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Forest plantation productivity – soil interactions within Western Forest-Steppe of Ukraine: effects of pH and cations

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ABSTRACT

Dark grey podzolized soils on the loess like loams, which are represented in the soil cover within fresh and humidity gradients in the Western Forest Steppe of Ukraine, are characterized by high forest vegetation potential, which ensure the formation of mostly pure and mixed larch and spruce stands with high level of the productivity. Despite the fact that both species are coniferous, their effect on the soil, in particular, on its acid-base indicators (actual and potential forms of acidity, sum of absorbed bases, degree of saturation of bases, content of mobile aluminium), which are important components of soil fertility, are specific. Due to the fact that there is a close interaction between forest plantations and soil properties, changing the participation of species in the stand, it is possible to adjust the actual soil fertility.

The soils under both pure and mixed spruce and larch stands are characterized by a high level of potential acidity that reaches the high acidic values in the upper horizons. A similar reaction of soil solution under coniferous forests is caused by acid hydrolysis of aluminosilicates and accumulation of mobile Al in the rhizosphere zone. Simultaneously, the same acidic characteristics, including the presence of movable aluminium, are also found in soils under broadleaved plantations. In general, acid-exchange properties of soils (high potential acidity, unsaturation of bases and availability of movable aluminium) traditionally are considered as unfavourable for vegetation. However, our researches refute it and prove that within certain values, these indicators do not limit the productivity of pure and mixed spruce and larch stands.

KEY WORDS

forest plantation, larch, spruce, oak, potential acidity, absorbed bases, movable aluminium

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INTRODUCTION

Among a number of soil characteristics that form soil fertility, of great importance are its acid-base indicators, which quite often limit the development and productivity of plants including woody vegetation (Remezov and Pogrebnyak 1965; Aune and Lal 1995; Shpakivska and Mariskevich 2008; Migunova 2010). Mostly, it occurs at the extreme values of the soil solution reaction – strongly acidic or strongly alkaline and is due to several causes. Physical (structure), physicochemical (absorption capacity, mobility of nutrients and their uptake by the plant), and biological properties of the soil (composition and microbiocoenosis activity) are closely related to pH value. Therefore, it is logical that pH should be considered as a key chemical indicator of forest soil quality (Schoenholtz 2000). Thus, some cations at certain concentrations have a toxic effect on plants (in a strongly acidic medium, these are H^+ and Al^{3+}, and in strongly alkaline medium – Na^+), the solubility of many compounds also changes, which complicates the mechanism of ion absorption by root systems and limits the ability of plants to meet their physiological needs for certain nutrients. In particular, the acidification of the root solution contributes to the absorption of anions, and alkalization, on the contrary – of cations. In acidic soils, the mobility of P, Fe, B, Mn, Cu, Zn increases, but the mobility of Mo, Mg – and sometimes Ca – decreases, and in alkaline soils, an inverse relationship is observed (Vozbutskaya 1964). In the extreme ranges of the medium reaction, the water-physical properties of soils significantly deteriorate (soil density increases, the structure breaks down, water permeability and water absorption capacity decrease, etc.), which also negatively affects the development and condition of vegetation.

Woody species have specific needs for acid-base soil characteristics, however, the vast majority of them show the highest productivity in the range from weakly acidic to weakly alkaline reaction (Remezov and Pogrebnyak 1965; Chertov 1981; Karpachevskiy 1981; Karpachevskiy et al. 1996; Gale et al. 1991). At the same time, it should be noted that in optimal climatic conditions (with sufficient heat and humidity), forest stands can achieve high productivity beyond this specified range. Usually, within the area of natural coniferous forests, soils are characterized by an acid reaction of varying degrees (from strongly to weakly acidic), broad-leaved forest area – from near-neutral (from weakly acidic to weakly alkaline reaction).

Given the close relationship between forest stands and soil properties (Binkley 1995; Russell et al. 2007; Cross and Perakis 2011; De Schrijver et al. 2012), the latter can be adjusted by changing the composition of the forest stand. This aspect is of particular importance in view of the introduction of a forest plantation system, which, among other components, involves the cultivation of fast-growing tree species. With optimal soil properties, the average timber increment of most fast-growing tree species can reach more than 10 m^3/ha per year, which is in line with the requirements of the term ‘fast growing species’. At the same time, the increment of the stock of stemwood volume of various species of larch and spruce under the appropriate growth regime can significantly exceed the indicated value (Debryniuk 2007). One of the important requirements for plantation forests (PF) is that their temporary and relatively short-term growing on the site where previously grew primary stands (beech, oak, ash, spruce, pine, etc.), with a view to the subsequent artificial regeneration of the latter after felling plantation crops, should not degrade the forest-growth conditions of the soil. At the same time, the effect of PFs of various compositions on the soil properties may be different (Finzi et al. 1998; Liang et al. 2016), which makes relevant the research on determining the specifics of their influence on soil properties, as well as, on the contrary, the influence of the latter on the productivity of forest stands.

MATERIAL AND METHODS

The object of the research is plantation-type forests with the participation of Norway spruce (*Picea abies* L.) and various species of larch (*Larix* L.) in the conditions of the Western Forest-Steppe. The subject of the research is acid-base indicators of soil under plantation forests of larch and spruce in fresh and moist fertile site types. The aim of the work is to investigate the relationship between acid-base soil indicators and productivity of stands with the participation of larch and spruce in fresh and moist fertile forest site types of the Western Forest-Steppe.

Using the methodological approaches of comparative ecology, the relationship between acid-base indicators of dark grey podzolized soils and the productivity of fast-growing stands was studied in similar forest site conditions (FSC) with different proportions of certain tree species (different types of larch and spruce) in the composition of the stands. Broad-leaved plantations served as a control (Tab. 1). Such a methodological approach with high probability leads to the assumption that the differences in soil indicators are mostly caused by the species composition of woody vegetation.

The objects of the research are located on the territory of the forest fund of the Western Forest-Steppe (Lviv, Ternopil, Chernivtsi regions), where 26 trial plots (TP) were laid out in a fresh and moist fertile forest site types – fresh and moist hornbeam-oak forests and fresh and moist beech-oak forests; the control – primary ash-oak and hornbeam-oak stands (trial plots 8a-1, 5ya, H-11).

The trial plots were laid out in accordance with generally accepted methods in forestry practice in stands with various participation of larch (L. *decidua* Mill., L. *kaempferi* Carr., L. *eurolepis* Henry), Norway spruce

Table 1. Stand composition and some mensuration indicators of stands

Trial plot No.	Stand composition	Age, years	Mensuration indicators of coniferous species		
			height, m	diameter, cm	site index
2p	10JL	39	23.5 ± 0.42	26.9 ± 0.70	I^{c}
5p	10JL	48	28.2 ± 0.33	27.8 ± 0.69	I^{c}
13lp	10EL+AH, NOM, POK	39	26.2 ± 0.63	28.1 ± 0.44	I^{d}
74	9EL1HBM	73	27.5 ± 0.21	29.6 ± 0.52	I^{a}
7a-2	9JL1AH	39	27.1 ± 0.88	38.6 ± 0.81	I^{d}
75	9EL1POK + HBM	58	24.7 ± 0.23	29.0 ± 0.54	I^{a}
4p	9HL1MASY+WEM, HBM	40	25.8 ± 0.30	26.9 ± 0.48	I^{d}
122a	8EL1CAR1POK + HBM, NS, SBI	56	31.9 ± 0.54	41.4 ± 0.87	I^{d}
1z	7EL1SP1BE1HBM+POK	58	29.8 ± 0.35	39.4 ± 0.99	I^{c}
7a-1	6JL3NS1AH	39	29.7 ± 0.10	36.2 ± 0.14	I^{e}
1p	6HL4ROK +SLI	42	26.3 ± 0.51	27.4 ± 0.71	I^{d}
100a	6EL3POK1SBI	56	26.9 ± 0.52	31.4 ± 0.92	I^{b}
22v	5EL5POK + SP	45	25.8 ± 0.22	36.2 ± 1.43	I^{c}
4pe	5JL3SP2NS + POK, HBM	36	21.2 ± 0.48	24.1 ± 0.44	I^{c}
116p	5EL5POK + SP, HBM	78	31.4 ± 0.25	50.9 ± 1.07	I^{b}
75a	7POK3EL + HBM	86	36.4 ± 0.74	46.9 ± 1.22	I^{c}
4d	7POK2HBM1EL	124	34.0 ± 0.08	78.6 ± 0.65	I^{a}
8a-1	6POK2AH1NOM1ROK	44	18.4 ± 0.31	19.5 ± 0.55	I
5ya	8POK2HBM + SBI, SLI, BE	51	20.0 ± 0.22	21.9 ± 0.43	I
15a	8POK1HBM1SBI + NS	51	19.7 ± 0.46	21.8 ± 0.66	I
17	9POK1NS	41	14.2 ± 0.60	15.6 ± 1.00	II
H-11	10POK + HBM	68	24.5 ± 0.86	26.2 ± 0.38	I
3B	10NS	54	25.6 ± 0.20	30.8 ± 0.62	I^{b}
6a-1	9NS1AH + POK	41	22.6 ± 0.12	26.8 ± 0.08	I^{b}
1m	9NS1POK + HBM, SLI	46	19.6 ± 0.37	26.4 ± 0.76	I^{a}
16ch	6NS4POK	39	19.9 ± 0.25	20.0 ± 0.42	I^{b}

Note: *Quercus robur* L. mensuration indicators are presented in the trial plots 8a-1, 5ya, H-11. Abbreviation of forest tree species: NS – Norway Spruce, POK – Common Oak, HBM – Hornbeam, SBI – Silver Birch, EL – European Larch, AH – European Ash, NOM – Norway Maple, CAR – Black Alder, BE – European Beech, MASY – Sycamore Maple, SP – Scots Pine, JL – Japanese Larch, ROK – Red Oak, HL – Hybrid Larch, SLI – Small-leafed Linden, WEM – Witch Elm

(*Picea abies* [L.] Karst.) and common oak (*Quercus robur* L.) (Grom 2010). Three soil profiles were laid out at typical sites for each TP, of which 78 samples were selected for laboratory analysis. The profiles were described in accordance with the generally accepted methods (Polupan et al. 1981), and sampling – by genetic horizons (He, HE (A); HI (AB); I (Bt); IP (BC) (FAO, 2006). Under laboratory conditions, the soil samples were brought to an oven-dry state and prepared for analysis; they were analysed according to the current DSTU (DSTU ISO 10390:2001, DSTU ISO 11260:2001, DSTU 4287:2004, DSTU ISO 14254:2005, DSTU 7537:2014).

According to the degree of acidity (pH$_{H_2O}$), the soils were differentiated into: strongly acidic (pH < 4), moderately acidic (pH 4–5), weakly acidic (pH 5–6); and pH$_{KCl}$ is very strongly acidic (<4.1), strongly acidic (4.1–4.5), moderate acidic (4.6–5.0) weakly acidic (5.1–5.5), near-neutral (5.6–6.0), neutral (6.1–7.0) (DSTU 4362: 2004).

Results and discussion

Among soil indicators, the reaction of the soil media, which is generally determined by the ratio of hydrogen ions (H $^+$) and hydroxyl ions (OH$^-$) in the soil solution, significantly affects the growth and productivity of woody plants. Hydroxyl ions (OH$^-$) are present due to the hydrolysis of mineral salts mainly of calcium, magnesium, potassium and sodium, whose exchange forms predominantly comprise the soil absorbing complex (SAC). The reaction of the soil solution also depends on external factors: climatic and geomorphological conditions, such as the water regime of the soil, the species composition and productivity of the vegetation cover.

Acidity is divided into actual (pH$_{H_2O}$), due to the presence of free H$^+$ in the solution, and potential that manifests itself in the interaction of the soil with salt solutions and is characterized by exchange (pH$_{KCl}$, H exch.) and hydrolytic forms of acidity. A very important indicator of soil fertility is also the composition of exchange cations. According to their physiological importance, their effect on soil and plant productivity, cations (provided they completely saturate SAC) are divided into three groups: 1) Ca $^{2+}$, St $^{2+}$ – determine the normal yield of plants; 2) Mg^{2+}, Mn^{2+}, Fe^{3+} Al^{3+}, H$^+$ – exhibit toxic properties, but the application of CaCO$_3$ into the soil normalizes productivity to a certain extent; 3) NH^{4+}, Na$^+$, K$^+$, Cd^{2+}, Ba$^{2+,}$ Ni^{2+}, Co^{2+}, Cu^{2+} – also exhibit toxic properties, but the introduction of CaCO$_3$ no longer corrects the yield situation (Gedroyts 1955).

In forest stands, the dynamics of soil acidity depends on a number of factors, in particular, the composition of the stands; also, there are certain patterns of its changes along the soil profile. It has already been noted that under coniferous species, an acidic reaction of the soil medium is formed, while under broad-leaved species, it is mostly near-neutral (Binkley 1995). However, our earlier studies showed that under broad-leaved forests, in particular, in a fresh maple-lime oak forest, the reaction of the soil solution is also in the acidic range – from weakly acidic to acidic (Raspopina 2011, 2012, 2017). Moreover, such a range is typical for dark grey soils in the forests of the southern part of the Eastern Forest-Steppe, in which the effervescence horizon is located at a fairly high level (110–130 cm). The properties of dark grey podzolized light loamy soils on loess like loams of the objects of study in the Western Forest-Steppe disagree even more with the generally accepted ideas about their acidic characteristics (Tab. 2).

Thus, if the values of the exchange acidity of the soil in coniferous and broad-leaved forests are rather similar, the hydrolytic acidity values are 16% higher under pure oak forests and stands in which common oak is dominant (>6 units) (t$_{05}$-4.25; n–59). The obtained results can be explained, first of all, by the better humus content of oak forest soils (see Tab. 2, Fig. 1), because it is well known that this form of acidity is the highest in humus horizons. In general, the studies have shown that soil-formation processes both under coniferous forests (spruce and larch) and broad-leaved forests (oak), as well as mixed ones (oak-spruce, oak-larch) occur mainly in a slightly acidic medium (pH$_{H_2O)}$, moderate – 5.4, the range is 4.2–7.2 units), while the potential soil acidity rises to strongly acid levels (pH$_{KCl}$ 4.2; 3.3–6.4 units) (see Tab. 2).

It should be noted that the phenomenon of pronounced acidity of the soil solution under broad-leaved stands that we discovered is rather atypical, because according to the available data (Zonn 1954; Pogrebnyak 1955), larch improves the acid-exchange properties of the upper horizons of the soil (reduces acidity and increases the saturation with bases). However, there are also conflicting opinions regarding the effect of larch

Table 2. Chemical composition of soils along genetic horizons under forest plantations of different composition

Stand composition	Hori-zons	pH_{KCl}	Humus	H hydr	S	H exch	V	Al^{3+}	N	P_2O_5	K_2O
			%	mg/100 g soil			%	mg/100 g soil			
1	2	3	4	5	6	7	8	9	10	11	12
10NS	He	3.8	2.86	14.2	3.4	11.4	19.3	50.4	9.8	6.8	9.4
	HI	4.2	1.32	8.2	3.8	4.7	31.7	19.8	5.3	3.2	8.2
	I	4.2	0.84	4.4	13.2	2.2	75.0	5.7	4.2	1.5	12.8
9NS1POK + HBM	He	3.8	3.18	14.5	1.8	9.5	11.0	46.0	7.8	7.1	8.0
	HI	4.2	1.12	8.1	0.8	5.0	9.0	25.2	4.6	5.2	6.2
	I	4.4	0.45	4.2	12.2	1.4	74.4	6.4	2.2	2.4	13.0
6NS4POK	HE	4.2	3.84	14.4	2.6	11.5	15.3	55.0	9.5	8.5	6.0
	Eh	4.4	1.18	8.5	2.0	8.4	19.0	44.5	4.5	8.7	3.8
	I	4.4	1.03	6.4	1.2	1.8	15.8	10.1	2.2	5.1	12.1
9POK1NS	He	4.2	4.52	20.0	3.5	10.5	14.9	58.4	11.4	6.5	10.5
	HI	4.8	2.10	14.2	3.0	11.2	17.4	50.6	5.1	1.7	4.8
	I	4.2	0.64	6.8	11.5	3.4	62.8	10.4	1.5	1.6	9.5
8POK1HBM1SBI + NS	He	4.2	5.84	18.2	3.2	6.8	15.0	31.4	13.1	9.32	11.2
	HI	3.9	2.00	9.0	4.4	6.0	32.2	27.5	9.2	8.94	8.4
	I	4.1	0.32	4.5	10.2	2.5	69.4	10.6	1.7	4.34	7.8
10EL + AH, NOM, POK, HBM	He	3.8	3.22	14.4	2.5	7.0	14.8	33.6	9.5	5.4	5.6
	HI	4.1	1.06	8.5	1.8	4.5	17.5	21.4	8.0	5.0	4.0
	I	4.0	0.51	4.5	12.5	1.7	73.5	6.6	1.4	2.8	12.4
9EL1HBM	HE	4.0	1.43	7.6	2.6	4.1	25.5	19.2	4.2	6.1	7.5
	Eh	4.2	0.65	3.8	9.2	2.0	70.8	4.4	1.8	14.2	13.5
	I	4.4	0.51	3.4	13.5	0.8	79.9	1.2	2.2	22.4	14.6
9EL1POK + HBM	HE	4.8	2.20	8.3	4.2	4.3	33.6	18.2	7.2	3.4	4.2
	Eh	4.7	0.84	4.0	3.2	3.0	44.4	21.4	4.8	1.2	1.1
	I	4.4	0.75	2.9	3.0	2.1	50.8	7.8	3.1	1.2	0.3
8EL1CAR1POK + HBM, SBI, NS	He	4.5	4.92	8.2	4.1	5.4	33.3	26.8	17.2	10.4	13.2
	HI	4.3	2.05	5.1	2.1	3.2	29.2	12.2	13.8	3.6	9.0
	I	4.4	1.02	4.8	0.4	1.5	7.7	3.6	11.2	1.2	4.4
7EL1SP1BE1HBM + MASY, POK	He	4.7	6.04	8.7	10.5	6.1	54.7	28.1	16.4	14.1	10.2
	HI	4.4	2.82	4.0	4.2	3.0	51.2	18.4	9.2	8.2	4.5
	I	4.4	0.47	2.2	3.1	2.1	58.5	3.6	5.0	10.5	8.1
6EL3POK1SBI	HE	5.5	5.41	9.2	16.4	7.7	64.1	36.8	22.2	12.4	18.5
	Eh	5.2	2.82	5.7	6.3	4.8	52.5	11.4	15.8	10.0	9.2
	I	4.8	0.96	2.9	6.4	2.0	68.8	1.3	8.5	2.6	8.8
5EL5POK + SP	He	3.8	3.41	14.2	2.6	6.8	15.5	33.0	6.4	3.5	9.2
	HI	4.2	0.96	8.4	1.8	4.8	17.6	24.4	5.0	1.7	4.5
	I	4.1	0.44	5.2	13.2	1.0	71.7	6.1	2.1	2.1	11.2

1	2	3	4	5	6	7	8	9	10	11	12
5EL5POK + SP, HBM	He	3.7	8.12	19.5	3.3	13.8	14.5	58.4	11.4	20.2	14.5
	HI	4.4	1.65	8.5	2.9	9.5	25.4	44.7	4.6	6.2	7.0
	I	4.3	0.81	8.3	10.2	9.6	55.1	43.8	1.8	1.4	11.5
5JL3SP2NS + MASY, POK, HBM	He	4.6	5.43	11.3	5.1	9.2	31.1	48.4	12.0	6.2	8.5
	Eh	4.6	2.75	6.1	3.1	4.1	33.7	14.3	7.4	3.0	12.6
	Ih	4.3	1.04	2.0	1.1	1.6	35.5	3.5	6.2	1.2	6.0
7POK3EL + HBM	HE	3.5	9.32	14.6	5.2	16.5	26.3	66.7	9.6	14.2	18.1
	Eh	4.2	1.34	8.8	2.1	9.0	19.3	44.0	4.4	5.0	8.0
	I	3.8	0.42	6.7	7.6	6.0	53.1	31.4	1.2	8.8	11.5
7POK2HBM1EL + SP	He	4.8	2.82	9.6	5.6	4.1	36.8	19.2	8.2	2.4	10.2
	HI	4.3	1.34	6.4	6.2	1.6	49.2	7.5	2.1	2.8	5.3
	I	4.9	0.61	4.7	2.7	0.9	36.5	2.6	0.9	8.1	12.4
8POK2HBM	He	4.2	3.04	14.2	2.8	7.2	16.5	33.6	10.2	6.5	7.5
	HI	4.5	1.14	8.4	1.9	4.2	18.4	17.5	4.1	12.6	4.2
	I	4.0	1.02	5.1	13.0	1.4	71.8	4.2	2.0	9.1	11.8
10POK + HBM	He	3.8	3.42	15.2	2.5	8.6	14.1	41.2	7.4	1.6	10.2
	HI	4.3	2.05	8.2	6.4	2.2	43.8	5.6	9.1	1.3	12.5
	I	4.2	0.42	3.5	10.2	1.2	74.5	3.3	1.8	1.2	5.3
6JL3NS1AH	He	3.6	2.03	11.9	–	–	–	36.4	8.1	1.5	11.4
	HI	3.9	1.40	7.5	–	–	–	15.1	4.2	1.3	11.4
	I	4.0	0.36	2.8	–	–	–	4.3	2.8	6.7	11.4
9JL1AH + NS	He	3.9	1.55	7.9	–	–	–	13.3	4.2	1.5	6.6
	HI	3.9	1.52	6.5	–	–	–	4.4	3.5	0.5	11.4
	I	4.3	0.40	2.5	–	–	–	0.81	1.4	3.1	15.6
9NS1AH + POK	He	3.9	3.01	11.4	–	–	–	15.1	7.0	7.8	9.0
	HI	4.0	2.14	7.5	–	–	–	4.3	4.2	0.5	11.4
	I	4.3	0.32	2.1	–	–	–	0.8	1.4	1.4	11.0
6POK2AH1NOM-1ROK + HB	He	4.0	2.60	9.8	–	–	–	10.5	7.00	0.5	9.0
	HI	4.1	1.76	7.0	–	–	–	1.4	4.2	1.1	11.4
	PI	6.4	0.32	0.7	–	–	–	0	1.4	12.5	1.6
6HL4ROK + SLI, NOM, HBM, BE	He	3.3	3.49	13.0	–	–	–	39.9	12.6	4.3	6.6
	I	3.9	1.72	7.0	–	–	–	26.7	6.3	2.4	6.6
10JL + NOM, BE	He	3.6	2.88	12.0	–	–	–	39.2	8.4	6.1	6.6
	I	3.8	1.61	8.0	–	–	–	27.6	5.3	6.5	6.6
9HL1MASY + WEM, HBM, CAR, SBI, SLI, BE	He	4.3	3.68	12.0	–	–	–	38.2	11.2	5.1	8.2
	I	4.5	2.02	9.0	–	–	–	25.9	7.1	4.7	7.4
10JL + MASY, HBM, NS, WEM	He	3.8	2.98	10.0	–	–	–	35.7	8.1	5.8	4.2
	I	4.3	1.72	8.0	–	–	–	23.1	5.5	6.1	4.8

Note: – not identified.

ing both ex situ and in situ protection (Zatloukal and Vančura 2004).

The yew wood and other parts of the tree are poisonous. The species have a broad spectrum of anti-cancer activity compounds e.g. taxels (Lee 1998), which promoted the using of this species with pharmacological purposes.

The aim of the study was to present the current situation of distribution, protection and restoration of this species in Ukraine.

THE DISTRIBUTION AND BIOECOLOGICAL PREFERENCES OF YEW IN UKRAINE

In Ukraine, yew is distributed in the Carpathians and Crimean Mountains (Fig. 1). Yew occupies mainly brown eutrophic soils on carbonates. The species often growth in ravines, on rocks, steep slopes and it prefers the specific microclimate of high humidity and shade conditions.

In the Carpathian Mountains yew growth in isolated populations. The largest such population is located in the Kniazhdvir Nature Reserve in Ivano-Frankivsk administrative region (about 22,000 individuals; Boratyński et al. 2001). However, the species also rarely occurs in Zakarpattia – Carpathian Biosphere Reserve and Chernivtsi administrative regions – Tysovyi Yar Natural Monument (Didukh 2009, Pryazhko 2005). The species is distributed in beech and fir-beech forests (*Cephalanthero-Fagion union*, *Querco-Fagetea class*) at the altitude of 400 to 900 m a.s.l. The total area of forests with yew is about 285.0 ha. Generally, the yew grows as admixture species, understory of matured or overmatured forest stands and it forms small trees with DBH from 2 to 10 cm and height from 1.5 to 6.5 m. Only some individuals possess DBH over 20 cm and height more than 10 m (Pavlyuk and Marchenco 2004; Zayachuk 2019). The Kniazhdvir Nature Reserve is characterised by: annual average temperature 8.4°C (Fig. 2A). The warmest month of the year is July, while the coldest month is January. Annual average temperature is 593 mm. The driest month is February, while the greatest amount of precipitation occurs in July.

In the Crimean Mountains yew grows in the small populations or individually specimen from Karabi Yayla to Ai-Petri. The largest populations are located in the valley of the Belbek River (2,000 trees), near the Tyrke Mountain (800 trees), and the Grand Canyon of the Crimea (400 trees). The species occupies the sessile oak and beech forests (*Dentario quinquefoliae-Fagion sylvaticae*), particularly in the upper mountain elevations, at an altitude of 500–1200 m a.s.l. (Didukh 2009). The valley of the Belbek River is characterised by: an-

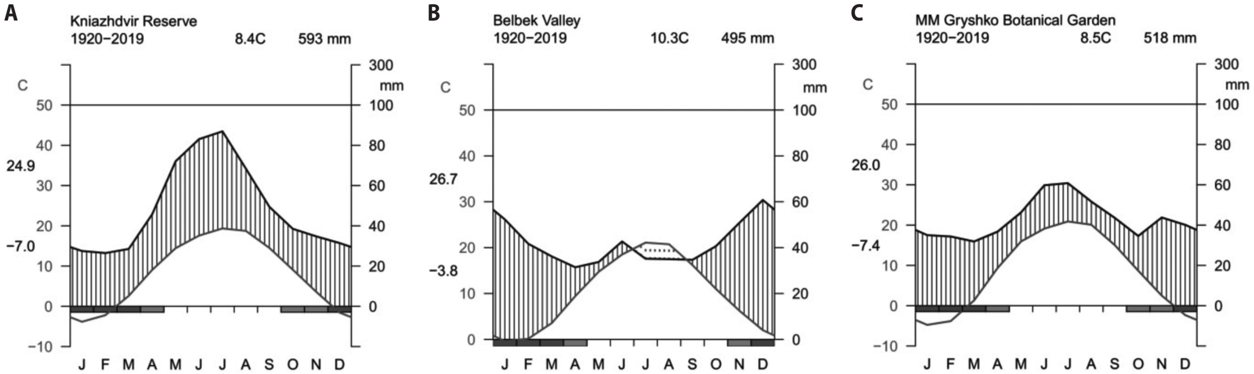

Figure 2. The Walter and Lieth climatic diagrams for Kniazhdvir Natural Reserve (A), Valley of Belbek river (B) and M.M. Gryshko National Botanical Garden (C). On the graphs monthly averages for precipitation (black line) and temperature (grey line). Annual averages of both elements in the upper part and at the left margin monthly averages annotations of the daily maximum and minimum temperatures of the warmest and coldest months. The rectangles under the 0°C axis show frost likelihood. Dark grey fill means that the average daily minimum is zero or negative, while light grey fill means that the absolute monthly minimum is zero or negative. The black vertical pattern depicts the humid months, while the dotted grey one shows when the aridity prevails (Guijarro 2014). The weather conditions of study sites for the period 1920–2019 were determined based on the data from Copernicus Climate Change Service [ECA&D project (https://www.ecad.eu)] (Cornes et al. 2018)

rent buffering state of soils in terms of acidity is mainly in the aluminium stage (pH = 3.0–4.2), and, to a lesser extent, in the exchange stage (pH = 4.2–5.0) (Hamkalo 2002). At pH < 3.8, iron ions enter the soil solution, which enhances the negative changes in the soil media.

Mobile aluminium appears due to acid hydrolysis of aluminosilicates at the acidic reaction of the medium. It should be noted that with increasing acidity, the amount of mobile aluminium increases regardless of the composition of the stands. Thus, its content under broad-leaved forest stands is almost the same as under coniferous ones and even slightly higher than these, and this applies both to mid-profile values – 2.53 versus 2.47 mmol equiv/100 g of soil (see Fig. 1), and values in the upper horizons of the soil (He (A), HI (AB)) (see Fig. 2). With the approach to the parent rock, the Al concentration changes dramatically – in the soils under oak stands, it is much smaller than under coniferous stands – 20.6 and 27.7 mmol equiv/100 g of soil, respectively (t_{05}-13.39; n–20), which is caused by the neutralization of free acids by the bases contained in the parent rock (loess like loam). In general, the range of Al^{3+} values under the study stands is in the range of 0–7.41 mmol equiv/100 g of soil. It was also found that humus substances in these soils are largely bound by Al (r = 0.61; n–28).

According to the soil profile, the dynamics of potential soil acidity under the stands of different composition has the following patterns. The average value of pH_{KCl} under broad-leaved stands varies in a small range of values – from 4.1 units in the upper humus horizon to 4.5 in the illuvial horizon, and under conifers, it narrows even more – to 4.1–4.3 units. The potential (exchange) acidity of the humus horizons is primarily caused by the content of exchange Al^{3+} in the SAC (between these indicators an almost functional relationship r = 0.97; n–28 was established), while in soils under broad-leaved stands (due to their better humus content), it is higher than under conifers. The values of exchange- and hydrolytic acidity decrease with depth under all the study stands (t_{05}-2.40; n–18), and in the ash-oak stand, with the approach to the parent rock (120–125 cm), the soil reaction becomes neutral (pH_{KCl}–6.4) (see Tab. 2).

Soils containing exchange H^+ and $A1^{3+,}$ and, therefore, having an acidic reaction of the medium, are characterized by unsaturation with bases. Thus, the average amount of absorbed bases is extremely low – 5.41 mmol equiv/100 g of soil and varies slightly – from 5.29 in coniferous stands of various compositions to 5.67 in oak forests. Its minimum value is characteristic of soils under stands, where spruce dominates – 4.56 mmol equiv/100 g of soil.

The amount of absorbed bases determines an important indicator of soil fertility – the degree of saturation with bases, which varies from 11.0% in spruce forests of composition 9NS1POK + HBM, SLI to 79.9% – in larch forests (9EL1HBM) (see Tab. 2) and averages 38.4% (Fig. 3). At the same time, the maximum average value of this indicator is characteristic for stands with the participation of larch (41.9%), the minimum – with spruce participation (30.1%), and in oak stands it occupies an intermediate position (37.3%).

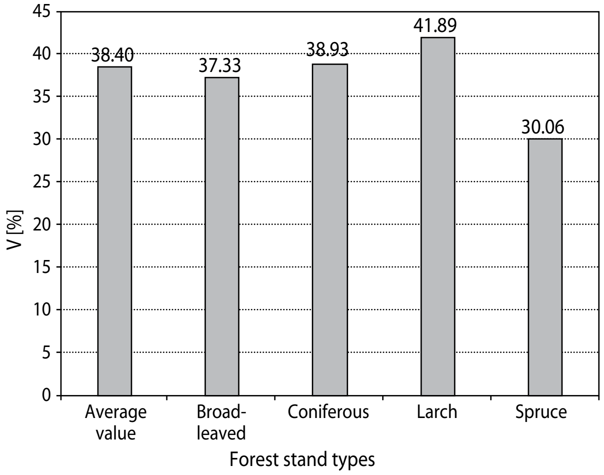

Figure 3. The degree of saturation with bases (V, %) of forest soils under stands of various compositions (Site conditions – D_2, D_3) in the conditions of the Western Forest-Steppe

In general, the degree of soil saturation with bases ranges from 30.1 to 50%, which corresponds to its low level. It was also found that under all the study groups of stands, the saturation of soil with bases increases with the approach to the parent rock (Fig. 4). At the same time, while in the stands with a predominance of oak and larch, the profile values of this indicator are quite similar (except for the upper humus horizon from which Ca^{2+}, Mg^{2+}, K^+, Na^+ leach out due to high hydrolytic acidity), in spruce stands, they are significantly smaller, especially in the upper part of the profile (t_{05}-4.08; n–37).

The lowest degree of soil saturation with bases under the predominantly spruce stand is due to the properties of its forest litter and the characteristics of the root system (pronounced shallow). Significant reserves, slow decomposition of spruce detritus, its chemical composition, high concentration of organic acids in the upper humus horizons is also due to the excretory function of the roots, which – 72.1–92.7% in length and 61.2–89.9% by weight – are concentrated in the upper 10 cm soil layer (Debryniuk 2002). This causes acid hydrolysis of the mineral part of the soil and leaching of the bases outside the profile.

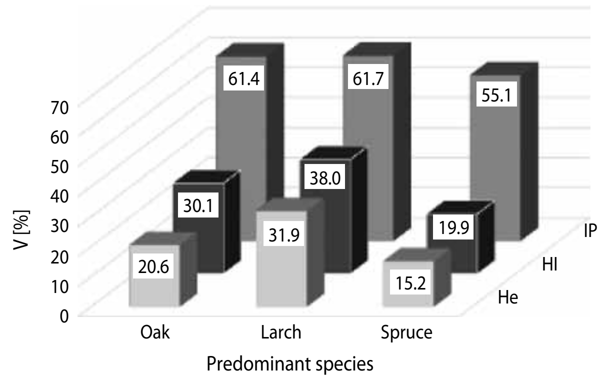

Figure 4. The degree of soil saturation with bases along genetic horizons under stands of various composition in the conditions of the Western Forest-Steppe

The results of the physicochemical analysis of soils showed that their acid-base properties are a strongly acidic solution reaction (both aqueous and saline), a low degree of saturation with bases, the presence of mobile aluminium, which is generally unfavourable for vegetation. However, the results of our studies argue against them, since the forest stands formed on these soils are characterized by a high level of productivity (see Tab. 1). Thus, the site index of middle-aged pure larch and forest stands with the dominance (6–9 units) of this species ranges from I to I^c index. In this case, the maximum site index is recorded with its participation as an admixture to broad-leaved species – *Fraxinus excelsior* L*., Ulmus glabra* Huds., *Acer platanoides* L. In stands, where the participation of larch is 5 units, its site index is I^a, regardless of the participation of associated species.

We also note that the site index of common oak stands, in case of its dominance in the composition of forest stands (8–9 units), is mainly I-I^a, and where the proportion of larch rises to 4 units and more – reaches the I^b index. Thus, the introduction of larch in oak cultures in the amount of 3–5 units positively affects the productivity of common oak. As to the spruce, its site index in pure and mixed stands with a share of 6–9 units varies within the I^a-I^b indexes.

Quite a wide range of varying site quality of coniferous stands (larch, spruce) enables us to analyse its dynamics depending on the acid-base characteristics of individual soil horizons (Fig. 5).

An analysis of the data indicates that there is no clear correlation between productivity (within I-I^c site indexes) and most of the soil indicators studied, and only with a decrease in the content of mobile aluminium, especially in the horizon close to the parent rock, the coniferous species site index is noticeably increased. It is well known that aluminium ions inhibit soil microflora and are phytotoxic, adversely affecting root development of woody plants (Bartels and Knabe 1990).

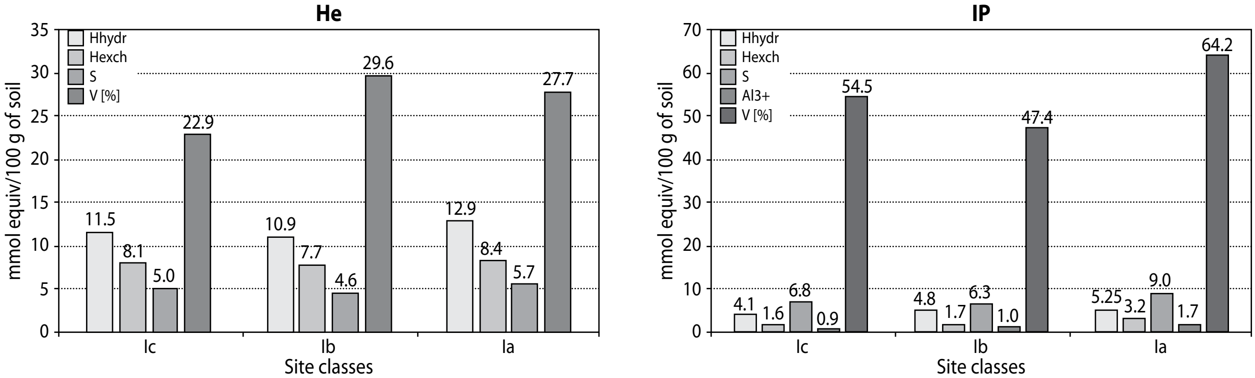

Figure 5. Average values of acid-base indicators in individual genetic horizons (He (A), IP (BC)) of the soil under coniferous stands of various productivity

At the same time, it can be said that the content of exchange Al^{3+} in a concentration of up to 7 mmol equiv/100 g of soil in the humus horizon under conditions D_2 and D_3 of the Western Forest-Steppe does not cause toxicosis or reduction in the biotic stability of the stands of Norway spruce, European larch and common oak, which grow on high site indexes I-I^c.

It is also noteworthy that in the stands of European larch of site index I^c, the degree of base saturation in the humus horizon is minimal compared to Norway spruce and common oak (t_{05}-15.5; n–37), which again, to a certain extent, contradicts the common opinion about base-enrichment of the soil under this species. In our opinion, this is due to the high need and energy of absorbing the bases by the fast-growing high-yielding larch stands. With depth, the degree of soil saturation with base under larch forests mainly increases sharply (up to 60–70% in the IP (BC) horizon), and this pattern is typical not only for larch, but also for most of the investigated stands.

A positive aspect of the high acidity of the soil solution is the transition of sparingly soluble phosphorus compounds into forms accessible to plants, which improves their phosphorus nutrition. According to our calculations, there is a rectilinear relationship between these indicators (r = 0.53; n–28).

The results of the physico-chemical analysis of soils under artificial plantations of various compositions made it possible to trace the changes in their acid-exchange characteristics that occur under the influence of spruce stands in fresh and moist fertile site types of the Western Forest-Steppe. According to the ‘traditional’ scientific provisions, spruce degrades soil properties, which can become a significant obstacle to its use in plantation forests. In this case, the main negative aspect of this impact is deterioration in the growth and development of restored primary stands in place of felled 30–40 year-old spruce crops. In general, forest vegetation is only one of the factors affecting the soil, and in nature one, can observe numerous cases when the soils under spruce stands are characterized by an insignificant degree of podzolization or this process does not limit their forest-growing potential (Tkachenko 1955). In our studies, we also did not record a visual intensification of the process of podzolization of dark grey forest soils on loess like loams under spruce in comparison with plantations of a different composition. We attribute this to the high potential level of soil fertility, the actual acid buffering (Hamkalo 2002) of which is very high, which contributes to the ‘mitigation’ of the podzolization effect of spruce. The moderation of podzolization of dark grey soils under spruce stands is enhanced by the climatic conditions of the Western Forest-Steppe, where rather moist forest site conditions are formed (C_3, D_3). According to a number of researchers (Gordienko 1953; Gordienko 1967; Shumakov 1963; Yakovenko 1972; Vakulyuk 1982), it is due to these causes that the effect of podzolization of spruce on the soil in moist fertile and fairly fertile site types is weakly manifested. Therefore, according to the conclusions of I. Yakovenko (1972), spruce cannot significantly degrade soil properties within one generation. Our studies also support these findings. Thus, pure spruce stands do not reduce the effective fertility of the above-mentioned soils, that is, no negative effect of this coniferous species on the edaphotope is observed (Debryniuk and Raspopina 2019). Thus, the introduction of plantation forests of spruce on dark grey soils on loess like loams can be an effective measure to increase the productivity of forest areas in the conditions of fresh and moist fertile (D) forest site types of the Western Forest-Steppe.

Conclusions

The processes of soil formation both under coniferous stands (pure and mixed spruce and larch ones) and broad-leaved (oak), as well as mixed (oak-spruce, oak-larch) stands occur mostly in a weakly acidic medium (moderate pH_{H2O} – 5.4, range – 4.2–7.2 units); at the same time, the potential (exchange) acidity of soils is characterized by a highly acidic level (pH_{KCl} 4.2; 3.3–6.4 units).

The values of soil exchange acidity in coniferous and broad-leaved forests are quite similar, while hydrolytic acidity values are 16% higher under pure oak stands and stands in which oak (> 6 units) dominates, which is due, first of all, to the better humus content of soils in oak forests.

The high level of acidity of the soil solution promotes the transition of sparingly soluble phosphorus compounds into forms accessible to plants, which improves their phosphorus nutrition.

In most trial plots, the level of soil potential acidity is high, which is caused by the presence of exchange Al^{3+}, the content of which is in the range of 0–7.41 mmol equiv/100 g of soil. Its content under broad-leaved stands is almost the same as under coniferous ones and even slightly higher than these, and this applies both to mid-profile values – 2.53 versus 2.47 mmol equiv/100 g of soil, and values in the upper soil horizons (11.75 versus 9.9), and with the approach to the parent rock, the dependence of its content sharply changes to the opposite – 20.6 under oak stands versus 27.7 mmol equiv/100 g of soil under coniferous species.

The content of exchange Al^{3+} at a concentration of up to 7 mmol equiv/100 g of soil in the A horizon in the conditions of D_2 and D_3 of the Western Forest Steppe does not cause soil toxicity and weakening of the biotic stability of the stands of Norway spruce, European larch and common oak growing in high site index I-I^c.

The average amount of absorbed bases is extremely low – 5.41 mmol equiv/100 g of soil, varying slightly from 5.29 in coniferous forests of different composition to 5.67 – in broad-leaved forests. The lowest value of this indicator (4.56 mmol equiv/100 g of soil) is characteristic of the soil under the stands where spruce dominates.

The degree of soil saturation with bases varies in the range from 11.0% in spruce forests (9 NS1POK + HBM, SLI) to 79.9% in larch forests (9EL1HBM) with a maximum average value under stands with larch (41.9%), a minimum – spruce (30.1%) and total – 38.4%, which corresponds to its low level under all the study plantation groups. With the approach to the parent rock, the degree of soil saturation with bases increases.

Despite the rather unfavourable acid-base properties (acidic and strongly acidic reaction of aqueous and saline solution, low degree of saturation with bases, presence of mobile aluminium), the larch and spruce forest plantations formed on these soils are characterized by a high level of productivity. There is no clear dependence between productivity (within I-I^c site indexes) and most of the acid-base soil parameters studied, and only with a decrease in the content of mobile aluminium, especially in the horizon close to the parent rock, the coniferous species site quality is noticeably increased.

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