.54	3.21	12.18	5.77	7.05	8.97	37.18	48.72	51.28		
	2–7	0.26	0.01	0.03	0.01	0.05	0.01	0.08	0.00	0.02	0.02	0.13	0.18	0.08	0.38	0.69
		100	3.85	11.54	3.85	19.23	3.85	30.77	0.00	7.69	7.69	50.00	69.23	30.77		
.3	0–2	1.55	0.05	0.02	0.04	0.10	0.07	0.21	0.04	0.11	0.13	0.55	0.66	0.89	0.18	0.43
		100	3.23	1.29	2.58	6.45	4.52	13.55	2.58	7.10	8.39	35.48	42.58	57.42		
	2–7	1.19	0.02	0.03	0.01	0.06	0.04	0.07	0.05	0.08	0.03	0.27	0.33	0.86	0.22	0.28
		100	1.68	2.52	0.84	5.04	3.36	5.88	4.20	6.72	2.52	22.69	27.73	72.27		

The three study sample plots greatly differed in the soil solution reaction. This was the result of a different minerological composition of the mine soils generated from the mine spoil originating from different layers of overburden above the coal seam. However, there was a similarity in the change in pH values with the solum depth. In all three profiles, topsoil layers 0-2 cm, in which the morphological signs of humus-accumulation horizon ware discernible, had higher pH values than the soil layers directly below them (Table 6). With solum depth, pH value increased and reached the highest value in the deepest layers. The sum of exchangeable base cations had a similar behaviour. Such a change in pH values and the sum of exchangeable base cations per soil depth indicates the processes of soil leaching, that precede the loessivage.

European black alder litterfall which reached the soil, and which was rich in nitrogen was subject to fast mineralisation. Mineralisation developed to the end products, therefore the greatest part of organic nitrogen after the ammonification phases was also liable to nitrification. Nitrates were highly soluble and mobile and they were readily translocated along the profile depth by descendent percolation. The excess nitrate nitrogen causes soil acidification and base cation depletion (Reuss & Johnson, 1986; Federer *et al.,* 1989; Horswill *et al.,* 2008). Together with NO_3 anion, the base cation was also translocated along the profile. Nitrates in the deeper, poorly aerated soil layers, in more intensve anoxidative conditions, under the effect of anaerobes and facultative anaerobes, were exposed to denitrification, (nitrate reduction to molecular nitrogen) to the form of nitrogen used in alder symbiotic nitrogen fixation. The descendent flow and leaching of bases on all three study sites was facilitated by the light textural composition of the soil. In the study mine soils, the dominant exchangeable base cation in all three sample plots was calcium, followed by magnesium. Their change in concentration per soil depth was similar to the changes in pH values. The concentration of exchangeable Ca^{++} and Mg^{++} was greater in the topsoil layer 0-2 cm than in the lower layers, and it increased with soil depth. Exchangeable Na^{+} did not show any changes per soil depth. The exchangeable potassium was the most abundant in the topsoil layer, and decreased with depth.

The quantities of total phosphorus in the deposited mine waste forming the reclaimed mine soil were exceptionally low, therefore the amounts of plant available forms could not be high (Table 7). Of all the investigated nutritive macroelements in European black alder litterfall, phosphorus was the least represented. Nevertheless, organic forms of phosphorus in the soil made up a significant part of the total phosphorus. They were most abundant in the surface layers, and they decreased with depth. C/P ratio in litterfall was rather wide. This means that small quantities of phosphorus were released by the mineralisation of phosphorus organic compounds and that a greater part of phosphorus from organic matter was used by saprophytic microorganisms for their nutrition. Plant available forms of phosphorus were low throughout the soil depth, which was also the cause of low contents of phosphorus in alder litterfall.

Table 6. Soil solution reaction under European black alder plantations and exchangeable cations

		pH			Exchangeable cations				Cation exchange capacity		
Plot	Depth	in H_2O	in KCl	in $CaCl_2$	On	K	Ca	Mg	CEC	BAs	V
	cm				Centimole/kg				Centimole/kg		%
	0 – 2	5.1	4.3	5.0	0.21	0.19	7.00	3.20	16.78	10.6	63.15
	2 – 7	4.9	3.8	4.7	0.31	0.17	5.90	2.60	14.55	8.98	61.69
	7 – 17	4.9	3.4	4.5	0.37	0.13	5.10	2.50	14.02	8.11	57.81
1	17 – 100	6.8	5.3	6.6	0.23	0.13	9.15	2.85	14.6	12.36	84.61
	0 – 2	5.0	4.3	4.7	0.11	0.17	11.36	4.00	22.02	15.65	71.03
	2 – 7	4.9	3.5	4.4	0.17	0.14	9.47	1.10	16.25	10.88	66.93
	7 – 17	5.6	3.8	4.9	0.10	0.15	10.20	2.70	14.20	13.15	92.63
2	17 – 100	6.4	4.4	5.8	0.10	0.17	14.20	3.20	19.69	17.68	89.80
	0 – 2	7.2	6.4	7.1	0.10	0.28	18.00	1.05	21.78	19.44	89.23
	2 – 7	7.1	6.2	7.0	0.10	0.22	14.15	2.75	19.36	17.22	88.95
	7 – 17	8.0	6.8	7.5	0.10	0.16	14.25	2.35	19.26	16.86	87.54
3	17 – 100	8.3	7.0	7.6	0.04	0.10	33.15	2.25	37.14	35.54	95.36

Table 7. Content of total, plant-available and organic phosphorus under European black alder plantations

OP	Depth	Total P_2O_5	Available P_2O_5	% of available in total P	Organic P_2O_5	% of organic in total P
	cm	mg/100g	mg/100 g		mg/100g	
5.1	0–2	72.00	1.60	2.22	27.95	38.83
	2–7	61.00	0.30	0.49	17.87	29.30
	7–17	50.00	0.00	0.00	8.48	16.96
	17–100	72.00	0.20	0.28	2.98	4.14
5.2	0–2	61.00	1.70	2.79	16.50	27.05
	2–7	50.00	0.30	0.60	9.39	18.79
	7–17	25.00	0.30	1.20	2.06	8.25
	17–100	40.00	0.50	1.25	2.06	5.16
5.3	0–2	90.00	0.70	0.78	21.08	23.42
	2–7	79.00	0.80	1.01	8.02	10.15
	7–17	79.00	0.00	0.00	5.73	7.25
	17–100	84.00	0.00	0.00	6.42	7.64

CONCLUSION

European black alder is characterised by rapid growth on mine soil poor in organic matter and nitrogen. For this reason, canopy formation and the establishment of protective function of European black alder monocultures is fast. The production of dead organic residues in European black alder monocultures is high and in the study plantations it ranged from 1775.5 to 2704.5 kg/ha. Organic matter which reaches the soil per year was characterised by narrow C/N ratio (11.72 to 13.74), so its greatest part was subject to fast mineralisation to end products. A small part of dead organic residues was transformed into humus. The content of total carbon in the study soil accounted for 1.55-1.57%. In the group fraction composition of humus, the dominant fractions were those which were poorly bound with the mineral component, therefore they were more liable to biochemical decomposition. The presence of agressive fulvic acid fractions (1a) was neglectible. The contents of humus fractions bound with calcium, sesquioxides and clay were also low, they occurred mainly as fulvic acids.

The content of total nitrogen in the soil was low and in the study plots it accounted for 0.085-0.132%. Intensive processes of organic nitrogen mineralisation into end products resulted in the loss of this element from the soil, because ammonium nitrogen was subject to volatilization, and nitrate-nitrogen to percolation losses. All three samples showed the signs of leaching and movement of base cations into deeper soil layers.

The content of phosphorus in European black alder litterfall was low (0.081-0.096%), consequently the P/N ratio was wide. For this reason, the presence of phosphorus in plant available forms was low. In the study sites under alder plantations, phosphorus accumulated in the topsoil layers in the organic form.

Based on the study results, it can be concluded that European black alder is not a suitable pre-culture on mine soils aimed at the establishment of plantations of tree species with higher nutritive requirements.

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