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GENESIS AND GEOGRAPHY OF SOILS

The Impact of Artificial Forest Plantations on Mountain-Meadow Soils of Crimea

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Abstract—A significant change in the properties of mountainous meadow soils of the Ai-Petri Plateau has taken place under the impact of artificial plantations of pine, birch, and larch created in the Crimean highlands in the middle of the 20th century. In comparison with the soils under meadow vegetation, the soils under forest vegetation are characterized by an increased content of large aggregates, a decrease in the humus content, and an increase in the soil acidity and in the iron content of the organomineral compounds. The most dramatic changes in the structural state of the soils are observed under the plantations of pine. The changes in the acidity and the iron content are most pronounced under larch stands. The decrease in the humus content is observed under all tree species. Thus, in the soil layer of 0–10 cm under pine, birch, and larch stands, the content of C_{org} is 1.2, 1.3, and 1.4 times lower, respectively, than that in the soil under meadow vegetation.

Keywords: Ai-Petri Plateau, mountainous meadow soil (Phaeozem), pine, birch, larch, structure, humus, acidity, iron

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INTRODUCTION

On a global scale, the creation of artificial forest plantations on the initially forestless or deforested areas is regarded an important factor enhancing sequestration of carbon dioxide in different natural and climatic zones of the world [32, 35, 44, 50–52].

Estimates of the portion of carbon accumulated by the soil in forest plantations vary from less than 1% [47] to 39% [53]. Such a range of available estimates of the contribution of soils to the CO_2 absorption is due to the strong dependence of the humus budget in forest ecosystems on a number of factors, including the initial humus content of the soil, the technology of its pre-planting preparation, the species composition and age of tree plantations, topography, climate, etc. [40, 43]. The most significant growth in the humus content of soils was observed during the forest planting or during natural overgrowing of abandoned arable lands with a low initial organic matter content [5, 38, 45, 46, 49, 50, 53]. At the same time, the planting of forests on pastures and in prairies led to some decrease in the storage of organic carbon and nitrogen in soils [39, 48].

Soil moistening also affects the dynamics of humus in soils under the forest. According to research in various regions of the world, a positive balance of humus is usually observed in the areas with precipitation of up to 800–1000 mm, and a negative balance of humus is observed in the areas with precipitation of more than 1000 mm [37, 38, 42, 49, 50].

Hence, forest planting may have a positive effect on the humus budget only for degraded soils of former agricultural lands under conditions of optimal moistening and the presence of grass cover in forest plantations.

In addition to the impact on the dynamics of organic matter, forest planting significantly affects other soil indicators, including, in particular, the composition of the soil adsorption complex. A number of researchers note that an increase in acidity and a decrease in the amount of exchangeable bases are more expressed under coniferous species [33, 36, 39, 45, 46, 53]. The acidifying effect of forest plantations increases with an increase in the age of forest plantations and in the degree of their moistening [40].

Beginning from the early works by Korzhinsky [16], Tkachenko [29, 30], and Gorshenin [10], studies of the impact of artificial forest plantations on soil in the chernozemic zone have traditionally been focused on identification of the features of soil degradation. Numerous studies showed that the creation of forest plantations in the steppe and forest-steppe zones on plains with the hydrothermal coefficient of Selyaninov of 0.6–1.3 leads to certain changes in the properties of chernozems and dark chestnut soils. In particular, under the impact of woody vegetation, the crumb–granular structure is transformed into the angular blocky structure, the acidity of the soils increases, the humus content decreases, and the C_{ha}/C_{fa} becomes smaller. Most scientists did not consider these changes as soil degradation [2, 3, 7, 20–22, 24] and emphasized the positive effect of forest vegetation on the original soil properties. The latter is manifested by an increase in the thickness of the humus horizon, an improvement of the soil physical and water-physical parameters, and leaching of soluble salts [3, 11, 13, 22, 23, 28, 31]. It was suggested that such soils should be referred to as forest-reclaimed chernozems [27].

Obviously, in the regions with a higher moisture content, the degree of soil transformation under forest plantations should be more pronounced, which might lead to a significant degradation of the soil initially formed under herbaceous (steppe) vegetation.

This is fully related to forest plantations created in the middle of the 20th century on the mountain-meadow soils of the Crimean Mountains, including, in particular, the Ai-Petri Plateau (Yayla), where the climate, according to the long-term observations of the Ai-Petri meteorological station, is characterized by the mean annual precipitation of 1041 mm, mean annual air temperature of +5.8°C, and the hydrothermal coefficient of the growing season (according to Selyaninov) is 1.5 [1]. Under conditions of excessive moistening and percolative soil water regime under meadow vegetation of the plateau, mountain meadow soils are formed. They are characterized by the dark color of the humus horizon, high humus content, and crumb–granular structure. Such soils differ from chernozems because of the absence of secondary carbonates in the profile, acid reaction, narrower C_{ha}/C_{fa} ratio, and lower optical density of humic acids. Under the natural forests of mountain plateaus, mountainous forest soils are formed. They are classified as lessivated brown forest soils (burozems) and differ from the meadow soils in a considerably lower humus pool, the predominance of brown humic acids in the composition of humus, higher acidity, and clear features of the textural differentiation of the soil profile. These facts allow us to assume the possibility of a more significant transformation of meadow soils after planting forests on them in comparison with the chernozems of the plains.

According to previous studies, an increase in acidity was observed under the mixed plantations of maple and pine on the Ai-Petri Plateau. Under pine plantations, a sharp increase in the content of coarse (>10 mm) aggregates took place [17, 18]. This report describes the results of further studies that included additional soil objects and soil indicators.

The aim of the study is to assess the impact of the artificial plantations of pine, birch, and larch on some characteristics of the structural state, humus content, acidity, and the content of organomineral iron compounds in the mountain-meadow soils of the Ai-Petri Plateau.

OBJECTS AND METHODS

The Ai-Petri Plateau is a unique object for studying the impact of forest species mountain-meadow soils because of the active planting of forests in 1957–1970 [4]. During this period, more than a thousand hectares of plantations of various species in the form of numerous small groves were planted on its territory.

Field studies were performed in 2009–2016 under the plantations of pine (*Pinus kochiana* Klotzsch ex K. Koch) and Siberian larch (*Larix sibirica* Ledeb) on the shallow mountain-meadow soil (Leptic Phaeozem) and birch (*Betula pendula* Roth)—on the shallow mountainous meadow–forest soil (Luvic Leptic Phaeozem). The latter soils passed through the stage of natural development under broadleaved (beech) forests that were probably cut off at the beginning of the 20th century [34].

According to the archival data of the Yalta Mountainous Forest Reserve, pine and birch plantations were planted in 1961–1963; larch plantations, in 1963–1964. Thus, by the beginning of our study, the age of pine trees was 48–51 years; the age of birch trees, 50–53 years; and the age of larch trees, 51–52 years.

As a control, we took a natural meadow on the mountainous meadow soil (pit 1353, Haplic Phaeozem) near the pine and larch plantations and a meadow on the mountainous meadow–forest soil (pit 1332, Luvic Leptic Phaeozem) near the birch plantation and the adjacent native beech forest formed on the thin acid lessivated brown forest soil (Leptic Luvisol).

All the objects were located within the heights of 1054–1155 m a.s.l. on flat or gently sloping parts of the plateau.

Before forest planting, the soils were tilled to the depth of 25–30 cm. Tree seedlings were planted according to the dense planting scheme with initial spacing of 2–3 × 0.5–1.5 m; subsequently, this high density caused the inhibition and death of a significant part of the trees.

By the time of the study, the plantations of pine were characterized by a large number of falls; the average canopy density was about 0.7; herbs covered 10–50% of the surface, and the thickness of the forest litter horizon was about 3–5 cm.

Larch plantation also contained the admixture of pine, linden (*Tilia cordata* Mill.), and ash (*Fraxinus excelsior* L.). Mountain-ash (*Sorbus domestica* L.) was present in the understory. In general, the canopy density was about 0.7–0.8, and the ground cover (about 50% of the surface) consisted of grasses and young trees. The thickness of the forest litter was up to 2–3 cm.

Table 1. Some soil properties under meadow vegetation and under artificial forest plantations

No. of soil pit	Horizon; depth, cm	Clay	C_{org}	DOMH	$Ec^{mg/mL}$	C_{ha}/C_{fa}	Fe_{ox}	Fe_{alk}
		%					%	
1353, under the meadow	AU, 0–10	35	4.73	22	12.4	1.78	0.25	0.05
	10–20	33	3.68	24	13.6	1.97	0.27	0.04
	20–30	31	3.12	24	17.0	1.92	0.26	0.04
	30–40	30	2.91	27	17.1	1.68	0.29	0.05
	40–50	33	2.54	28	17.9	2.47	0.26	0.05
1280, under the pine plantation	AU, 0–10	34	3.41	20	17.5	1.27	0.29	0.08
	10–20	35	2.46	25	17.7	1.39	0.29	0.06
	20–30	38	2.36	27	17.2	1.66	0.29	0.05
	30–40	37	2.38	31	18.3	2.51	0.29	0.04
	40–50	39	2.34	30	18.2	2.40	0.29	0.03
1351, under the larch plantation	AU, 0–10	44	4.10	24	13.0	1.20	0.39	0.41
	10–20	42	3.41	26	15.1	1.57	0.39	0.33
	20–30	45	2.91	28	15.2	1.87	0.37	0.37
	30–40	49	2.51	25	16.8	1.54	0.31	0.44
	40–50	54	2.34	20	16.5	1.39	0.32	0.16
1332, under the meadow	AY, 0–10	31	3.49	25	9.3	1.17	0.31	0.05
	10–20	30	2.74	22	10.6	1.08	0.32	0.03
	20–30	37	2.07	23	10.2	1.25	0.30	0.02
	ABm, 30–40	56	0.90	23	7.4	0.81	0.17	<0.01
	40–50	59	0.98	15	6.6	0.59	0.19	<0.01
1333, under the birch plantation	AY, 0–10	27	2.30	24	9.1	0.89	0.42	0.10
	10–20	31	1.93	19	10.0	0.89	0.39	0.05
	ABm, 20–30	44	0.99	19	8.7	0.82	0.30	0.02
	30–40	45	0.93	19	9.1	0.65	0.26	0.01
	40–50	45	1.02	21	8.5	0.83	0.25	0.01
1352, under the beech forest	AY, 0–10	21	4.63	17	10.2	0.64	0.45	0.15
	ABe, 10–20	28	1.61	13	12.4	0.55	0.36	0.21
	20–30	40	0.96	14	12.6	0.47	0.33	0.05
	BM, 30–40	61	0.73	13	–	–	0.26	0.01
	40–50	59	0.84	12	–	–	0.28	0.01

Birch plantation was damaged by tree falls. The canopy density did not exceed 0.6, and the projective cover of herbs reached 50–70%. The forest litter horizon was very thin (1 cm) and had a fragmentary pattern.

Meadow (mountainous meadow steppe) vegetation in the control areas was represented by *Cariceta humilis* associations and by mountainous herbs [9]; it covered 100% of the surface, which is typical of the mountainous meadow soils of Crimean yaylas.

The beech forest with dead cover had the canopy density of about 0.9 and the litter thickness of only 1–2 cm because of the high rates of mineralization of plant falloff.

Pine, larch, birch, and beech stands were characterized by one soil pit each; two pits were examined on the control with meadow vegetation. Soil samples were taken along the vertical columns with a 10-cm interval with due account for the genetic horizons (Table 1). On all of the plots, topsoil (0–10 cm) samples were taken in 5–21 replicates to ensure calculation of the average values of the soil properties. In June 2016, one sample of forest litter was specially taken under each of the artificial plantations and under the beech forest.

In the soil samples, we determined the content of total organic carbon (C_{org}), the carbon of humic and fulvic acids (C_{ha}, C_{fa}) [15], and the optical density of humic acids ($Ec^{mg/mL}$) [25]. The degree of organic matter humification (DOMH) was calculated as the portion of C_{ha} in C_{org}. Particle-size distribution analysis was performed by the pipette method with pyrophosphate pretreatment of the samples [8]; pH_{KCl}, total (hydrolytic) acidity (Ac_{tot}) according to the Kappen method in modification TsINAO [12], and the composition of exchangeable bases displaced by the 0.2 N NH_4Cl solution were also determined. Detailed description of analytical procedures used to determine extractable aluminum (Al_{extr}) and total cation

Table 2. Results of dry sieving of samples collected from the soil layer of 0–10 cm

Plot	No.	Content of fractions (mm), %						
		>10	7–10	5–7	3–5	2–3	1–2	<1
Pine	16	61 ± 17	14 ± 5	9 ± 5	5 ± 3	6 ± 3	3 ± 2	2 ± 1
Meadow near the pine	20	17 ± 10	13 ± 6	14 ± 4	12 ± 2	21 ± 5	14 ± 7	9 ± 6
Birch	6	45 ± 10	17 ± 4	12 ± 2	7 ± 2	10 ± 2	5 ± 1	4 ± 1
Meadow near the birch and beech	5	28 ± 18	15 ± 4	14 ± 4	10 ± 4	16 ± 7	10 ± 5	7 ± 3
Larch	7	22 ± 8	18 ± 6	15 ± 2	10 ± 2	16 ± 5	12 ± 6	7 ± 3
Meadow near the larch	5	12 ± 8	14 ± 4	15 ± 4	12 ± 1	20 ± 4	15 ± 5	12 ± 6
Beech	5	14 ± 5	12 ± 2	16 ± 1	13 ± 1	22 ± 2	14 ± 2	9 ± 2

exchange capacity (CEC) and calculate total exchangeable acidity (Acexch) and base saturation on the basis of these data was given earlier [19]. According to this procedure, weighed portions of the soil were repeatedly washed with a solution of 1 M sodium acetate and 0.05 M NaOH (pH 12.7); the content of Al_{extr} was determined in the obtained extract, and the residue on the filter was washed with 0.1 N $BaCl_2$ solution until the complete displacement of sodium from the exchange complex with further determination of the CEC by the Bobko–Askinazi method in the TsINAO modification [26]. The obtained CEC was considered the CEC of the soil devoid of the acidic components in the exchange complex and was referred to as the total CEC. The difference between the total CEC and the sum of exchangeable bases gave us the value of the total exchangeable soil acidity, and the ratio of the sum of exchangeable bases to the total CEC characterized base saturation (BS). The values of the latter obtained by this method were lower than the values of BS traditionally calculated as the ratio of the sum of exchangeable bases to the sum of exchangeable bases and total (hydrolytic) acidity.

The oxalate-extractable iron (Fe_{ox}) was determined according to Tamm; the iron from the organomineral compounds (Fe_{alk}) was extracted via 16-h-long treatment of the soil with 0.1 n NaOH solution at the soil : solution ratio of 1 : 50. The advantage of the alkaline extract instead of the traditionally used Na- or K-pyrophosphate extracts is that it is widely applied for extracting humic substances associated with R_2O_3; in contrast to pyrophosphate, it extracts very little iron from the low-humus mineral soil horizons. The Fe concentration in the soil extracts was determined by the colorimetric method with sulfosalicylic acid [14].

In the dried and crushed samples of the forest litter, pH_{KCl} was determined.

The statistical processing of the results was performed using STATISTICA 6 software package.

RESULTS AND DISCUSSIONS

The parent material of the studied plots is represented by the carbonate-free weathering products of the hard Upper Jurassic limestone. The thickness of the loose layer under forest plantations was 50–60 cm; under meadow, up to 100 cm (pit 1353); and under beech forest, 70 cm.

Mountainous meadow soils usually have a light clayey or medium clayey texture with a relatively even distribution of the main fractions along the soil profile. A significant differentiation of clay characteristic of the forest soils of upper slopes and plateaus of the Main Ridge of the Crimean Mountains was observed in the burozem under beech forest and in the meadow–forest soil under birch plantation and under the adjacent meadow, where, as note earlier, beech trees could grow in the past [33].

The pits made under meadow vegetation and under artificial forest plantations differed in the soil density and structure. The soils under forest plantations were characterized by the higher content of coarse blocky and crumb aggregates and by the higher density of the solid phase. The most significant changes in the structural state of the soils were observed under the pine plantation, where they could be traced down to 60 cm [17, p. 52; 18]. Moreover, under the pine plantation, coarse angular blocky structure was clearly expressed already in the surface horizon; under the larch and birch plantations, coarse (>10 mm) aggregates in the upper horizon were represented by crumbs, and angular blocky aggregates appeared in the middle part of the profile.

According to the results of dry sieving of the samples from the upper (0–10 cm) layer, an almost fourfold increase in the number of aggregates >10 mm occurred in the soil under the pine plantation, and the content of aggregates <1 mm decreased in comparison with that in the soil under meadow (Table 2). The lowest content of coarse aggregates was observed in the soil under the larch plantation, though it was two times higher than that in the soil under meadow. In the beech forest, the contents of aggregate fractions in the upper (0–10 cm) layer were close to those in the meadow soil studied near the plantations of pine and larch. According to the contents of fractions >10 mm and <1 mm, the meadow–forest soil under the birch plantation occupied an intermediate position between the soils

Table 3. Average values of soil properties in the layer of 0—10 cm

Area	No.	C_{org}	DOMH	$Ec^{mg/mL}$	C_{ha}/C_{fa}	Fe_{ox}	Fe_{alk}
		%				%	
Pine	21	3.09 ± 0.81	24 ± 4	14.7 ± 1.9	1.25 ± 0.30	0.30 ± 0.05	0.14 ± 0.04
Meadow near the pine	21	3.67 ± 0.87	24 ± 4	14.6 ± 2.1	1.06 ± 0.28	0.30 ± 0.03	0.09 ± 0.03
Birch	11	2.97 ± 0.63	22 ± 5	8.4 ± 0.6	1.05 ± 0.16	0.41 ± 0.02	0.13 ± 0.03
Meadow near the birch and beech	12	3.97 ± 0.64	20 ± 3	9.0 ± 0.9	1.12 ± 0.29	0.39 ± 0.04	0.08 ± 0.03
Larch	8	3.57 ± 0.38	24 ± 2	13.2 ± 0.4	1.13 ± 0.11	0.35 ± 0.02	0.38 ± 0.06
Meadow near the larch	5	5.13 ± 0.34	22 ± 2	11.4 ± 0.2	0.98 ± 0.04	0.36 ± 0.03	0.14 ± 0.02
Beech forest	19	4.24 ± 0.71	18 ± 4	8.8 ± 1.5	0.83 ± 0.25	0.52 ± 0.09	0.19 ± 0.05

under the pine and larch plantations. However, this soil was characterized by the minimum degree of transformation in comparison with the adjacent meadow soil. In turn, the content of coarse (>10 mm) aggregates in the latter was two times higher than that in the soil under the beech forest.

Changes in the structural state of the soils under artificially planted trees in the steppe and forest-steppe zones were noted by many researchers [2, 3, 6, 23, 28]. In comparison with degraded arable soils, these changes—transformation of the silty–crumb or silty–blocky structure into granular or crumb–granular structure—were assessed as positive changes. According to our data, the planting of forests on virgin meadows or meadow fallow lands of the Ai-Petri Plateau definitely leads to degradation of the soil structure, which is most clearly expressed under pine plantations with the thickest forest litter horizon. Forest litter not only hampers the growth of herbs but also serves as a source of specific substances gluing soil particles and promoting for an increase in the size of aggregates. The data provided by Gorshenin [10] also attest to a significant (by 200–250%) increase in the content of coarse (>10 mm) aggregates under the plantations of pine and birch on chernozems.

The creation of artificial forest plantations had a negative effect on the organic matter accumulation. According to the values of C_{org} (Table 1), the soil under meadow vegetation contains 1.1–1.4 times more humus than the neighboring soil under forest plantations. This is also confirmed by the averaged data on C_{org} in the upper (0–10 cm) layer, according to which we may reconstruct the dynamics of modern processes of humus accumulation. As seen from Table 3, the average values of C_{org} under the meadow exceed the corresponding values under the pine, birch, and larch plantations by 1.2, 1.3, and 1.4 times, respectively. The lowest content of C_{org} in the upper horizon and a sharp decrease in the humus content down the soil profile was found in the meadow–forest soil under birch trees; along with a clearly expressed differentiation of clay in this soil, this attests to a long stage of the development of this soil under forest vegetation.

A decrease in the degree of humification of meadow soils after forest planting is a natural consequence of the pre-planting soil plowing with the destruction of the sod layer. Later, it cannot recover to the initial state under the gradually closing forest canopy. The falloff of trees cannot replace herbs as the source of humus. In contrast to herbs, a larger part of the falloff of trees is mineralized on the soil surface. This leads to significant differences between distribution patterns of C_{org} in the profiles of the meadow soil and brown forest soil (burozem). Therefore, the creation of the artificial forest plantations on the mountainous meadow soils of Crimean plateaus under conditions of excessive moistening does not enhance long-term carbon sequestration owing to the accumulation of stable humus compounds in the surface soil layer.

Along with the differences in the C_{org} contents, forest and meadow soils of the plateau also differ in the quality of humus. In this context, it is interesting to study the effect of forest planting on the degree of the organic matter humification, the C_{ha}/C_{fa} ratio, and optical density of humic acids. As follows from Table 1, the degree of humification under meadow communities and under forest plantations is approximately the same; it is significantly higher than that in the burozem under beech forest. The comparison of the mean data on the degree of humification in the upper (0–10 cm) soil horizon (Table 3) also attests to the absence of significant changes in this index during the existence of forest plantations in comparison with the initial meadow soil.

The lowest values of the optical density of humic acids were found in the burozem under beech forest and in the soils under both meadow vegetation and under birch plantation. In the upper part of the profile under pine plantation, they were higher than under the meadow, but their mean values obtained from the data of a large number of observations were almost equal (Table 3). Under the birch plantation, the average values of $Ec^{mg/mL}$ of the upper soil layer were lower than those in the soil of the adjacent meadow. The average values for the entire profiles were almost equal (9.1 and 8.8. respectively) and did not differ much from

Table 4. Acidity and composition of exchangeable cations in the soils under meadow vegetation and artificial forest plantations

No. of soil pit	Depth, cm	pH_{KCl}	Ac_{tot}	Al_{extr}	Ac_{exch}	Al_{extr}, % Ac_{exch}	BS
			cmol(+)/kg			%	
1353, soil under the meadow	0–10	5.38	3.8	7.9	27.4	29	50
	10–20	5.46	3.2	9.2	32.5	28	39
	20–30	5.46	2.9	11.5	29.6	39	45
	30–40	5.37	3.6	13.5	29.8	45	43
	40–50	5.42	2.6	15.4	30.1	51	45
1280, soil under the pine plantation	0–10	4.13	9.0	12.7	29.1	44	40
	10–20	4.14	7.7	12.7	28.7	44	41
	20–30	4.19	7.6	10.7	28.5	38	40
	30–40	4.33	6.8	13.6	30.6	44	40
	40–50	4.57	5.7	12.1	29.8	41	44
1351, soil under the larch plantation	0–10	3.86	15.9	27.2	48.6	56	25
	10–20	4.00	12.6	26.1	43.5	60	28
	20–30	3.94	12.8	27.7	44.1	63	24
	30–40	3.97	11.7	27.5	44.6	62	23
	40–50	3.99	12.2	25.7	41.6	62	30
1332, soil under the meadow	0–10	3.99	6.3	8.7	21.9	40	50
	10–20	3.97	5.2	9.5	30.7	31	40
	20–30	4.45	4.5	10.1	24.4	41	47
	30–40	4.66	2.6	8.7	24.8	35	54
	40–50	6.19	1.8	7.1	22.4	32	59
1333, soil under the birch plantation	0–10	3.79	10.0	13.1	26.0	50	37
	10–20	3.81	8.7	12.7	28.7	44	36
	20–30	4.40	4.5	9.2	25.4	36	48
	30–40	4.56	3.8	8.1	23.1	35	54
	40–50	6.22	1.5	5.1	21.1	24	64
1352, soil under the beech forest	0–10	4.04	9.1	11.5	34.8	34	36
	10–20	3.76	12.4	16.9	34.8	49	21
	20–30	3.76	13.1	17.9	35.0	51	28
	30–40	3.77	13.7	17.9	40.0	45	36
	40–50	3.88	9.9	13.9	32.4	43	47

those under the larch plantation. At the same time, the average value in the upper soil horizon under the larch was approximately 2 points higher than that under the meadow.

The values of C_{ha}/C_{fa} in the soil profiles were generally higher for meadow soils. However, the average values in the upper horizon were higher in the soils under pine and larch plantations. In our opinion, this is explained by a more active accumulation of young humus with low optical density and low C_{ha}/C_{fa} values in the upper horizon under meadow vegetation. In the soils under forest plantations, the main part of organic matter was accumulated during the meadow stage, and, therefore, their humic acids were characterized by a greater "maturity" and by higher values of the optical density and C_{ha}/C_{fa} ratio.

As shown earlier [17], the creation of artificial forest plantations on the mountainous meadow soils of Crimea leads to a significant soil acidification and leaching of bases. According to the acidity and base saturation values (Table 4), these changes were observed in the upper part of the profiles down to the depth of 40–50 cm and were most pronounced in the topmost (0–10 cm) horizon, where the acidity often exceeded the value typical of the burozem under beech forest. Among the studied tree species, the strongest acidifying effect on the entire soil profile was seen under larch. Only under the larch plantation, the average pH_{KCl} was less than 4 (3.95); the total (hydrolytic) acidity in this soil was higher than that in the burozem under beech forest, and the degree of base saturation was lower. However, the most evident manifestation of the acidifying impact of larch was seen from the higher values of total Ac_{exch}, the content of Al_{extr}, and its portion in the total Ac_{exch} in comparison with the soils under pine and birch plantations and beech forest. The results obtained in this study are in agreement with the

Table 5. Average values of physicochemical soil properties in the layer of 0–10 cm

Vegetation	No. of samples	pH_{KCl}	Ac_{tot}	Al_{extr}	Ac_{exch}	Al_{extr}, % of Ac_{exch}	BS
			cmol(+)/kg			%	
Pine	18	4.13	10.4 ± 3.1	14.7 ± 4.2	31.7 ± 5.8	47 ± 11	35 ± 8
Meadow near the pine	18	4.50	7.6 ± 1.7	12.8 ± 3.4	28.4 ± 3.4	46 ± 13	44 ± 6
Birch	11	3.94	10.6 ± 1.5	11.6 ± 1.5	23.9 ± 4.2	50 ± 10	42 ± 6
Meadow near the birch and beech	12	4.56	6.6 ± 1.3	8.8 ± 1.6	22.3 ± 3.0	40 ± 7	50 ± 6
Larch	8	3.73	16.6 ± 1.1	22.5 ± 2.8	29.9 ± 3.6	74 ± 9	36 ± 6
Meadow near the larch	5	4.62	9.2 ± 1.0	9.3 ± 0.3	20.5 ± 2.0	46 ± 5	56 ± 3
Beech	18	3.75	12.9 ± 4.2	11.3 ± 2.1	27.9 ± 8.7	43 ± 11	39 ± 13

data of Khakimov et al. [33], according to which the pH of the salt extract under the 99-year-old larch plantation on gray forest soils of Moscow oblast was significantly lower than that under the mixed forest and fallow soil because of acidifying effect of larch litter [29, 41]. Our data confirm this; the pH_{KCl} of larch litter was 4.39; of pine litter, 5.00; of birch litter, 5.94; and of beech litter, 5.36. Recognizing the strong acidifying effect of larch, Tkachenko [29], nevertheless, believed that this species exerts a positive effect on forest soils improving their structure and favoring the accumulation of available nitrogen and phosphorus,

According to the acidity characteristics of the upper 10-cm-thick layer (Table 5), the average pH and base saturation values under forests were lower, and total acidity and the extractable aluminum content were higher than those under meadow vegetation. The maximum difference between the acidity indices of meadow soils and soils under forest plantations was specific for larch plantation. The content of Al_{extr} in the soil under beech forest was lower than that in the soils of artificial forest plantations and even in the meadow soil near the pine plantation.

Among data on the acidity indices and the composition of exchangeable cations, data on the accumulation of extractable aluminum (Tables 4 and 5) in the soil under larch are of particular interest. It was found earlier [19] that the content of extractable aluminum in the mountainous forest and meadow soils of Crimea is greatly affected by the clay content and the total acidity. A seen from the plots presenting the dependence of the content of extractable aluminum on the C_{org} and total acidity (Fig. 1), in the soil under the larch plantation, the Al_{extr} content is higher than the upper limits for the soils under meadow, pine, birch, and beech. The particular mechanisms of the accumulation of extractable aluminum in the soil under larch should be further studied.

During the investigations, the impact of artificial tree plantations on the content of Fe_{ox} and its fraction associated with the organic matter (Fe_{alk}) were investigated for the first time. In general, Fe_{ox} is evenly distributed in the soil profiles under meadow vegetation and forest plantations. The accumulation of Fe_{ox} in the upper part of the profile with a sharp decrease down the soil profile was observed in the brown forest soil

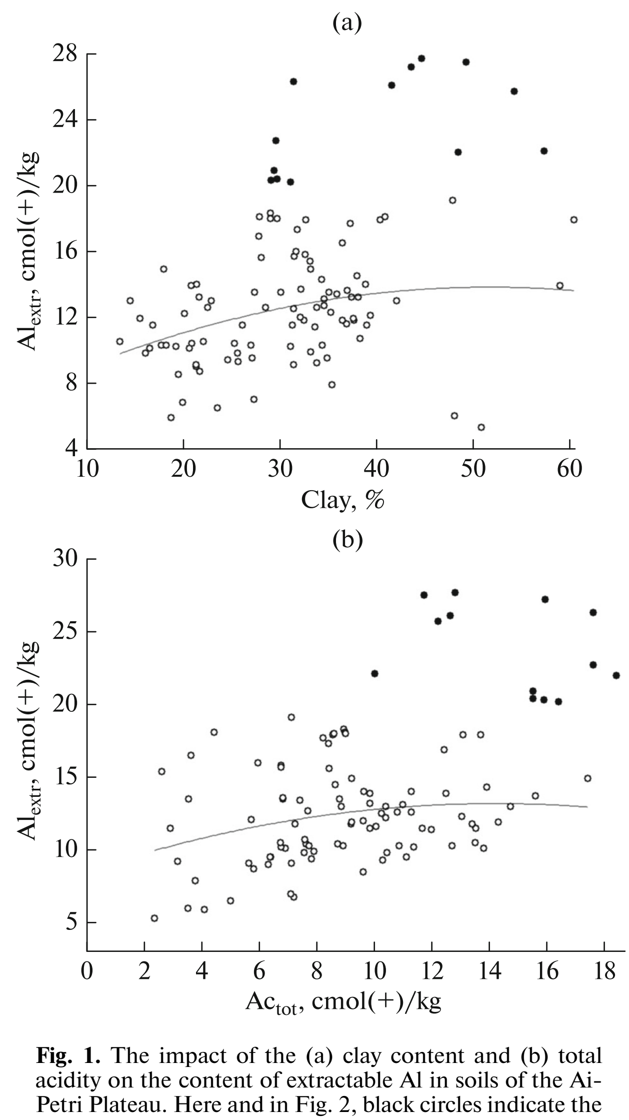

Fig. 1. The impact of the (a) clay content and (b) total acidity on the content of extractable Al in soils of the Ai-Petri Plateau. Here and in Fig. 2, black circles indicate the soils under the larch plantation, and blank circles are the soils under the pine, birch, and beech plantations and under the meadow vegetation.

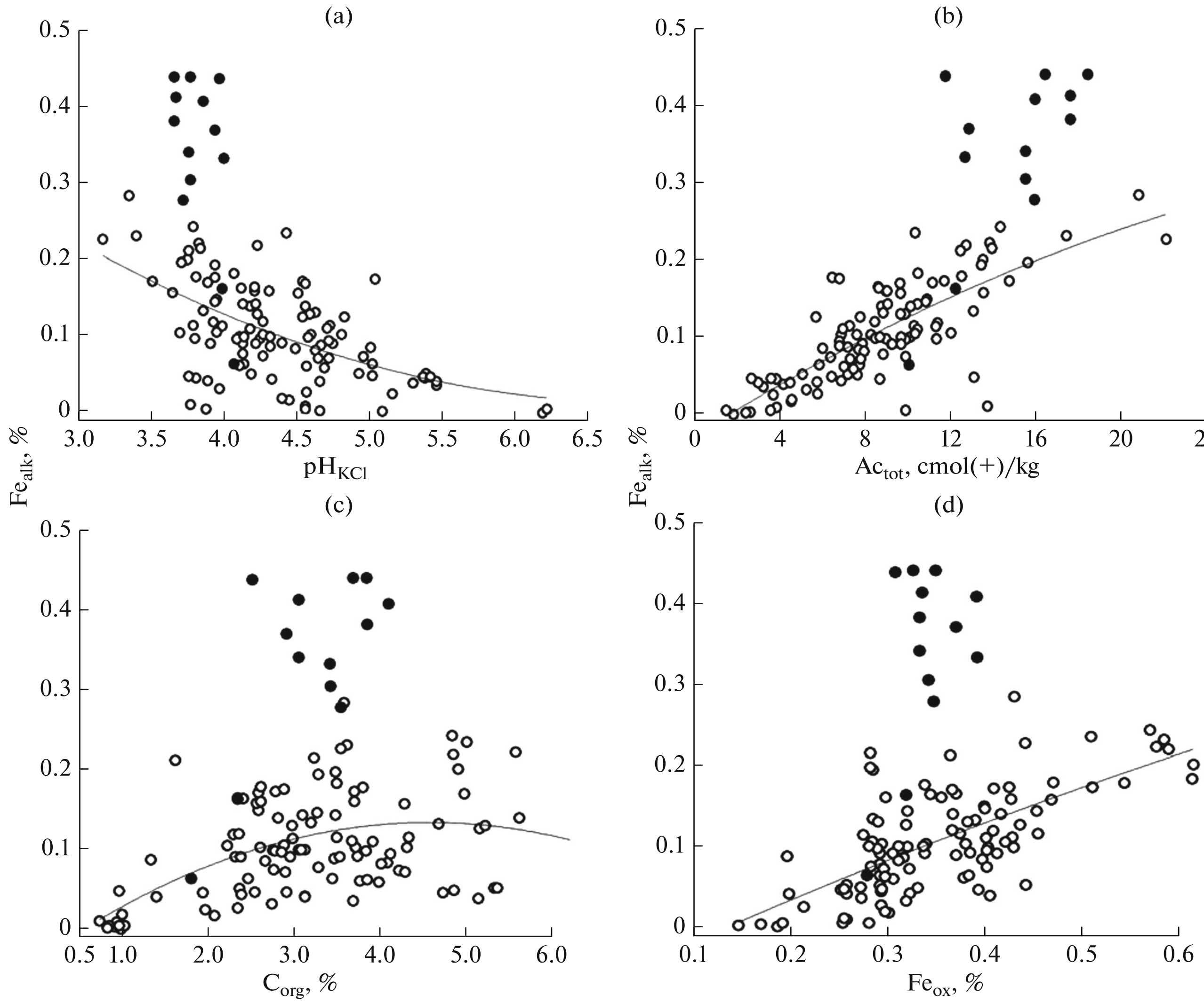

Fig. 2. The impact of (a) pH, (b) Ac_{tot}, (c) C_{org}, and (d) Fe_{ox} on the Fe_{alk} content in soils of the Ai-Petri Plateau.

under beech forest. Some decrease in the amount of Fe_{ox} down the soil profile was also observed in the soil under birch plantation. In the soils under birch and larch plantations, the Fe_{ox} content was close to that in the meadow soils in the lower horizons and was higher in the upper horizons. According to the results of Fe_{ox} determination in top soil layer (0–10 cm), its highest content was in the burozem under beech stand (Table 3). In the soils under artificial forest plantations, no significant increase in the Fe_{ox} content was observed in comparison with the adjacent soils under meadow vegetation.

The results of our study suggest that the alkaline-extractable iron (Fe_{alk}) is the fraction of mobile iron, whose content in the soil depends the composition of vegetation. An increase in its amount (in comparison with that in meadow soils) was noted under all forest species. In the upper part of the profile under the larch plantation, the content of Fe_{alk} was slightly higher than the content of Fe_{ox} and was higher than that in the burozem under beech stand. Thus, we may suppose that a significant part of the amorphous iron in the studied soils has been transformed into organomineral complexes under the impact of forest vegetation, although the mechanism of this process is not quite clear. As in the case of extractable Al, the amount of Fe_{alk} under the larch plantation exceeds the range of its values dispersion depending on the total acidity, pH, C_{org}, and Fe_{ox} (Fig. 2) in the soils of other plots.

According to the results of multiple regression analysis (without data on the soil under larch plantation), the most pronounced impact on the content of Fe_{alk} is exerted by the total (hydrolytic) acidity; the impacts of the contents of Fe_{ox} and C_{org} are much lower (($R = 0.86$; $r_{Ac_{tot}} = 0.70$; $r_{Fe} = 0.39$; $r_C = 0.30$; $n = 105$). However, the Fe_{alk} fraction is obviously bound to the organic matter, which is seen from a sharp decrease in the content of Fe_{alk} down the soil profiles in pits 1332, 1333, and 1352 in parallel to a decrease in the C_{org} content even at high values of the total acidity.

CONCLUSIONS

(1) Approximately 50 years after forest planting on the mountainous meadow soils of the Ai-Petri Plateau, the content of aggregates >10 mm in the upper 10-cm-thick layer under the pine, larch, and birch plantations increased by 3.6, 1.8, and 1.6 times in comparison with that in the adjacent meadow soils.

(2) Pre-planting soil tillage and the change in the composition of vegetation during the creation of forest plantations led to a decrease in the C_{org} content under all tree species. Somewhat higher values of the extinction coefficient ($Ec^{mg/mL}$) of humic acids in comparison with those in the meadow soil were found under the larch plantation. The C_{ha}/C_{fa} values were higher under the larch and pine, which could be due to a more intense accumulation of “young” humic substances with low C_{ha}/C_{fa} values under meadow vegetation and retardation of this process under the forest plantations.

(3) Replacement of meadow vegetation by forest vegetation favored an increase in the soil acidity under all forest species. The sharpest decrease in pH and an increase in the total acidity, the content of exchangeable Al, and its portion among exchangeable bases took place under the larch plantation.

(4) An increase in the soil acidity under the forest species led to an intensive accumulation of Fe_{alk}, its maximum amount was also observed under the larch plantation.

(5) An increase in the exchangeable Al and Fe_{alk} contents under the larch did not correspond to the regularities of changes in these parameters in relation to the increase in the soil acidification under other tree species and under meadow communities. This may attest to a specific nature of the interaction between larch plantations and soils and should be further studied in order to identify the reasons for this phenomenon.

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