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SOIL CHEMISTRY

Available Potassium in Volcanic Soils of Kamchatka

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Abstract—The distribution of available potassium in the profiles of synlithogenic volcanic soils of Kamchatka has been studied. Most of the soils in the Central Kamchatka Depression and the Western Kamchatka Lowland are characterized by a medium content of nonexchangeable potassium and a high content of exchangeable potassium. The soils of the east coast are less rich in potassium. The reserves of available potassium in the root layer of the virgin and cultivated soils of Kamchatka have been calculated. It is shown that differences in the reserves of potassium are related to different degrees of the soil tolerance toward the depletion of potassium and to the uneven application of potassium fertilizers. In most cases, soil cultivation is accompanied by a general rise in the reserves of available potassium with an increase in the portion of exchangeable potassium relative to its nonexchangeable forms.

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INTRODUCTION

The Kamchatka Peninsula is a unique region of Russia because of the active past and present volcanism. The soils of this region are studied sufficiently well. The genetic features, classification, and nomenclature of these soils; the specificity of their water regime, mineralogical composition, and physicochemical characteristics; and the general regularities of volcanic pedogenesis under conditions of the cold humid climate are described in a number of publications [3, 4, 8, 10, 13, 14]. The study of the synlithogenic volcanic soils of Kamchatka is of great theoretical and practical importance.

Potassium is one of the macroelements whose behavior in soils is controlled by the natural geochemical conditions and by anthropogenic activity. Data on the bulk contents of potassium in the soils, forest litters, and major plant species of Kamchatka can be found in the literature. However, data on the available forms of this element (nonexchangeable, exchangeable, and water-soluble) in the soils of Kamchatka are very scarce. Information on the content and reserves of exchangeable potassium in several soil types (ocherous, podzolized ocherous, and light ocherous volcanic soils) can be found in [14]. Information on the other forms of available potassium in the soils of Kamchatka is virtually absent, though the great importance of this element for ecosystems is well known. Being a biophilous element, potassium participates in soil biological processes, and the content of its available forms is one of the major factors affecting the quality and functioning of ecosystems.

Volcanic soils are widely used for agricultural purposes throughout the world. There are data on the irreversible loss of potassium from intensely cultivated volcanic soils [16]. It also known that the application of potassium and organic fertilizers to volcanic soils often leads to a significant gain in the yield of vegetables even upon the high bulk content of potassium in these soils [17–19].

Some data on the content and behavior of the available potassium in agricultural soils of Kamchatka are reported in [10, 14]. It is stressed that the loss of potassium upon the soil plowing is very active because of the percolative soil water regime and coarse soil texture. To replenish the reserves of available potassium, regular application of potassium fertilizers is recommended; mineral potassium fertilizers should be applied together with organic fertilizers.

We studied the potassium status of natural and agricultural soils of Kamchatka on different parts of this peninsula.

OBJECTS AND METHODS

The most widespread agricultural soils and their natural analogues were investigated. Light ocherous volcanic and stratified podzolized ocherous volcanic soils were studied in the Central Kamchatka Depression (in the Kamchatka River valley); gray-humus alluvial soils, stratified ocherous volcanic soils, and stratified light ocherous volcanic soils developed from different deposits were studied in the eastern coastal region (in the Avacha River valley); and gray-humus alluvial soils and podzolized ocherous volcanic soils of different textures were studied in the western part of Kamchatka (in the Bystraya River valley). The soil samples were taken from the major genetic horizons of the natural soils and from the plow (0–20 cm) and subplow (20–35 cm) layers of cultivated soils.

Routine analytical methods were used: the soil humus content was determined according to the Tyurin method (wet combustion), the soil water and salt (KCl) pH values were determined by the potentiometric method, the exchangeable bases were replaced by ammonium acetate, and the exchange capacity was determined according to the method of Bobko and Askinazi for noncalcareous soils. The water-soluble potassium was determined in soil water (1 : 50) extracts with distilled water free from carbon dioxide after 5 minutes of shaking; afterwards, the water solution with the dissolved potassium was subjected to concentration. The exchangeable potassium was replaced from the exchange complex by a 1 N NH_4COOH solution (pH 7) with the soil-to-solution ratio of 1 : 10 with 1-h shaking (the Maslova procedure). The content of nonexchangeable potassium was calculated as the difference between the content of potassium extracted from the potassium-bearing minerals via their boiling with 2 N HCl for 30 min (the soil-to-solution ratio was 1 : 10) and the content of exchangeable potassium (this method was developed by the Dokuchaev Soil Science Institute) [1]. The following soil grouping with respect to the content of nonexchangeable potassium was used: 8–20 mg/100 g, low-potassium soils; 20–40 mg/100 g, moderately low-potassium soils; 40–60 mg/100 g, medium-potassium soils; 60–90 mg/100 g, moderately high-potassium soils; 90–140 mg/100 g, high-potassium soils; and >140 mg/100 g, very high-potassium soils.

RESULTS

The following primary minerals predominate in the mineralogical composition of the volcanic soils: light-colored volcanic glass (20–40%), pyroxenes and amphiboles (10–24%), quartz (2–7%), feldspars (40–60%), and biotite (0.6%) [5]. Some argillization of the feldspars and micas is seen in the underlying volcanic deposits, where halloysite and hydromica are present in small amounts. All the genetic horizons have a qualitatively similar mineralogical composition. Therefore, the soil weathering does not lead to radical structural changes of the phyllosilicates in the hydromica $\rightleftarrows$ montmorillonite $\rightleftarrows$ kaolinite system [10].

According to [2], the volcanic glass contains 5–6% K_2O, which is easily mobilized from the glass in the course of weathering. The high stability of the feldspars and the low content of mica explain the low effect of these minerals on the amount of nonexchangeable potassium and its behavior in the soils. The mineralogical composition of the volcanic soils of Kamchatka points to their relatively low immobilization capacity with respect to potassium.

The small content of clay minerals explains the low cation exchange capacity and the rapid depletion of nutrients upon the extensive soil cultivation under the conditions of the humid climate. As shown by Zonn with coauthors [4], the continuous use of pastures and hayfields in the Kamchatka River valley turns them into low-fertile barrens in just 4–5 years.

Most of the soils of Kamchatka are light loamy in the upper layers and loamy sandy in the deeper layers (Table 1). The soil texture becomes coarser down the soil profile. In the stratified ocherous and light ocherous soils, the sand fraction predominates; in other soils, the coarse silt fraction predominates. The content of clay particles is low; their maximum content is observed in the upper horizons. The accumulation of the fine particle-size fractions in the upper horizons attests to the active biogenic and chemical weathering of the primary minerals in the root zone. According to [10], various organic colloids constitute about 50% of the clay fraction in the upper soil horizons. In the deeper horizons, secondary organomineral compounds predominate in the clay fraction.

The Western Kamchatka Lowland

The upper horizons of the virgin gray-humus alluvial soils and podzolized ocherous soils are characterized by a high humus content (5.2–11.8%) with its gradual decrease down the soil profile. The soil reaction varies from moderately acid to strongly acid values (pH_{KCl} 4.3–4.9). The content of exchangeable bases is relatively low because of the coarse soil texture; it reaches its maximum (5.6–21.0 meq/100 g) in the surface soil horizons. The soil exchange capacity is also low with a maximum in the upper organic and humus horizons (Table 2).

The content of nonexchangeable potassium is medium in the upper horizons and in the BC horizon and is low in the middle part of the profile (Table 3). The exchangeable potassium content in both soil types has a maximum in the humus horizons. In the gray-humus alluvial soils, it corresponds to the medium values; in the podzolized ocherous soils, to the high values. In the lower horizons of both soil types, the content of exchangeable potassium is low. The maximum content of the water-soluble potassium is also typical of the upper humus horizons. The contents of all the forms of potassium in the light loamy podzolized ocherous soils are somewhat lower than those in the medium loamy podzolized ocherous soils.

The Central Kamchatka Depression

The stratified podzolized ocherous soils and light ocherous soils in the Central Kamchatka Depression are characterized by complicated humus profiles. The humus content in the upper horizons varies from 3.44 to 13.78%; in the illuvial and buried horizons, it varies from 1.26 to 6.03%. The soil reaction is moderately acid in the upper and middle parts of the soil profiles and slightly acid in the lower part. The sum of the

Table 1. The particle-size distribution in some soils of Kamchatka, % of the absolutely dry soil

Horizon	Depth, cm	Particle size, mm						
		1.0–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	<0.01
Pit 15. Light loamy gray-humus alluvial soil on alluvial deposits								
AУ	0–20	14	16	43	12	6	9	27
BHi	20–36	22	32	35	3	4	4	11
BChi	36–60	21	37	24	6	8	4	18
Pit 10. Light loamy light ocherous soil on gravelly alluvium								
AO	1–18	15	22	43	2	9	9	20
BH	18–35	17	25	37	13	7	1	21
BAN	35–60	35	28	13	9	11	2	22
C ˜˜	60–80	38	35	11	4	10	2	16
Pit 21. Medium loamy podzolized ocherous soil on alluvial deposits								
AУ	0–10	16	12	35	18	7	12	37
EL	10–15	12	25	39	12	10	2	24
BH	15–25	5	47	29	4	4	11	19
BC	25–40	12	41	30	3	12	2	17
2C ˜˜	40–60	75	7	7	3	6	2	11
3C ˜˜	60–75	35	37	11	1	10	6	17
Pit 7. Light loamy stratified podzolized ocherous soil on volcanic deposits								
AO	0–10	10	8	61	9	9	3	21
C ‶	10–12	22	16	48	4	4	6	14
BH	12–25	14	35	35	3	10	3	16
2 C ‶	25–28	9	40	32	8	9	2	19
BAN	28–37	13	13	56	7	9	2	18
3 C ‶	37–47	4	6	72	7	9	2	18
2BH	47–67	26	26	27	6	3	12	14
4 C ‶	67–110	51	20	18	1	9	1	11
Pit 35. Light loamy stratified ocherous soil on volcanic deposits								
AУ	0–9	23	28	25	11	8	5	24
BH	9–18	46	20	13	12	3	6	21
C ‶	18–31	32	23	21	11	8	5	24
2BH	31–41	29	26	24	3	10	8	21
2BAN	41–65	22	20	35	10	5	8	13
BC	65–85	21	22	22	7	4	4	15
Pit 31. Light loamy gray-humus alluvial soil on volcanic deposits underlain by gravelly sandy alluvium								
AУ	0–12	15	33	29	4	7	12	23
BHi	12–26	29	26	21	18	2	4	24
BChi	26–35	34	44	9	2	8	3	13
C ˜˜	35–60	84	2	3	2	8	1	11
Pit 24. Light loamy stratified light ocherous soil on volcanic deposits underlain by gravelly sandy alluvium								
AУ	0–9	38	14	26	4	8	10	22
BH	9–21	46	11	24	8	10	1	19
C ‶	21–32	72	3	9	8	6	2	16
BH	32–43	48	15	16	9	9	3	21
2BH	43–53	38	25	15	9	11	2	22
BAN	53–75	34	21	24	8	11	2	21

Table 2. Physicochemical properties of the studied soils

Horizon	Depth, cm	Humus, %	pH		Exchangeable bases, meq/100 g			Exchange capacity, meq/100 g
			water	salt	Ca^{2+}	Mg^{2+}	sum	
Pit 15. Light loamy gray-humus alluvial soil on alluvial deposits								
АУ	0–20	11.77	5.07	4.38	3.6	2.0	5.6	21.54
BHi	20–36	6.75	5.01	4.54	1.8	1.0	2.8	14.92
BChi	36–60	1.97	5.17	4.62	1.5	1.1	2.6	9.59
BAN	60–85	0.05	5.17	4.75	2.0	1.6	3.6	6.37
C ~~	85–110	0.00	5.40	4.66	1.2	0.8	2.0	3.82
Pit 16. Light loamy agrohumus alluvial soil								
P	0–20	11.69	4.98	4.43	4.8	2.6	7.4	24.05
BHi	20–35	4.82	5.02	4.59	3.6	0.6	4.2	10.06
Pit 19. Light loamy podzolized ocherous soil on volcanic deposits								
АУ	0–9	9.49	5.31	4.49	14.0	7.0	21.0	25.37
EL	9–14	3.18	5.30	4.37	2.2	2.0	4.2	10.95
1BH	14–30	10.61	5.03	4.38	4.6	2.4	7.0	17.72
2BH	30–47	8.78	5.03	4.43	2.8	1.4	4.2	16.14
BAN	47–65	7.07	5.17	4.57	3.4	1.6	5.0	13.55
BC	65–95	3.62	5.25	4.60	2.0	1.6	3.6	10.09
C ~~	95–150	0.00	5.82	4.41	3.0	2.2	5.2	6.28
Pit 20. Light loamy podzolized agroocherous soil								
P	0–20	9.27	5.05	4.35	5.4	4.4	9.8	14.59
BH	20–35	8.92	5.14	4.56	5.0	1.4	6.4	17.47
Pit 21. Medium loamy podzolized ocherous soil on alluvial deposits								
АУ	0–10	7.46	5.04	4.85	12.6	10.4	23.0	23.10
EL	10–15	2.93	4.84	4.37	3.8	2.4	6.2	12.11
1BH	15–25	3.95	4.72	4.33	1.8	1.6	3.4	14.05
2BH	25–40	2.60	4.82	4.40	1.6	0.6	2.2	11.22
BC	40–60	0.00	5.09	4.49	1.8	21.2	23.0	5.96
C ~~	60–75	0.00	5.27	4.72	1.2	1.0	2.2	5.36
2C ~~	75–130	0.00	5.13	4.47	2.0	1.2	3.2	5.28
Pit 22. Medium loamy podzolized agroocherous soil								
P	0–20	5.21	5.48	4.90	5.4	4.4	9.8	8.53
Pit 7. Light loamy stratified podzolized ocherous soil on volcanic deposits								
AO	0–10	3.44	5.24	4.62	2.4	34.2	36.6	8.96
C"	10–12	0.21	5.57	4.80	1.2	0.4	1.6	3.82
BH	12–25	1.26	5.72	4.88	2.2	1.0	3.2	7.01
2 C"	25–28	0.10	5.83	5.06	1.6	0.8	2.4	4.22
BAN	37–47	0.31	5.76	5.09	2.6	0.8	3.4	5.87
3 C"	47–67	1.63	6.04	5.44	4.2	2.2	6.4	8.57
2BH	67–110	0.86	6.12	5.52	3.2	1.3	4.5	6.70
Pit 8. Light loamy stratified podzolized agroocherous soil								
P	0–26	2.05	4.94	4.38	1.5	0.7	2.2	7.84
BAN	26–40	1.27	5.74	5.47	4.8	2.6	7.4	8.74

Table 2. (Contd.)

Horizon	Depth, cm	Humus, %	pH		Exchangeable bases, meq/100 g			Exchange capacity, meq/100 g
			water	salt	Ca^{2+}	Mg^{2+}	sum	
Pit 10. Light loamy light ocherous soil on gravelly alluvium								
AO	0–18	13.78	5.37	4.86	8.8	8.0	16.8	22.80
BH	18–35	1.95	5.70	5.17	5.4	4.0	9.4	13.93
BAN	35–60	6.03	6.06	5.09	7.8	6.8	14.6	12.39
C ~~	60–80	0.47	6.23	5.11	6.2	2.8	9.0	8.39
Pit 9. Light loamy light agroocherous soil								
P	0–20	6.55	5.95	5.56	9.8	7.6	17.4	15.92
BH	20–35	2.63	6.22	4.86	8.6	4.0	12.6	12.97
Pit 35. Light loamy stratified ocherous soil on volcanic deposits								
АУ	0–9	7.40	4.57	4.43	5.0	0.8	5.8	15.06
BH	9–18	6.25	4.99	4.43	3.0	0.4	3.4	8.47
C"	18–31	1.86	5.30	4.80	2.4	0.6	3.0	6.34
2BH	31–41	4.03	5.47	4.87	2.3	0.7	3.0	6.46
2BAN	41–65	4.10	5.23	5.01	2.0	1.0	3.0	8.12
BC	65–85	2.53	5.48	4.98	4.8	2.2	7.0	13.55
Pit 36. Light loamy stratified agroocherous soil								
P	0–20	8.37	5.98	5.47	12.4	0.8	13.2	15.24
BH	20–35	3.86	5.33	5.05	4.2	2.4	6.6	7.70
Pit 24. Light loamy stratified light ocherous soil on volcanic deposits underlain by gravelly sandy alluvium								
АУ	0–9	9.05	5.13	4.83	8.4	3.4	11.8	20.65
BH	9–21	6.15	5.25	4.74	3.6	1.8	5.4	9.51
C"	21–32	3.23	5.45	4.81	3.6	1.2	4.8	8.85
BH	32–43	6.41	5.31	4.76	3.2	2.2	5.4	12.82
2BH	43–53	8.92	5.75	4.80	20.4	3.4	23.8	26.96
BAN	53–75	4.00	5.42	4.95	5.0	2.6	7.6	12.44
Pit 25. Light loamy stratified light agroocherous soil								
P	0–20	5.53	5.31	4.94	5.4	1.8	7.2	11.52
BH	20–35	2.40	5.29	5.08	4.8	0.8	5.6	10.49
Pit 31. Light loamy gray-humus alluvial soil on volcanic deposits underlain by gravelly sandy alluvium								
АУ	0–12	16.04	5.34	5.19	22.2	2.2	24.4	33.57
BHi	12–26	5.11	5.52	5.12	9.2	1.0	10.2	14.23
BChi	26–35	4.60	5.19	4.46	15.8	3.0	18.8	24.55
C ~~	35–60	0.84	5.47	4.52	2.6	0.9	3.5	6.97
2C ~~	60–90	0.16	5.65	4.47	2.2	0.8	3.0	5.26
Pit 32. Light loamy agrohumus alluvial soil								
P	0–20	6.00	5.23	5.00	9.6	1.2	10.8	14.41
BH	20–35	6.16	5.38	4.83	7.4	1.1	8.5	12.65

exchangeable bases is medium in the upper raw-humus horizon of the stratified podzolized ocherous soils and is very low in the deeper horizons. In the light ocherous soils, it varies from moderately high to low values. The exchange capacity is low in the entire soil profile, and its values in the light ocherous soils are somewhat higher than those in the stratified podzolized ocherous soils.

The nonexchangeable potassium content is very low and low in the stratified podzolized ocherous soils and light ocherous soils, respectively (Table 4). In the former soils, the distribution of nonexchangeable

Table 3. Contents of available potassium in soils of the Western Kamchatka Lowland, mg/100 g

Horizon	Depth, cm	Nonexchangeable	Exchangeable	Water-soluble
Pit 15. Light loamy gray-humus alluvial soil on alluvial deposits				
AУ	0–20	44.6	11.6	2.4
BHi	20–36	24.1	8.7	0.7
BChi	36–60	38.2	8.6	0.7
BAN	60–85	40.3	8.7	0.5
C~~	85–110	37.1	8.7	0.5
Pit 16. Light loamy agrohumus alluvial soil				
P	0–20	20.3	12.5	1.8
BHi	20–35	39.9	10.1	1.2
Pit 19. Light loamy podzolized ocherous soil on volcanic deposits				
AУ	0–9	42.4	22.8	4.2
EL	9–14	39.2	9.8	3.1
1BH	14–30	30.7	7.5	1.1
2BH	30–47	31.4	6.8	1.1
BAN	47–65	31.1	7.1	0.8
BC	65–95	39.7	9.3	0.8
C~~	95–150	43.8	10.6	0.5
Pit 20. Light loamy podzolized agroocherous soil				
P	0–20	37.6	16.8	2.2
BH	20–35	39.1	20.7	2.3
Pit 21. Medium loamy podzolized ocherous soil on alluvial deposits				
AУ	0–10	46.4	26.2	4.8
EL	10–15	42.8	13.6	2.1
1BH	15–25	33.7	9.9	1.4
2BH	25–40	31.7	11.9	1.3
BC	40–60	35.6	5.8	1.0
C~~	60–75	38.2	3.4	1.0
2C~~	75–130	47.5	6.1	0.8
Pit 22. Medium loamy podzolized agroocherous soil				
P	0–20	39.5	15.9	3.78

potassium in the soil profile has an irregular pattern; in the latter soils, it is characterized by a gradual increase in the deeper horizons. The exchangeable potassium content is moderately high in the light ocherous soils and is very high in the stratified podzolized ocherous soils. The maximum content of exchangeable potassium is observed in the upper horizons, and the buried podzolized horizons of the stratified podzolized ocherous soils have the minimum content of exchangeable potassium. The upper raw-humus horizon of these soils represents a homogenous mechanical mixture of the raw organic material with volcanic ash; the clay content is very low in this horizon. Therefore, the content of nonexchangeable potassium in it is also very low, though the content of exchangeable potassium is high. The maximum content of the water-soluble potassium is in the surface soil horizons; the content of water-soluble potassium gradually decreases down the soil profiles.

The Eastern Coastal Zone

The virgin stratified ocherous volcanic soils in this part of Kamchatka are rich in humus; their surface horizons

Table 4. Contents of available potassium in soils of the Central Kamchatka Depression, mg/100 g

Horizon	Depth, cm	Nonexchangeable	Exchangeable	Water-soluble
Pit 7. Light loamy stratified podzolized ocherous soil on volcanic deposits				
AO	0–10	6.1	26.7	2.7
C"	10–12	21.7	4.5	1.1
BH	12–25	26.6	4.4	1.1
2 C"	25–28	19.1	4.3	1.0
BAN	28–37	29.7	4.8	1.0
3 C"	37–47	35.9	4.9	1.1
2BH	47–67	27.0	5.8	1.1
4 C"	67–110	23.5	4.7	1.0
Pit 8. Light loamy stratified podzolized agroocherous soil				
P	0–26	26.8	17.8	2.7
BAN	26–40	25.0	6.0	1.1
Pit 10. Light loamy light ocherous soil on the gravelly alluvium				
AO	0–18	12.9	17.1	1.8
BH	18–35	22.5	15.7	0.7
BAN	35–60	39.2	9.6	0.7
C ˜˜	60–80	60.6	9.6	0.5
Pit 9. Light loamy light agroocherous soil				
P	0–20	20.0	20.7	3.5
BH	20–35	41.3	22.9	0.8

contain up to 7.4–9.5% humus. In the lower horizons, the humus is irregularly distributed, and its content varies from 1.86 to 8.92%. In the gray-humus alluvial soils, the humus content gradually decreases down the soil profile. The maximum humus content (16.04%) is in the uppermost horizon. The soil reaction varies from strongly acid to moderately acid values. The sum of exchangeable bases is low to moderate (5.8–11.8 meq/100 g) in the stratified volcanic soils and is high (24.4 meq/100 g) in the gray-humus alluvial soils (Table 2).

The stratified ocherous soils in the eastern part of Kamchatka are characterized by a moderately low content of nonexchangeable potassium in the upper and lower parts of the profile and by the low content of this form of potassium in the middle part of the profile. The stratified light ocherous soils have a moderately low content of nonexchangeable potassium in their entire profile, whereas the gray-humus alluvial soils have a moderately high content of this element (Table 5). In all the stratified ocherous volcanic soils, the distribution of nonexchangeable potassium in the middle part of the profile is very irregular. The exchangeable potassium content is high in the surface horizons of the stratified ocherous volcanic soils and is low to medium in the deeper horizons. In the gray-humus alluvial soils, it is medium in the upper horizon and is very low in the deeper horizons. The content of water-soluble potassium has a maximum in the humus horizon and decreases down the soil profile.

DISCUSSION

The obtained data make it possible to suppose that the low content of nonexchangeable potassium in the soils of Kamchatka is related to the relatively coarse soil texture and the low amount of minerals bearing firmly fixed potassium. Some increase in the content of nonexchangeable potassium in the humus horizon (in comparison with the middle-profile horizons) is only seen in the gray-humus alluvial soils, though the clay content in them does not differ from that in the other soils. This may be due to the location of the alluvial soils in the depressions of the relief (river valleys) and their receiving some amount of potassium with the snowmelt runoff from the adjacent slopes. Also, some amount of potassium taken up by the roots of herbs and grasses from the root zone (0–50 cm) returns to the soil with the plant litter and enriches the soil solution. This potassium is fixed by labile silicate minerals in the uppermost soil layer (0–20 cm). The role of the active biological turnover in the accumulation of nonexchangeable

Table 5. Contents of available potassium in soils of the eastern coast of Kamchatka, mg/100 g

Horizon	Depth, cm	Nonexchangeable	Exchangeable	Water-soluble
Pit 35. Light loamy stratified ocherous soil on volcanic deposits				
AУ	0–9	22.7	21.3	3.6
BH	9–18	13.7	7.9	1.4
C"	18–31	15.5	8.1	1.4
2BH	31–41	15.2	5.4	1.6
2BAN	41–65	11.1	7.7	1.2
BC	65–85	29.1	6.5	1.0
Pit 36. Light loamy stratified agroocherous soil				
P	0–20	20.2	14.2	2.5
BH	20–35	10.8	13.0	2.4
Pit 24. Light loamy stratified light ocherous soil on volcanic deposits underlain by the gravelly sandy alluvium				
AУ	0–9	32.0	23.4	5.6
BH	9–21	30.0	13.6	2.8
C"	21–32	32.1	11.5	1.2
BH	32–43	24.0	8.8	0.9
2BH	43–53	34.7	10.5	0.9
BAN	53–75	28.4	4.4	0.7
Pit 25. Light loamy stratified light agroocherous soil				
P	0–20	26.5	25.5	7.4
BH	20–35	29.3	8.9	1.5
Pit 31. Light loamy gray-humus alluvial soil on volcanic deposits underlain by the gravelly sandy alluvium				
AУ	0–12	47.8	12.1	2.8
BHi	12–26	35.6	3.9	1.2
BChi	26–35	32.2	3.3	1.0
C~~	35–60	34.0	4.4	0.9
2C~~	60–90	23.4	3.2	0.9
Pit 32. Light loamy agrohumus alluvial soil				
P	0–20	39.7	15.7	2.6
BH	20–35	72.2	12.4	3.7

potassium in the uppermost horizons of the soils of the depressions was stressed by Liversovskii [7].

In all the virgin soils of Kamchatka, the maximum contents of exchangeable and water-soluble potassium are seen in the upper humus horizons. This is obviously related to the accumulative effect of the vegetation [9]. The humus and raw-humus horizons of the volcanic soils are the main sources of the available potassium released from the weathering of the ashes and from the mineralized plant litter [11]. This idea is indirectly supported by the close relationships between the contents of exchangeable and water-soluble potassium and the humus content in the virgin soils (r = 0.44 and 0.50, respectively; n = 36) (Fig. 1).

In the virgin soils, reliable correlative relationships exist between the contents of nonexchangeable, exchangeable, and water-soluble potassium (r = 0.38 and 0.75; n = 36), which attests to the dynamic equilibrium between the different forms of available potassium. Positive correlative relationships (r = 0.40–0.47; n = 36) are also observed between the contents of exchangeable and water-soluble potassium and the contents of the clay (<0.001 mm) and physical clay (<0.01 mm) fractions.

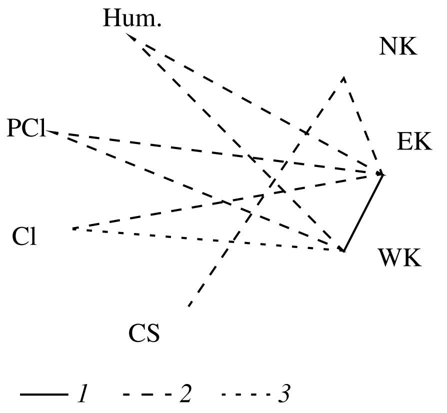

Fig. 1. Relationships between the parameters of the potassium state of the soils, the soil particle-size distribution, and the soil humus content. Probability characteristics: (*1*) 0.999, (*2*) 0.99, and (*3*) 0.95. Designations: NK, nonexchangeable potassium; EK, exchangeable potassium; WK, water-soluble potassium; CS, coarse silt; Cl, clay; PCl, physical clay; and Hum, humus.

The content of nonexchangeable potassium is correlated with the coarse silt content ($r = 0.44$; $n = 36$). At the same time, it is not correlated with the clay fraction content, which may be explained by the very low amount of the latter. Similar relationships were reported for loamy and loamy sandy soddy-podzolic soils of Russia and Belarus [6, 12]. The significant role of the coarse silt fraction in the soil supply with nonexchangeable potassium was explained by the high content of this fraction enriched in the micaceous minerals with defective crystal lattices and in the feldspars transformed by postmagmatic processes. It is probable that the same explanation can be applied to the studied volcanic soils. According to [10], the chemical weathering of mineral particles in these soils affects not only their exterior parts but also their interior parts, so that the surface of the interaction between the soil solid phase and the soil solution becomes much larger, despite the low intensity of the physical weathering.

The studied soils differ considerably from one another in the horizonation of their profiles and in the thickness of the soil horizons. Therefore, in order to compare the reserves of available potassium and its different forms in these soils, we have calculated them for a standard 20-cm-thick upper soil layer (the root zone) (Fig. 2). In the eastern coastal region and in the Central Kamchatka Depression, the reserves of available potassium in the agrogenic (cultivated) soils are generally higher than those in their virgin analogues. Within the Western Kamchatka Lowland, the reserves of available potassium in the agrogenic and virgin soils are approximately equal. The difference between the cultivated and virgin soils in the western and central parts of Kamchatka is related not only to the application of potassium fertilizers to the cultivated soils but also to the agrogenic soil compaction with a corresponding increase in the bulk density values [14].

The reserves of available potassium in the virgin soils of Kamchatka vary within broad limits (217–730 kg/ha). In the agrogenic soils, they are generally higher and vary from 415 to 840 kg/ha with a minimum in the light ocherous soils and a maximum in the medium loamy podzolized ocherous soils. The most significant difference between the pools of available potassium in the

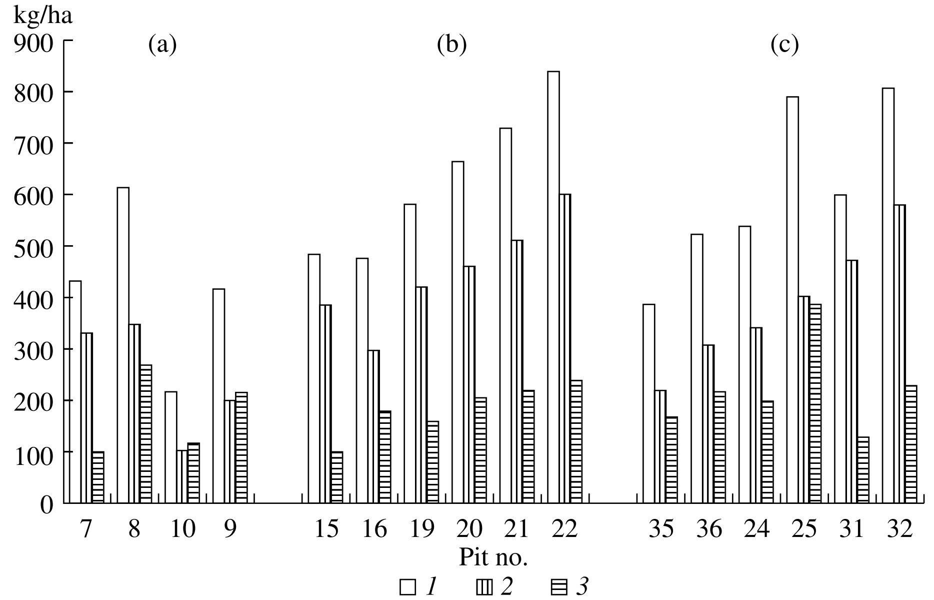

Fig. 2. The reserves of available potassium in soils of the (a) Western Kamchatka Lowland, (b) Central Kamchatka Depression, and (c) eastern coastal region. Forms of potassium: (*1*) available, (*2*) nonexchangeable, and (*3*) exchangeable.

virgin and cultivated soils is noted for the Central Kamchatka Depression and for the eastern coastal region; within the Western Kamchatka Lowland, this difference is smaller. In the cultivated gray-humus alluvial soil of this area, the reserves of available potassium are even somewhat smaller than those in the virgin soil. The cultivated soil is characterized by an increase in the pool of exchangeable potassium at the expense of the pool of nonexchangeable potassium. This is a negative phenomenon attesting to the beginning of the potassium depletion from the cultivated soil.

The analysis of the different forms of available potassium in the studied soils shows that the soil cultivation results in some rise in the total pool of available potassium, mainly at the expense of its exchangeable form. As a result, the ratio of the reserves of nonexchangeable potassium to the reserves of exchangeable potassium decreases from 0.9–3.9 in the virgin soils to 0.9–2.5 in the agrogenic soils. According to [15], this phenomenon is generally typical of coarse-textured soils with a low clay content and a low cation exchange capacity. The volcanic soils of Kamchatka satisfy these criteria. The probability of potassium leaching off from these soils upon their cultivation is high.

The considerable variability in the distribution of the available potassium in the soils of the different natural regions of the Kamchatka Peninsula may by explained by the uneven soil tolerance to the potassium depletion and by the uneven rates of application of potassium fertilizers in different parts of Kamchatka.

CONCLUSIONS

(1) Most of the soils in the Central Kamchatka Depression and in the Western Kamchatka Lowland are characterized by a medium content of nonexchangeable potassium and by a moderately high content of exchangeable potassium. The contents of the nonexchangeable and exchangeable potassium in the volcanic soils of the eastern coastal region are somewhat lower.

(2) Moderately low and medium contents of nonexchangeable potassium are typical of the coarse-textured soils of Kamchatka with a low amount of minerals capable of potassium fixation.

(3) The uneven distribution of the different forms of potassium in the genetic horizons of the Kamchatka soils points to the discrete character of the volcanic pedogenesis interrupted by the deposition of new portions of volcanic ash onto the soil surface.

(4) The highest reserves of available potassium are typical of the medium loamy podzolized ocherous volcanic soils of Kamchatka, whereas the lowest reserves of available potassium are found in the light ocherous soils.

(5) The differences in the reserves of available potassium are related to the different soil tolerances toward potassium depletion and to the uneven application of potassium fertilizers to cultivated soils in the western, central, and eastern parts of Kamchatka.

(6) The cultivation of volcanic soils is usually accompanied by some increase in the reserves of available potassium, and this is accompanied by an increase in the relative content of exchangeable potassium and a decrease in the relative content of nonexchangeable potassium.

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