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Features of the Macroelement Composition of Plants and Soils in the Zones of Natural Growth of Ginseng (*Panax ginseng* C.A. Meyer) Based on the Study of Forest Ecosystems of the Verkhneussuri Station (Primorsky Territory)

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Abstract—This paper examines certain aspects of the ecological and geochemical specificity of forest ecosystems in the Southern Sikhote-Alin within the natural habitats of ginseng (*Panax ginseng*). Using the territory of the Verkhneussuriysky Biogeocenological Station of the FEB RAS (Primorye Territory) as a case study, the patterns governing the formation of the macroelement composition (Al, Fe, Mn, Ca, Mg, K, Na, P) in dominant plant species, soils, and forest litter are analyzed. The plants exhibit maximum accumulation of K, Ca, P, and Mg, and minimal accumulation of Na. The average content of P and K in the analyzed plant samples surpasses world clarkes by a factor of 2–3 but is 7 times lower in Na content and up to 2.5 times lower in Fe content. Ginseng is distinguished by an elevated content of Fe, Na, and Al, and weak accumulation of Mn and Mg. The element accumulation by plants is closely related to their life form. More actively, woody species accumulate Al and Mn, shrubs accumulate Ca and Mg, while herbaceous species accumulate Na. Compared to world soil clarkes, the soils of the study area are enriched in Na, P, and Mn (by a factor of 1.7–2) but are slightly deficient in Al content (by a factor of 1.3). The accumulation order of chemical elements in soils is headed by Al and Fe, and finished by P and Mn. The litter is characterized by the highest Ca content, which is almost 1.5 times higher than its level in plants and up to 2 times higher than in soil. As for other macroelements, litter is from 3 (Mg, Mn) to 9–10 times (Na, Al) inferior to their content in soils. Compared to plants, the litter is significantly enriched in Al and Fe (up to 40 times or more), as well as Na (up to 20 times), but is close to them in Mg content.

Keywords: geochemical ecology, phytogeochemistry, chemical composition of plants and soils, macroelements, forest litter, *Panax ginseng*, Southern Sikhote-Alin

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INTRODUCTION

The work was carried out on the territory of the Verkhneussuriysk forest station of the Federal Scientific Center of Biodiversity of the Far Eastern Branch of the Russian Academy of Sciences as part of a study of the natural habitats of a relict rare plant of the Russian Far East—true ginseng (*Panax ginseng* CA Meyer). The species is listed in the Red Data Books of the Russian Federation [2024] and Primorsky Krai [2008] with the status of being critically endangered. Due to the great rarity of the species, information about taiga ginseng remains extremely limited, and data on the ecological characteristics of natural habitats are fragmentary. Conservation measures, including the selection of sites most favorable for reintroduction and forest cultivation, as the main methods of preserving ginseng, are complicated by the lack of criteria for optimal habitats. [Zhuravlev et al., 2003; Fedina, Burundukova, 2020].

According to the available literature data, the chemical properties of soils, including the content of a number of macroelements (Ca, Fe, S, Mg, Al, etc.), under conditions of forest cultivation of the genus Panax L. have a positive effect on plant growth, accumulation of biomass and an increase in medicinal compounds in the root [Kim et al., 2015; Thyroff, Griscom, 2019; Pang et al., 2025; Hei et al., 2025]. In some cases, litter from certain tree species is used to optimize soil parameters under ginseng cultivated in forests [Sun et al., 2017].

The aim of our research was to determine the characteristics of the macroelement chemical composition

of the predominant plant species and soils of the forest ecosystems of the station, as one of the original habitats of natural ginseng.

The station was established in 1973 in the Pravaya Sokolovka River basin (a fourth-order right tributary of the Ussuri River) as a monitoring site for conducting routine observations of typical mountain forests in the southern part of the Sikhote-Alin and comprehensive biogeocenotic studies of the area. Over the many years of the station's existence, the cenotic and floristic composition of vegetation, the characteristics of the soil cover and other biotic components of ecosystems, as well as the characteristics of the water regime of local watercourses and the climatic conditions of the territory were studied in detail. The research results are summarized in numerous monographs and collections, scientific journals, dissertations, published mainly in the 70–80s of the 20th century and the beginning of the 21st century. Currently, active research has been resumed at the station to study the features of the global biogeochemical cycle in forest biogeocenoses [Gladkova et al., 2025].

Physical and Geographical Features of the Territory

According to the geobotanical zoning of B.P. According to Kalesnikova (1961), the research region belongs to the Far Eastern (Manchurian) province of cedar-broadleaf and oak forests of the East Asian coniferous-broadleaf region and is part of the Upper Ussuri Mountain-Plain District of cedar and spruce-broadleaf, oak and broadleaf (linden) forests. Soil cover according to the classification of G.I. Ivanova (1964, 1976) corresponds to the Far Eastern brown mountain-forest soils of coniferous-broad-leaved forests and mountain brown-taiga and mountain-podzolic soils of dark coniferous forests.

About 98% of the territory of the Verkhneussuriysk Station (VUS) is covered by forests. The station is characterized by a high diversity of forest formations, due to the highly dissected mountainous terrain (444–1108 m asl), formed predominantly by low- and mid-mountain massifs of the Southern Sikhote-Alin with an average elevation of 500–800 m asl

Detailed and most recent area studies of the vegetation of the Verkhneussuriysk station were carried out in the early 20s of the current century, including the compilation of a geobotanical map of forest vegetation at a scale of 1 : 25000 and a model of the spatial structure of the forest territory of the station was developed [Yakovleva, 2010]. According to the data obtained, the largest area of the station is occupied by cedar-dark coniferous forests with woolly birch, confined to gentle slopes of shady exposures. The steep southern slopes and convex small peaks are covered with oak-cedar forests, while the western and eastern slopes, with moderate heat and humidity, are covered with broadleaf-dark coniferous-cedar and dark coniferous-cedar forests with a large proportion of shrubs.

The soils of the station attracted the attention of many researchers, including such famous soil scientists as S.V. Zonn (1906–2002), A.P. Sapozhnikov (1933–2010) and others. The bulk of soil studies of the area were carried out in the first decades of the station's operation, and the results were summarized in numerous collections from the 70s and 80s of the 20th century. The results of the first area soil survey are presented in the article by G.I. Gavrenkova [1977]. The author identified 4 types of soils: mountain-forest brown soils on deluvial deposits of mountain slopes under coniferous-broadleaf forests, brown taiga illuvial-humus soils on alluvium and deluvium of slopes and tops of watersheds under dark coniferous fir-spruce forests, primitive soils of tops of watersheds and mountain-valley soils on alluvial deposits under valley cedar and elm-ash forests.

Modern soil mapping of the station territory [Bugayets et al., 2021] showed that more than half of its territory (54%) is covered by mountain-forest brown soils (typical brown soils according to the modern classification [Classification..., 2004]) under cedar-broadleaf forests with spruce, underlain by limestone deluvium. They occupy the middle and upper parts of the slopes. On the more gentle middle parts of the slopes, mountain-forest brown podzolized soils (podzolized burozems) on eluvial-deluvial deposits predominate, confined to cedar-broadleaf forests with linden (9% of the territory). The second most common soil types in the territory of the station (18% of the area) are mountain brown-taiga illuvial-humus non-podzolized and podzolized soils (rzhavozems, coarse-humus illuvial-humus typical and podzolized) under dark coniferous forests (spruce-fir with cedar and ferns). They are typically found on the summits of watersheds and steep slopes in the upper and middle parts of mountains. The underlying rocks in these conditions are eluvial and eluvial-deluvial rubble deposits.

RESEARCH MATERIAL AND METHODOLOGY

Two temporary sample plots (SPs) of 500 m^2 each were established on the territory of the research station: SP 1—in the basin of the Berezovy Stream (middle part of a northeast-facing slope of moderate steepness), and SP 2—in the basin of the Pravaya Sokolovka River (middle–upper part of a steep southeast-facing right slope).

At each test site, geobotanical descriptions of vegetation were made and plant and soil samples were collected for chemical analysis. For phytochemical analysis, assimilation organs of edificators and dominants of plant communities were selected, including the above-ground phytomass of herbaceous plants, as well

as leaves and needles of tree-shrub species, as indicators of the annual accumulation of elements. Each sample consisted of a mixed plant sample containing 5-10 individuals of each species. For woody plants, samples were taken from the lower part of the crown, and for shrubs, from the middle part of the bush. To study the chemical composition of the grass and soils, 10-meter plots were laid out in two directions: 5 sites on the slope and 5 along the slope. On each of them, the entire grass stand (hereinafter referred to as mown grass stand) was cut to account for the phytomass and subsequent elemental analysis of its composition, and litter and a soil sample to a depth of 0–15 (20) cm were also taken for analysis.

Among herbaceous plants, in addition to the dominant species, companion species of ginseng found in the test area were also taken for analysis [Grushvitsky, 1961]. Due to the rarity and value of the material being studied, ginseng leaves were collected for analysis in the minimum required quantity and dried as herbarium specimens. For chemical analysis, air-dried mixed samples of 7–10 leaves were used.

The testing was carried out after a 4-5-day rainless period, at the end of the growing season (before the leaves began to turn yellow), corresponding to the time of maximum accumulation of elements. The samples were then dried to an air-dry state and crushed. A mixed sample was taken from the obtained material for chemical analysis. The mown grass stand of meter-sized plots was weighed in wet and air-dry states.

A total of 55 plant samples, 44 forest litter samples and soil samples were collected and analyzed for elemental composition.

Chemical analysis of the collected material was performed in Primorsky Center for Local Elemental and Isotope Analysis of the Far Eastern Geological Institute, Far Eastern Branch of the Russian Academy of Sciences, Vladivostok. Accreditation certificate No. RU.ILC.1.1315.27.

The elemental composition of plant and soil samples (Al, Fe, Mn, Ca, Mg, K, Na, P) was determined by inductively coupled plasma atomic emission spectrometry (ICP-AES) using an iCAP 7600 Duo spectrometer (Thermo Scientific, USA). Sample preparation of the plant material involved microwave digestion with HNO_3, while soil samples were digested with a mixture of acids ($HClO_4$ + HNO_3 + HF).

Statistical processing of the obtained analytical data was carried out using the standard software package Microsoft Excel and STATISTICA 13.

RESULTS

Vegetation Features of the Sample Plots

Test plot 1. Broadleaf-dark coniferous-cedar forest with birch and linden, liana-maple-mixed shrubs, forbs, ferns. Composition of the forest stand: 2K2Lt4Bzh1Pts1Ea + Kl, where K is Korean cedar, Lt is Take linden, Bzh is yellow birch, Pc is whole-leaved fir, Ea is Ayan spruce, Kl are different types of maple.

The territory of the trial plot was covered in the 1960s by selective logging (mainly cedar pine was cut down). The stand is mixed, the overall density is 0.5–0.6. The main forest-forming species are Korean cedar, or Korean pine (*Pinus koraiensis* Siebold et Zucc.[1]), Abies holodets (*Abies holophylla* Maxim.), ribbed birch, or yellow birch (*Betula costata* Trautv.), linden Take (*Tilia taquetii* CK Schneid.). The Ayan spruce is also represented singly (*Picea ajanensis* (Lindl. et Gord.) Fisch. ex Carr.), elm (elm) lobed (*Ulmus laciniata* (Trautv.) Mayr). The lower sub-tier is dominated by elm and ukurundu, or yellow, maples (*Acer ukurunduense* Trautv.), as well as mono, or small-leaved (*A. mono* Maxim.). There are isolated specimens of Maak's bird cherry (*Padus maackii* (Rupr.) Com.).

The shrub layer is well defined, and the density in some areas of the sample plot reaches 40-50%. It is formed mainly by bearded maple (*A. barbinerve* Maxim.), spiny berry (*Eleutherococcus senticosus* (Rupr. et Maxim.) Maxim.) and mock orange (*Philadelphus tenuifolius* Rupr. et Maxim.). There are isolated bushes of Manchurian currant (*Ribes mandshuricum* (Maxim.) Kom.) and Maksimovich (*R. maximoviczianum* Kom.), as well as Amur barberry (*Berberis amurensis* Rupr.).

The bushes are intertwined with numerous vines of two species—actinidia kolomikta (*Actinidia kolomikta* (Maxim.) Maxim.) and Schisandra chinensis (*Schisandra chinensis* (Turkish) Baill.), which sometimes form dense thickets that are difficult to penetrate.

The average projective cover of the herbaceous layer is 20–25%. It is formed by ferns (*Adiantum pedatum* L., *Gymnocarpium dryopteris* (L.) Newm.), *Dryopteris crassirhizoma* Nakai), which dominate the herbage. Other species include the filamentous thalictrum (*Thalictrum filamentosum* Maxim.), New Manchurian Line (*Neomolinia mandshurica* (Maxim.) Honda), missed ripeness (*Cacalia praetermissa* (Pojark.) Pojark.), Clintonia udica (*Clintonia udensis* Trautv. et Mey), Selkirk violet (*Viola selkirkii* Pursch ex Goldie), common wood sorrel (*Oxalis acetosella* L.), heart-leaved two-petal (*Circea cordata* Royle) and a whole range of other species with single participation, including ginseng.

Air-dry weight of grass stand of a 1 m^2 area makes up, on average, 5.0 g (varies across 10 survey sites from 1.8 to 10.7 g; variation coefficient—56%). The average natural moisture content of the grass stand is 24% (varies from 13 to 40%; variation coefficient is 31%).

[1] The names of plants are given according to the summary "Vascular plants... [1985–1996]".

Table 1. The content of macroelements in plants of the Verkhneussuriysk station

Statistical indicators	Content of chemical elements in plants (mg/kg dry matter)							
	K	**Ca**	**P**	**Mg**	**Mn**	**Al**	**Fe**	**Na**
Average content in woody plants ($n = 12$)	9832	9557	2048	1517	292	196	84	34
Average content in shrub species ($n = 10$)	28869	28779	3411	3268	258	93	116	53
Average content in woody vines ($n = 2$)	31554	17281	2787	2673	116	46	48	47
Average content in mown grass ($n = 12$)	30001	17689	3499	2879	102	134	118	64
Overall average content ($n = 55$) ± SEM	25309 ± 1458	17166 ± 1115	3124 ± 142	2623 ± 118	185 ± 28	119 ± 15	99.3 ± 5.1	68.4 ± 6.4
Minimum content	5333	2836	1305	824	40	18	33.7	1.1
Maximum content	49702	35776	7294	5063	1325	573	212.1	230.5
Coefficient of variation, %	43	48	34	33	114	91	38	69

Test plot 2. Broadleaf-dark coniferous-cedar forest with liana-mock orange-variegated shrubs, sparse ground cover and grassy cover. Composition of the forest stand: 3K3Bzh2La1Ea1Pts.

The overall density of the stand is 0.4–0.5. The forest stand is represented by Korean cedar, ribbed birch, Amur linden (*Tilia amurensis* Rupr.) with occasional participation of Ajan spruce and Abies holodeckii. The lower sub-tier is formed by mono- and green-barked maples (*Acer tegmentosum* Maxim.). The undergrowth is dominated by fir, cedar pine, lobed elm, and mono maple. Many drying specimens of Ayan spruce up to 5 m in height have been noted.

The shrub layer is well defined and abundantly intertwined with vines. The most common plant in the trial plot is the thin-leaved mock-orange, which forms continuous thickets in certain areas of the trial plot. Much less frequently found in the test area are other species: bearded maple, prickly freeberry, Manchurian hazel (*Corylus mandshurica* Maxim.), Manchurian and Maximovich currants, golden-flowered honeysuckle (*Lonicera chrysantha* Turcz. ex Ledeb). Among the vines, the following are noted: Chinese magnolia vine, actinidia kolomikta and Amur grape (*Vitis amurensis* Rupr.). The abundance of vines increases higher up the slope (at the upper boundary of the test plot).

The total projective cover of the herbaceous layer does not exceed 15 (20)%, decreasing in some areas to 10% or less. The species composition of the grass stand is represented by the following species: cut twig (*Rhabdosia excisa* (Maxim.) Hara), common touch-me-not (*Impatiens noli-tangere* L.), missed unripeness (*Cacalia praetermissa* (Pojark.) Pojark.), Asian frima (*Phryma asiatica* (Hara) Probat.), Dahurian bedstraw (*Galium davuricum* Turcz. ex Ledeb.), New Manchurian Line, common wood sorrel (*Oxalis acetosella* L.), maidenhair fern (*Adiantum pedatum*), Maynik two-leaved (*Maianthemum bifolium* (L.) FW Schmidt). Single specimens of the thick-rhizome shield fern (*Dryopteris crassirhizoma*), common golokuchnik (*Gymnocarpium dryopteris*), black cohosh (*Actaea acuminata* Wall. ex Royle), heart-leaved madder (*Rubia cordifolia* L.) and a number of other species.

Along a geological fissure with a temporary watercourse, running along the eastern side of the test area, narrow-leaved nettle grows abundantly (*Urtica angustifolia* Fisch. ex Hornem.), common touch-me-not, Amur leptorumora (*Leptorumohra amurensis* (Christ) Tzvel.).

Average air-dry weight of grass stand of a 1 m m m m m^2 is 8.0 g (varies across sites from 3.5 to 11.6 g; variation coefficient is 34%). The average natural moisture content of the grass stand is 23% (varies in the test area from 14 to 29%; the variation coefficient is 18%).

According to the 1 : 50000 digital soil map of the Verkhneussuriysk station territory [Tereshkina et al., 2019], mountain-forest brown soils (according to the modern classification—typical brown soils) are widespread in the test plots.

Elemental Composition of Plants

Statistical indicators of the macroelement composition of the analyzed sample of plants are given in Table 1.

Maximum contents were found in the content of K and Ca—some of the main chemical components of living matter on land. The greatest range of values, according to the data in Table 1, is characteristic for

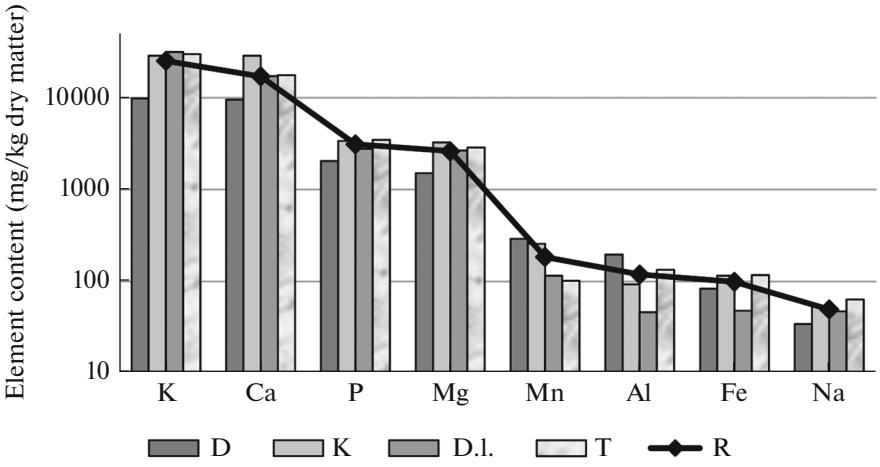


Fig. 1. The content of elements in different life forms of plants. D—trees, K—shrubs, D.l.—woody vines, T—mown grass stand, P—average content of VUS in plants.

the content of Mn and Al. Moreover, the maximum Mn content was recorded in the leaves of Manchurian hazel, and the minimum in the above-ground phytomass of filamentous meadowsweet at SP 2. The highest Al content is found in the needles of Abies solifola (SP1), the minimum is found in the leaves of Aralia elata (*Aralia elata* (Miq.) Seem.) on the territory of the hospital base. It is also interesting to note that ginseng (family Araliaceae Juss.) is the leader among the tested plant samples in terms of accumulation of Na and Fe (SP 2), and Clintonia udica (family Asparagaceae Juss.)—K, Ca and Mg (SP1).

The elemental composition of plants, as our studies have shown, depends not only on the species composition, but also on the life form of the plants (Fig. 1).

The ecological and geochemical characteristics of the tree species in the study area are expressed in a greater accumulation of Al and Mn, shrubs—Ca and Mg, and herbaceous species—Na. Lianas accumulate K, Ca and Mg only relative to trees, but have the lowest contents of Al and Fe.

Using the data we obtained on the biomass of the grass stand of the mown areas, the balance of macronutrients in grams per 1 hectare of forest area was calculated. It can be represented by the following ranked series in decreasing order of mass of elements (g/ha): K (1216) > Ca (749) > P (149) > Mg (118) > Al (6.4) > Fe (5.1) > Mn (4.2) > Na (0.42). These indicators are in full agreement with the previously obtained materials of A.F. Kostenkova [1984]. It indicates a high content of potassium (up to 0.31 kg/ha) and calcium (up to 0.38 kg/ha) in the ground cover of VUS and minimal accumulation of sodium (0.009 kg/ha).

Ecological and Geochemical Specifics Leaves Panax Ginseng

The specificity of the chemical composition of ginseng was assessed both in relation to the elemental composition of the VUS vegetation as a whole, and in comparison with herbaceous species, including its companion species and the general composition of the grass stand (using the example of mown areas). It was found that ginseng differs from the general macroelement composition of VUS vegetation by its increased content of Fe and Na (almost 2 times), Al (1.6 times), but is up to 3 times inferior in the amount of Mn and up to 1.5 times inferior in Mg.

It is also interesting to note that ginseng, in comparison to woody plants, only slightly accumulates K and P, but is significantly inferior to them in Mn content, which is quite consistent with the ecological and chemical characteristics of herbaceous plants in general.

The similarity of the macroelement composition of ginseng with herbaceous species is most clearly expressed in the close content of K, Ca, Na and P. Its species specificity was manifested in the enrichment of Fe and Al and the dispersion of Mn and Mg. At the same time, relative to the mown grass stand, ginseng accumulates Na (almost 2 times), Al and Fe (up to 1.5 times), but disperses Mg and Mn (up to 1.7 times). Similar patterns were obtained when comparing ginseng with its herbaceous companion species, with the only difference being that it even more actively accumulates Al (2.6 times) and Fe (1.8 times) and disperses Mn and Mg (almost up to 2 times).

Among companion species, the closest associative links, regardless of habitat conditions, were established in *Panax ginseng* with the following types: *Oxalis*

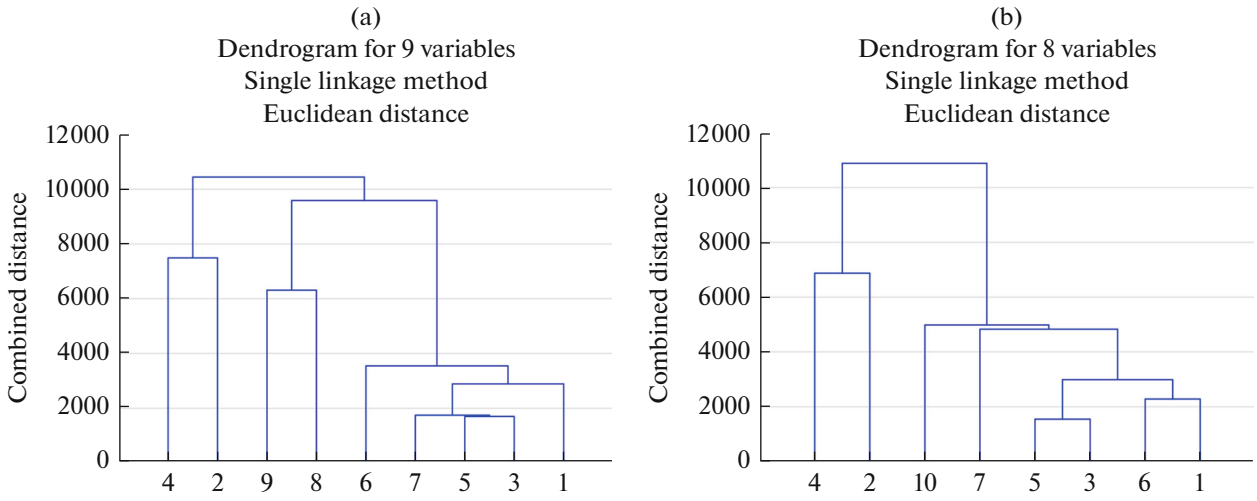


Fig. 2. Dendrograms of associative relationships of the chemical composition of ginseng and its companion species on SP 1 (a) and SP 2 (b). (1) *Panax ginseng*, (2) *Adiantum pedatum*, (3) *Maianthemum bifolium*, (4) *Neomolinia mandshurica*, (5) *Oxalis acetosella*, (6) *Phryma asiatica*, (7) *Thalictrum filamentosum*, (8) *Viola selkirkii*, (9) *Clintonia udensis*, (10) *Galium davuricum*.

acetosella, *Maianthemum intermedium* and *Phryma asiatica* (Fig. 2).

If we compare the species of the Araliaceae family (*Aralia elata* (Miq.) Seem., *Eleutherococcus senticosus*, *Panax ginseng*) with the rest of the species composition of plants, their phytogeochemical specificity is manifested in a significant enrichment of Ca (1.6 times) and an insignificant accumulation of Fe, P and Na (up to 1.3 times) with a simultaneously lower content of Mn (up to 1.4 times). At the same time, Araliaceae are identical to the other species in the sample in terms of Al, K and Mg content.

Elemental Composition of Soils

According to the data obtained, the chemical composition of soils is more stable compared to plants. The variability of the content of elements depending on the sampling location does not exceed 30% (Ti). The main statistical indicators of chemical elements in the studied soils are given in Table 2.

In contrast to plants, the highest contents are recorded in the content of Al and Fe—elements that dominate the chemical composition of the continental crust.

Correlation analysis performed for the composition of macroelements in VUS soils allowed us to establish the closest positive relationships between the following elements: Ti and Fe ($r = 0.95$), Ti and Mg ($r = 0.91$), Mg and Na ($r = 0.91$).

Elemental Composition of Litter

The average content of macroelements in litter (in mg/kg dry matter) can be represented by the following descending order: Ca (24828) → Al (5374) → Fe (4280) → K (3135) → Mg (2493) → P (1544) → Na (1161) → Mn (605). It should be noted that the litter in

Table 2. The content of macroelements in the soils of the Verkhneussuriysk station

Statistical indicators	Content of chemical elements in soils (*mg/kg dry matter*)								
	Al	Fe total	K	Ca	Na	Mg	Ti	P	Mn
Average content ($n = 12$) ± error of the mean	56041 ± 671	34670 ± 1548	16868 ± 407	13259 ± 882	10574 ± 388	7846 ± 510	5210 ± 459	1763 ± 61	1717 ± 34
Minimum content / Maximum content	50603 / 58697	26492 / 43688	14599 / 19136	9424 / 17889	8793 / 13000	5590 / 11409	3063 / 8039	1421 / 2067	1478 / 1922
Coefficient of variation, %	4	15	8	22	13	23	30	12	7

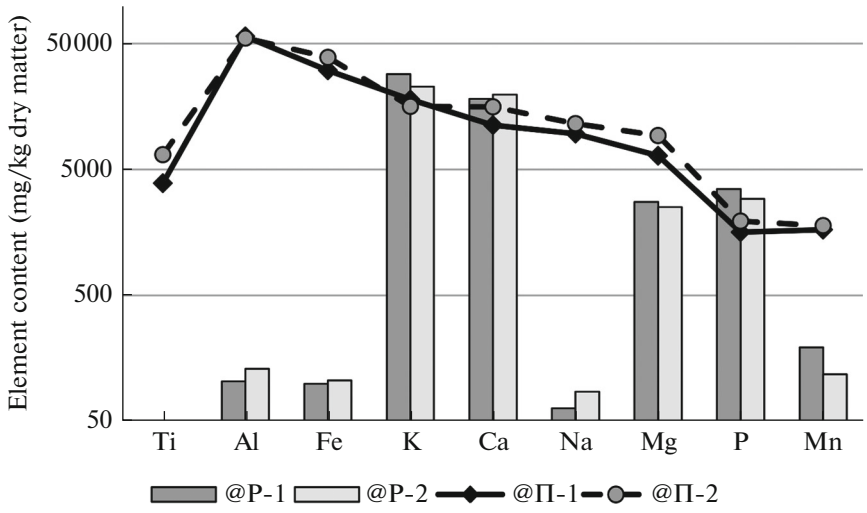


Fig. 3. Comparative assessment of the content of elements in soils (P) and plants (P) of sample plots 1 and 2.

the test plots was predominantly coniferous and deciduous.

The highest variability across the survey sites was noted for the Fe content (1713–11625 mg/kg): the variation coefficient was 76%. The most stable values are for Ca (28320–22617 mg/kg) and P (1703–1365 mg/kg): variation coefficients are 7 and 8%, respectively.

An analysis of the quantitative ratio of elements in litter and surface soil horizons indicates that most of the compared elements are dispersed in litter from 3 (Mn, Mg) to 8–10 times (Fe, Na, Al). There are 2 exceptions to this rule: P—with similar contents in litter and soil, and Ca, the concentration of which in litter is almost 2 times higher than its level in soil. It is also interesting to note that Ca turned out to be the only element whose content in litter was higher, both relative to soil (2-fold) and plants (1.5-fold).

If we compare the quantitative composition of elements in litter and in plants, then litter exceeds plants in most of the analyzed elements. These excesses are especially significant in the content of Al—up to 40 times in grass and almost up to 38 times in the leaves and needles of woody plants and shrubs, as well as Fe—up to 36 and 46 times, respectively. In addition, a 20–30-fold accumulation of Na and a 4-fold accumulation of Mn were noted in the litter. Close values between litter and plants were recorded only in the Mg content: 2493 mg/kg in litter and 2623 mg/kg according to average values in plants. However, litter is inferior to plants in P content up to 2 times, and also K—up to 6 times in woody plants and up to 10 times in herbaceous plants.

Comparative Ecological and Geochemical Assessment of Test Plots

A general analysis of the data obtained for the two surveyed test plots made it possible to establish some differences not only in location and geomorphological features, vegetation composition, as shown above, but in a number of cases also in the amount of macroelements contained in soils and plants. For example, approximately half of the analyzed composition of elements in SP 2 soils exceeds, to varying degrees, the same elements that form the composition of SP 1 soils (Fig. 3). The maximum superiority was noted for Ti—almost twofold. To a lesser extent, this pattern holds true for Fe, Mg and Ca—1.3–1.4 times higher. Only the contents of Al, Mn and K were stable.

Somewhat different patterns were noted when analyzing the macroelement composition of plants (Fig. 3). Vegetation SP 1 accumulates Mn more actively (up to 1.6 times) and less significantly K (1.3 times); SP 2—Na (1.4 times) and Al (1.3 times). The greatest differences are observed in tree and shrub species: more than 2-fold excess of Mn in SP 1 and Na in SP 2. Herbaceous plants (mown grass stand) SP 1 exceed SP 2 grasses in Na and Mn content (up to 1.7 times), but are inferior in Ca content (1.5 times). Only the contents of Fe, Mg, K and P in plants from different habitats were practically the same. It should be noted that the P content was stable in both plants and soils.

Ginseng leaves in SP 2 environmental conditions more actively accumulate all analyzed elements except K and P, but the maximum is Na (19 times) and Al (6 times). Next come Fe (2 times), Mg (1.7 times), Mn (1.5 times) and Ca (1.3 times).

Half of the studied elements in the litter samples at SP 2 also had higher chemical indices than in the SP 1 samples, including: Fe—more than 2 times; Na, Al

Table 3. The intensity of accumulation of chemical elements by plants of the Verkhneussuriysk station

Biological absorption series of chemical elements*	Elements	KBP*	KBN	
			SP 1	SP 2
Strong biological accumulation	P	$n \times 10$–$n \times 100$	2.2	1.6
Strong biological accumulation	Na	$n - n \times 10$	1.6	2.1
Strong biological accumulation	Mg	$n - n \times 10$	1.5	2.2
Average biological capture	Ca	$n - n \times 10$	0.45	0.13
Weak biological capture	Mn	0, $n - n$	0.11	0.06
Very weak biological capture	K	$n - n \times 10$	0.007	0.005
Very weak biological capture	Fe	0, n	0.003	0.003
Very weak biological capture	Al	0, $n - 0.0\,n$	0.002	0.002

* Classification by A.I. Perelman [1979].

and Mg—about 1.5 times. The contents of Ca and P were equal, and K and Mn were close.

Intensity of Biological Accumulation of Chemical Elements

To assess the intensity of accumulation of elements, the biological accumulation coefficient (BAC) was used. It is calculated as the ratio of the element's content in the plant to its content in the soil. Summarized data on the KBN of VUS plants are given in Table 3.

In the sample of plants we compared, the CBN changed over a wide range of values: from 0.001 (Al) to 2.7 (Na). According to the "Series of biological absorption of chemical elements by living organisms on land" in the geochemical classification of A.I. According to Perelman [1979], these indicators correspond to elements of weak biological capture (Al) and strong biological accumulation (Na).

Trees and shrubs, compared to herbaceous species, more actively accumulate Mn (2.2 times) and Ca (1.6 times) from the soil, while grass stands accumulate Na (1.9 times) and K (1.4 times).

Among the species composition of plants, the highest values of KBN on SP 1 were noted in Clintonia udica in the accumulation of P (KBN = 4.6) and Ca (KBN = 0.8). Under these conditions, Korean pine accumulates Mn (CBP = 0.52) and Al (CBP = 0.010) more intensively than other tested species, filamentous meadowsweet accumulates K (CBP = 0.017), and Manchurian currant accumulates Fe (CBP = 0.006). At SP 2, the maximum CBN were recorded in Manchurian currant in the accumulation of Mg (CBN = 3.7) and Na (CBN = 3.3), and in thin-leaved mock orange—P (CBN = 2.6). Common wood sorrel and Maximowicz's currant accumulate Mn more actively than other species: KBN = 0.15 and KBN = 0.14, respectively. In addition, wood sorrel, along with the mown grass stand, showed high accumulative capacity for Ca (KBP = 0.2).

Ginseng primarily accumulates P (KBN = 2.3), Na (KBN = 2.1), Mg (KBN = 1.8) from the soil. Moreover, the intensity of P accumulation is the highest among the compared sample of plants. Particularly active accumulation of P was noted at SP 1 (KBP = 2.6), and Na (KBP = 2.6) and Mg (KBN = 2.2)—at SP 2. In addition, ginseng on SP 2 absorbs Fe (KBN = 0.005) and K (KBN = 0.015) to the maximum among the tested floristic composition, which is 2 and 3 times higher, respectively, than the average values of the coefficient for the test plot.

DISCUSSION

Basic Patterns of Formation of the Elemental Composition of Plants

Judging by the available literary data [Bowen H., 1966; Romashkevich E.A., 1988; Dobrovolsky V.V., 1998] and the spectra of element contents shown in Fig. 4, the plants of the station exceed the world clarkes in potassium (2–3 times) and phosphorus (almost 2 times), but are significantly inferior to them in the content of sodium (7–17 times relative to the clarke values given by different authors) and iron (up to 2.5 times).

The established distinctive features in the accumulation of elements by different life forms of plants are largely determined by the sizes of their above-ground and underground organs and, consequently, the different areas of interaction with the environment and the potential for the accumulation of chemical elements, as well as the species-specific biogeochemical specificity of plants.

If we compare woody plants (trees, shrubs, vines) and herbaceous plants (Table 1, Fig. 1), the greatest differences are observed in the significant accumulation (up to 2 times) of Mn in woody plants (125 mg/kg versus 263 mg/kg), and Na in herbaceous plants (43 mg/kg versus 88 mg/kg). To a lesser extent (1.5 times), this pattern is preserved in woody plants in relation to Al, and in herbaceous plants—for K.

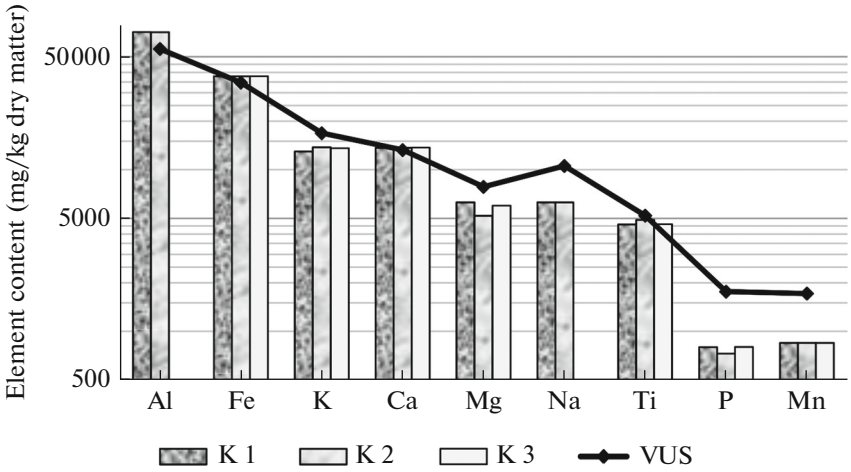


Fig. 4. Spectra of chemical elements in VUS plants (solid line) relative to their clarke values (dashed lines).

The high content of Mn in woody plants (especially conifers) is usually associated with the high content of tannins—tannins that activate intracellular metabolism and regulate the oxidation-reduction processes of these species [Levanidov L.Ya., Davydov S.T., 1961].

According to the results of studies of herbaceous plants, mown grass and ginseng companion species differ little in the activity of macronutrient accumulation. However, when assessing the characteristics of accumulation of chemical elements by herbaceous plants in general, the mown grass stand is a more accurate indicator of the ecological and geochemical conditions of the environment.

It is also interesting to note that ginseng leaves under VUS conditions, compared to our previously obtained data on the elemental composition of leaves in several natural ginseng populations in Primorsky Krai [Shikhova et al., 2020], significantly exceed them in P content (3914 mg/kg under VUS conditions and 1100 mg/kg on average for Primorsky Krai) and, less significantly, K (29555 and 21000 mg/kg, respectively). At the same time, they are inferior in terms of Ca content (18500 mg/kg in the VUS territory and 36000 mg/kg on average in Primorye) and Mg (1717 and 2200 mg/kg, respectively). This demonstrated the population geochemical specificity of ginseng in the territory of the hospital.

Regional Features of the Elemental Composition of Soils VUS

Unfortunately, from the extensive database of literary sources on vegetation and soils of VUS, published mainly in the 70–80s of the 19th century, there was very little data that could be used for comparison with what we obtained. There are many reasons for this: primary data on many of the test plots established when the station was founded have been lost; specialists who worked at the station for many years and who could have provided the necessary clarifications have passed away; chemical analysis methods and sensitivity have changed significantly, leading to significant errors when comparing results, etc.

To compare our results with similar data from other researchers, we nevertheless used some literary sources. In the monograph of the famous Far Eastern soil scientist G.I. Ivanova [Soil formation..., 1976] provides materials on the gross composition of soils in Primorsky Krai and the southern part of the Far East. According to the data of the monograph, the soils of the station are inferior in the gross composition of most elements (especially Na_2Oh, Al_2O_3, Fe_2O_3) 1.5–2 times higher than the mountain brown forest soils of the Far East, surpassing them only in content P_2O_5 (up to 1.5 times).

To assess the iron content in the soils of the station and other regions, data from the general monograph by S.V. Zonna [Iron..., 1982]. According to the materials contained in it, the total content of Fe, depending on the type of soil and genetic horizon, varies over a wide range of values: in soils of the world—within 0.92–52.5%, in soils of the Far East—4.39–7.58%. Our statistical analysis of the factual material contained in the monograph on the accumulation of Fe in the upper horizons of soils around the world showed that its average content (52 values) is 9.46% and varies from 0.65% to 18.3%, which is almost 3 times higher than the average Fe content in VUS soils and up to 4 times higher than the maximum values.

Figure 5 shows the spectrum of macroelements of the soils we studied and the clarke constants for soils of the world according to data from different authors.

It should be noted that at present, a unified global reference soil standard has not yet been developed, nor has a regional soil standard for Primorsky Krai. For a comparative assessment of the obtained data, the Clark of the world soils of A.P. is most often used.

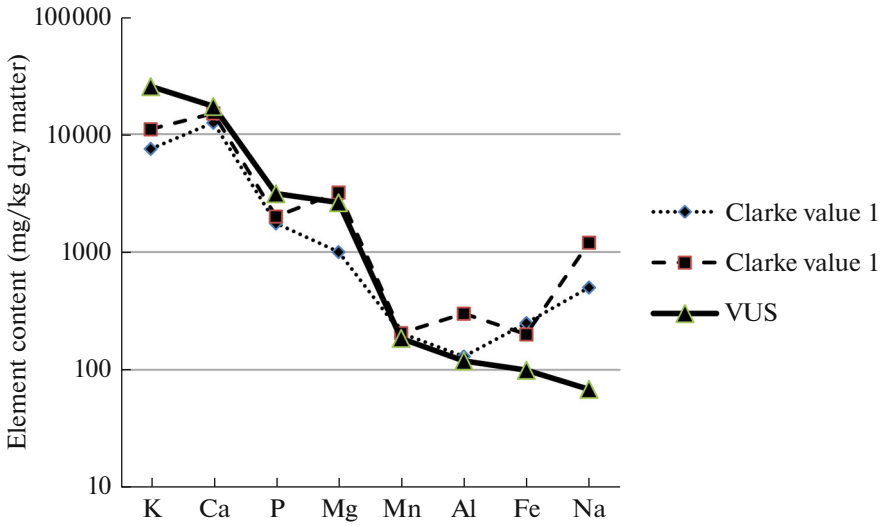


Fig. 5. Average content of macroelements in VUS soils and their clarke indices (K). VUS—Verkhneussuriysk hospital, Clark 1—according to A.P. Vinogradov (1957), Clark 2—according to E.V. Sklyarov and others. (2001), Clark 3—by A.H. Sheujen (2018).

Vinogradov [1957] and its variants, slightly modified in a number of elements, presented in the works of other authors [Beus et al., 1976; Sklyarov et al., 2001; Sheudzhen, 2018, etc.]. If we compare the content of elements in the soils of the station with the clarkes of the world's soils, we observe a very significant enrichment of P (2.2 times), Mn (2.0 times), Na (1.7 times), and to a lesser extent K (1.3 times), but a slight depletion of Al (1.3 times). The contents of Ca, Ti and Fe are close to the clarkes of the world's soils.

Regarding the assessment of the Mn content in the soils of the stationary site, some clarification is necessary. In the work of the Far Eastern soil scientist V.I. Head [Contents..., 2010] provides, along with 10 microelements, the regional clarke of soils in the Far East for Mn, which is 1510 mg/kg dry matter. Consequently, the Mn content in the surveyed VUS soils significantly exceeds the world soil clarke, but is very close to the regional soil clarke.

When comparing the soils of the station with the soils of Russia and neighboring countries [Kudrin, 1963; Beus et al., 1976] A similar quantitative composition was noted for most elements. The only exceptions are the contents of Pb, Mn and Ti, which are 1.5–2 times higher than the values given by the authors for other Russian territories.

The differences found in the chemical composition of soils and plants in the surveyed test plots (Fig. 3) are due to a number of reasons. In addition to the above-mentioned features of geomorphology and vegetation composition, the primary reason may be some uniqueness in the geological conditions of the compared territories. It is known that the composition of the parent rocks on which soils are formed largely determines their chemical content.

According to literary data [Triassic..., 2004], the underlying rocks of the soils of SP 1 are represented by deposits of the Norian stage of the Triassic (T_3)—sandstones, gravelstones, conglomerates, siltstones, siliceous rocks. The soils of SP 2 are formed on the rocks of the Okrainskaya suite of Jurassic deposits ($J_{1\text{-}2}$ ok)—fractured sandstones, siltstones with fragments and blocks of limestone, flint, gabbroids, siliceous rocks, tuffs and lavas of basic composition.

Undoubtedly, the specified specificity of the compared test plots was reflected not only in the formation of the chemical composition of soils, but also of plants. However, in our opinion, the composition of the litter was influenced to a greater extent by the characteristics of the species composition of the phytocenoses of the sample plots.

A.P. points out the high content of Ca and P in the litter of spruce-broadleaf forests of Southern Primorye. Sapozhnikov [1973], but their total stock in litter is determined by the species composition of the main forest-forming organisms. For example, despite the fact that Ca accumulates in the litter of all species, its content in the coniferous litter of fir trees is higher than in the leaf litter of linden, birch and oak. Unlike Ca, the P content in the litter of coniferous and deciduous trees is almost the same. The accumulation of Mg is observed only in the coniferous litter of spruce and cedar, as well as in the leaf litter of birch.

Features of Biogenic Migration of Chemical Elements in the VUS Territory

The concentration of elements in plants is ultimately determined by the absorption capacity of plants and the subsequent involvement of elements in their metabolic and growth processes. According to

the summary data contained in the Table 3, the studied area presents an almost complete spectrum of biological accumulation of elements—from very weak biological capture (Al, K, Fe) to strong biological accumulation (Mg, Na, P).

Some differences in the accumulation of elements by plants under different growing conditions are noteworthy: P, Ca, Mn and K are more actively accumulated by plants on SP 1, which is characterized by a large presence of maples in the tree stand and a mixed-herb-fern lower tier, and Na and Mg—on SP 2, which is characterized by sparse grass cover and a high proportion of participation in the shrub layer mock orange.

In general, in comparison with the geochemical classification of A.I. According to Perelman [1979], the composition of plants and soils studied by us, VUS, accumulates Ca, Al and P from the soil less (approximately by an order of magnitude), Fe much less (almost by 2 orders of magnitude), but K especially less (by 2–3 orders of magnitude). Such differences are caused, in our opinion, to a large extent by the different values used in calculating the indicators of biological activity of plants. Classification of A.I. Perelman's model is based on data characterizing the average chemical composition of the ash of living organisms on the planet relative to the clarkes of the solid earth's crust. Our research is based on the air-dry composition of plants and soils.

CONCLUSIONS

The patterns of formation of the macroelement composition of plants, litter and soils of forest ecosystems of the Verkhneussuri biogeocenotic station (Primorsky Krai), as one of the characteristic places of natural growth of real ginseng, were studied. *Panax ginseng*) within the Southern Sikhote-Alin.

It was established that plants in the studied area accumulate maximum K (25309 mg/kg dry matter), minimum Fe (99 mg/kg) and Na (68 mg/kg); forest litter accumulates Ca (24828 mg/kg) and Mn (605 mg/kg), respectively. The soils showed the highest content of Al (56041 mg/kg) and Fe (34680 mg/kg), but low content of P (1763 mg/kg) and Mn (1717 mg/kg).

Compared with global clarkes, the studied floristic composition is distinguished by an increased content of K (up to 3 times) and P (2 times), but is inferior in the content of Na (7 times) and Fe (up to 2.5 times). The chemical composition of plants largely depends on their biomorphic affiliation: woody species are characterized by a high accumulation of Al and Mn, shrubs by Ca and Mg, and herbaceous species by Na. In this regard, when conducting comparative assessments of vegetation cover, it is more appropriate to compare similar life forms of plants. When assessing the characteristics of accumulation of chemical elements by herbaceous plants, a more accurate indicator of the ecological and geochemical conditions of the environment is the mown grass stand.

The ecological and geochemical specificity of ginseng was manifested in comparison with the general macroelement composition of the stationary vegetation in the increased content of Fe and Na (almost 2 times), as well as Al (1.6 times), but lower Mn (up to 3 times) and Mg (up to 1.5 times). When comparing ginseng with herbaceous plants, a similar pattern in the accumulation and dispersion of elements was noted, but less pronounced in quantitative terms. Of the herbaceous companion species of ginseng, the closest to it in chemical composition are *Oxalis acetosella*, *Maianthemum intermedium* and *Phryma asiatica*.

The soils of the station, relative to the clarke of the world's soils, are enriched with P (2.2 times), Mn (2.0 times), Na (1.7 times), and slightly with K (1.3 times), but are somewhat inferior to them in terms of Al content (1.3 times). In soils, to a greater extent than in plants, heterogeneity in the macroelement composition of the two surveyed areas is observed. At SP 2, compared to SP 1, an increased content of more than half of the elements was recorded, especially Ti and Ca (1.7–1.8 times), and to a lesser extent Fe and Mg (1.3–1.4 times).

Forest litter significantly exceeds plants in the balance of most elements, especially in the amount of Al, Fe and Na (20–40 times or more), but is inferior to soils in all elements except Ca and P from 3 (Mn, Mg) to 8–10 times (Fe, Na, Al). At the same time, litter is close to plants in Mg content, and to soils in P content. The Ca content in litter alone is 2 times higher than its level in soil and up to 1.5 times higher than in plants.

The intensity of biological accumulation of elements by plants varies in a wide range of values: from KBN = 0.001 (Al is an element of weak biological uptake) to KBN = 2.7 (Na is an element of strong biological accumulation). Vegetation of the station compared with the series of biological absorption of elements by A.I. Perelman [1979] found that Ca, Al and P accumulate approximately an order of magnitude less, Fe significantly less (almost 2 orders of magnitude), and K especially less (2-3 orders of magnitude).

Ginseng accumulates P (CBP = 2.3), Na (CBP = 2.1) and Mg (CBP = 1.8) from the soil more intensively than other species, the values of which correspond to elements of strong biological accumulation. In addition, it accumulates K (KBN = 0.008) more than 2 times more actively than other species and Fe (KBN = 0.005) up to 1.5 times more actively.

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AUTHOR CONTRIBUTION

Shikhova N.S. She took direct part in collecting field material, primary processing and preparation of soil and plant samples for chemical analysis, systematization of field research results and obtained analytical data, and their generalization in the form of an article manuscript.

Burundukova O.L. participated in organizing field research, collecting field material, and preparing the manuscript for publication.

Zarubina N.V. was responsible for chemical analytical studies of soil and plant samples.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This work does not contain any human or animal studies.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflict of interest.

REFERENCES

Beus, A.A., Gribovskaya, L.I., and Tikhonova, N.V., *Geokhimiya okruzhayushchei sredy* (Geochemistry of the Environment), Moscow: Nedra, 1976.

Bowen, H.J.M., *Trace Elements in Biochemistry*, New York, London: Academic, 1966.

Bugaets, A.N., Pshenichnikova, N.F., Tereshkina, A.A., Lupakov, S.Yu., Gartsman, B.I., Shamov, V.V., Gonchukov, L.V., Golodnaya, O.M., Krasnopeev, S.M., and Kozhevnikova, N.K., Digital soil mapping for hydrological modeling by the example of experimental catchments in the South of Primorsky Krai, *Eurasian Soil Sci.*, 2021, vol. 54, pp. 1375–1384.

Dobrovolskiy, V.V., *Osnovy biogeokhimii* (Fundamentals of Biogeochemistry), Moscow: Vyssh. Shk., 1998.

Fedina, L.A., and Burundukova, O.L., *Panax ginseng* (Araliaceae) in the South Sikhote-Alin spurs: Gavrenkov, G.I., On the characteristics of soils at the Verkhne-Ussuriysk field station, in *Statsionarnye Issledovaniya v Lesakh Sikhote-Alinya* (Stationary Studies in the Forests of Sikhote-Alin), Vladivostok: Dal'nevost. Nauchn. Tsentr Akad. Nauk SSSR, 1977, pp. 18–25.

Gladkova, G.A., Sibirina, L.A., Omelko, A.M., Zhmerenetskiy, A.A., Ukhvatkina, O.N., and Kuprin, A.V., Formation and fractional composition of forest litterfall in broadleaved-Korean pine forests of the southern Sikhote-Alin, *Lesovedenie*, 2025, no. 5, pp. 643–655.

Golov, V.I., Content of trace elements and heavy metals in arable soils of the Russian Far East, *Vestn. Ross. Akad. S-kh. Nauk*, 2010, no. 4, pp. 16–19.

Grushvitskiy, I.V., *Zhenshen: voprosy biologii* (Ginseng. Questions of Biology), Leningrad: Akad. Nauk SSSR, Sib. Otd. Dal'nevost. Fil. im. V.L. Komarova, 1961.

Hei, J., Li, Y., Rui, R., Faisal, N., Peng, J., Wang, B., Wang, S., and He, X., The cultivation of *Panax notoginseng* enhances the metabolites and microbial network complexity in the soil of *Pinus armandii* rather than *Pinus kesiya, Front. Microbiol.*, 2025, vol. 16, 1616266.

Ivanov, G.I., *Pochvy Primorskogo kraya* (Soils of Primorsky Krai), Vladivostok: Dal'nevost. Kn. Izd., 1964.

Ivanov, G.I., *Pochvoobrazovanie na yuge Dal'nego Vostoka* (Soil Formation in the South of the Far East), Moscow: Nauka, 1976.

Kim, C., Choo, G.C., Cho, H.S., and Lim, J.T., Soil properties of cultivation sites for mountain-cultivated ginseng at local level, *J. Ginseng Res.*, 2015, vol. 39, pp. 76–80.

Klassifikatsiya i diagnostika pochv Rossii (Classification and Diagnostics of the Soils of the USSR), Smolensk: Oykumena, 2004.

Kolesnikov, B.P., Vegetation, in *Dal'nii Vostok: Fiziko-geograficheskaya Kharakteristika* (Far East. Physical Geogpraphic Characteristic), Moscow: Akad. Nauk SSSR, 1961, pp. 183–245.

Kostenkova, A.F., Ash composition of cedar-broadleaved forests and the biological cycle of substances, in *Struktura i produktivnost' lesnykh biogeotsenozov* (Spatio-Temporal Structure of Forest Ecosystems), Vladivostok: Dal'nevost. Nauchn. Tsentr Akad. Nauk SSSR, 1984, pp. 71–88.

Krasnaya kniga Primorskogo kraya: Rasteniya. Redkie i nakhodyashchiesya pod ugrozoi ischeznoveniya vidy rastenii i gribov (Red Data Book of Primorsky Krai: Plants. Rare and Endangered Species of Plants and Fungi), Vladivostok: Apelsin, 2008.

Krasnaya kniga Rossiiskoi Federatsii. Rasteniya i griby (The Red Data Book of the Russian Federation (Plants and Fungi)), Ministry of Natural Resources and Environment of the Russian Federation et al., Geltman, D.V., Eds., Moscow: Vseross. Nauchno-Issled. Inst. "Ekologiya", 2024.

Kudrin, S.A., Average chemical composition of the main types of soils in the European part of the USSR according to bulk analyzes, *Pochvovedenie*, 1963, no. 5, pp. 21–25.

Levanidov, L.Ya. and Davydov, S.T., *Marganets kak mikroelement v svyazi s biokhimiei i svoistvami tannidov* (Manganese as a Trace Element in Relation to the Biochemistry and Properties of Tannins), Chelyabinsk: Chelyab. Kn. Izd., 1961.

Pang, F., Gao, Y., Zhuang, Z., Li, C., Zhao, Y., and Liu, Q., Microecological mechanisms of mountainous forest cultivated ginseng growth vigor and saponin accumulation, and the characterization of bionic microbial fertilizer, *Front. Microbiol.*, 2025, vol. 16, 1548481.

Perelman, A.I., *Geokhimiya: Ucheb. posobie* (Geoecology: a Study Guide), Moscow: Vyssh. Shk., 1979.

Romankevich, E.A., The living matter of the Earth (biogeochemical aspects of the problem), *Geokhimiya*, 1988, no. 2, pp. 292–306.

Sapozhnikov, A.P., Ash composition of needles and leaves in spruce-broadleaved forests of the Southern Primorye, *Tr. Biol.-Pochv. Inst. Dal'nevost. Nauchn. Tsentra Akad. Nauk SSSR*, 1973, vol. 16, no. 119, pp. 129–133.

Sheudzhen, A.Kh., *Biogeokhimiya* (Biogeochemistry), Maykop: Adygeya, 2003.

Shikhova, N.S., Burundukova, O.L., Butovets, G.N., Zarubina, N.V., and Polyakova, N.V., Elemental composition of the leaves of *Panax ginseng* (Araliaceae) in natural populations of the Primorye Territory, *Rastit. Resur.*, 2020, vol. 56, no. 3, pp. 257–269.

Sklyarov, E.V., Gladkochub, D.P., Donskaya, T.V., Ivanov, A.V., et al., *Interpretatsiya geokhimicheskikh dannykh: Uchebnoe posobie* (Interpretation of the Geochemical. Data: A Manual), Sklyarov, E.V., Ed., Moscow: Intermet Inzhiniring, 2001.

Sosudistye rasteniya Sovetskogo Dal'nego Vostoka (Vascular Plants of the Soviet Far East), Kharkevich, S.S., Ed., St. Petersburg: Nauka, 1985–1996.

Sun, H., Wang, Q.X., Liu, N., Li, L., Zhang, C.G., Liu, Z.B., and Zhang, Y.Y., Effects of different leaf litters on the physicochemical properties and bacterial communities in *Panax ginseng*-growing soil, *Appl. Soil Ecol.*, 2017, vol. 111, pp. 17–24.

Tereshkina, A.A., Pshenichnikova, N.F., Bugaets, A.N., Golodnaya, O.M., and Krasnopeev, S.M., Digital soil map of the Sokolovka River catchment (territory of the Verkhneussuriysky Research Station, Federal Scientific Center of the East Asia Terrestrial Biodiversity, Far Eastern Branch of the Russian Academy of Sciences), in *Geograficheskie i geoekologicheskie issledovaniya na Dalnem Vostoke* (Geografical and Geoecological Investigations in the Far East), Baklanov, P.Ya., Ed., Vladivostok: Dal'nauka, 2019, no. 1, pp. 126–136.

Thyroff, E.C. and Griscom, H.P., Experimental study of soil and aspect on American ginseng in an appalachian cove ecosystem, *Nat. Areas J.*, 2019, vol. 39, no. 3, pp. 378–383.

Trias i yura Sikhote-Alinya. Kniga 1. Terrigennyi kompleks (Triassic and Jurassic Sikhote-Alinya. Book 1. The Terrigenous Complex), Markevich, P.V., and Zakharov, Yu.D., Eds., Vladivostok: Dal'nauka, 2004.

Ussuriysky State Nature Reserve (Primorsky Region), *Izv. Irkutsk. Gos. Univ., Ser. Biol.*, 2020, vol. 32, pp. 35–49.

Vinogradov, A.P., *Geokhimiya redkikh i rasseyannykh khimicheskikh elementov v pochvakh* (Geochemistry of Rare and Dispersed Chemical Elements in Soils), Moscow: Akad. Nauk SSSR, 1957.

Yakovleva, A.N., A Model of vegetation pattern at the Verkhneussuriysky biogeocenotic station, *Russ. J. Ecol.*, 2010, no. 41, pp. 307–315.

Zhuravlev, Yu.N., Gaponov, V.V., and Fomenko, P.V., *Zhen'shen Primorya. Resursy i organizatsiya vosproizvodstva* (Ginseng of Primorye. Resources and Reproduction Organization), Vladivostok: Apelsin, 2003.

Zonn, S.V., *Zhelezo v pochvakh* (*geneticheskie i geograficheskie aspekty*) (Iron in Soils: Genetic and Geographical Aspects), Moscow: Nauka, 1982.

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