Soils of natural, arable and fallow Lands of the Selenga River delta

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Abstract. Soil-geographical investigations were made in the Selenga river delta (the southeastern coast of Lake Baikal) in the summer of 2017 and 2018. The Selenga delta developed Fluvisols aridic, Fluvisols umbric (gleyic), Fluvisols humus, Fluvisols mollic-gleyic, Fluvisols Histic-gleyic, Folic-podburs, Gray (metamorphic) and Folic-gray soils. Fertile soils of the second bottom with Chernozems and Phaeozems are used as arable lands. Agricultural lands of terraces with Gray and Folic-gray soils are used as pastures. The soils of the low floodplain are put to agricultural use. It was established that the soils in most of agricultural lands are in satisfactory agricultural condition. The upper horizons of Gray soils under forest and Chernozems under steppe in natural condition have high humus concentrations. In soils permanently used in agriculture, humus content decreases. In fallow lands, its concentrations are recovering. The reaction of the medium (pH of water) in the soils is largely neutral. Gray soil under forest is distinguished by slightly acidic reaction. It was found that the soils of the Selenga delta have mostly a light granulometric composition.

1. Introduction
The study area lies on the coast and in the neighboring territory of the world's deepest and cleanest lake, Baikal. Some of the floodplain soils of the coast which were used previously for agricultural purposes are abandoned to date and are used for pastures and for recreational purposes.

The formation of the climatic conditions of the Selenga delta is influenced by the location of this territory in the belt of midlatitudes, and by characteristics of mountain-depression topography. The mean annual precipitation amount is 250-400 mm.

Within the Selenga delta, three large elements of geomorphological structure are distinguished: protruding delta (modern delta) and floodplain, lake-river terraces (residuals of ancient deltas), and tectonic trough with parent rocks and topography specific to each of them. The Selenga delta is located on a thick Pleistocene and Late Alluvium mantle. Parent rocks are dominated by Quaternary deposits. Vegetation cover of the Selenga delta is represented by various (from forest-steppe to bog) phytocenoses.

2. Objects, data and methods
Soil-geographical investigations were made in the mouth of the Selenga river delta and in the adjacent territory in the summer of 2017 and 2018. Soil sampling sites are located in the Kabanski district (Republic of Buryatia) in the vicinity of the village of Istomino, in the territory where the BINM SB
RAS research base is situated. A total of 150 soil samples and rocks were collected for their physicochemical analysis. The chemical and physicochemical analysis soils were made at the IG SB RAS Chemical-Analytical Center using a generally accepted technique [1-3]. The Institute’s Chemical-Analytical Center is a licensed entity and forms part of the Chemical Research Shared-Use Center ISC SB RAS. Classification and Diagnostics of Soils of Russia, 2004 [4], was used in soil diagnostics.

3. Results and discussion
According to the soil map [5, 6], the Selenga delta developed Fluvisols aridic, Fluvisols umbric (gleyic), Fluvisols humus, Fluvisols mollic-gleyic, Fluvisols histic-gleyic, Folic-podburs, Gray (metamorphic) and folic-gray soils. There occur Chernozems on a high floodplain, and Arenosols (humus) on aeolian mounds.

The right-bank area of the delta developed Folic-gray soils [7, 8]. In the left-bank area there occur Folic-podburs and gray and folic-gray soils. Small residuals of terraces are occupied mainly by Folic-gray soils. On the contact of the Tvorogovo-Ivolginskoe upland with the floodplain, a part of the terraces is scoured by channel flows, and they have turned into residuals. The residuals developed Folic-gray soils, Fluvisols mollic-gleyic and Fluvisols Histic-gleyic in depressions, and Chernozems in floodplain elevations; alluvial Phaeozems constitute the background.

Soil cover of the Katusnyi tectonic trough formed in the process of swamping of the ancient delta whose topography was represented by modern and cutoff lakes and channels of small rivers and by-channels, periodically inundated floodplains, mid-channel bars and levees. This area developed the following soils: Fluvisols mollic-gleyic, Fluvisols histic-gleyic, Histic-Gleysols, mollic-gleyic, and Histosols; there occur Folic-gray soils [7, 8]. Fertile soils of the high floodplain with Chernozems and Phaeozems are used as arable lands. Some of the agricultural lands are abandoned and are used for pastures. Agricultural lands of terraces with gray and folic-gray soils are abandoned and are being overgrown with young pine trees. Soils of the low floodplain with Fluvisols mollic-gleyic are currently put to agricultural use.

The physicochemical analyses revealed that the soils of agricultural lands are in good agronomic condition (tables 1 and 2). The upper horizons of gray soils under forest and of Chernozems under steppe in a natural state contain more than 5 and 15% of humus, respectively. In the soils permanently used in agriculture, its content decreases to 1.4–2.8%. In fallow lands, its concentrations recover to vary from 2.6 to 11.6%, depending on its initial content in the undisturbed soil. In the soils which have been put to agricultural use recently the humus content is relatively high, from 11.6 to 23.1%.

The soils have largely a neutral reaction (pH of water), which is a favorable condition for plant development. The gray soil under forest is distinguished by a weakly acidic reaction. Alkaline reaction corresponds to the lower Chernozem horizons and the Fluvisol mollic-gleyic horizon as a result of input of calcareous alluvium during spring floods. The lower horizons of plowed former Chernozems (Anthrosols, sites nos. 3-4) have a weakly alkaline reaction. The subsurface humous horizon of the Anthrosol mollic-gleyic soil also has a weakly acidic reaction. The plowing horizon has a neutral reaction.

It was established that the soils of the Selenga delta have largely a light granulometric composition. Therefore, the plowing of slopes with an inadmissible steepness can be accompanied by erosion processes, losses of the upper horizons, humus and the main plant nutrition elements.

As regards the content of the main plant nutrition elements, there is a deficit of potassium in cultivated soils and in soils of agricultural fallow lands, except for former plowed Chernozems (currently Anthrosols, sites nos. 3-4). The upper soil horizons of natural landscapes show a sufficient potassium concentration, 174-1045 mg/kg. According to the scale of the FBGU Center of Agrochemical Service Irkutskii, the potassium content is characterized as: very low, <100; low, 101-200, medium, 201-300, above medium, 301-400; high, 401-600, and very high, >600 mg/kg [8].
A high content of phosphorus was revealed in all soils of natural landscapes and agricultural lands, from 204 to 891 mg/kg, except for Fluvisol mollic-gleyic and its anthropogenic analog (sites nos. 11.12 and 15.16). The Fluvisol mollic-gleyic Anthrosol mollic-gleyic soils show A medium content of phosphorus and a deficit of potassium concentration. According to the scale of the FBGU Center of Agrochemical Service Irkutskii, the content of labile phosphorus in soils is characterized as: very low, <25; low, 26-50, medium, 51-100; above medium, 101-150, high, 151-250, and very high, >250 mg/kg [8].

The content of nitrates in all the soils investigated does not exceed sanitary and hygienic rates (MACs for nitrates are 130 mg/kg). The study revealed a medium and high concentration of nitrate and ammonium nitrogen in undisturbed, some of the fallow (area no. 3–4, former Chernozem),

### Table 1. Agrochemical properties of soils in key areas of cultivated, abandoned and unused lands of the Selenga river delta.

| Site no. | Location, use | Soil     | Horizon  | pH of water | C org. | Humus content, % | Main elements of plant nutrition |
|---------|--------------|----------|----------|-------------|--------|------------------|---------------------------------|
|         |              |          |          |             |        |                  | NO₃  | NH₄  | P₂O₅ | K₂O  |
| 1-2     | Selenga floodplain, fallow 15 years | Anthrosol | AYpa | 6.6 | 2.4 | 4.1 | 0.9 | 3.72 | 252.6 | 290.0 |
|         |              |          | P       | 6.4 | 1.5 | 2.6 | 0.2 | 1.36 | 204.3 | 53.0 |
|         |              |          | C       | 6.8 | 0.8 | 1.4 | 0.1 | 0.79 | 248.7 | 73.5 |
| 3       | By-channel of main channel, Selenga river | Chernozem | AU     | 7.4 | 11.8 | 20.3 | 9.0 | 12.25 | 891.0 | 1045.0 |
|         |              |          | BCA     | 8.6 | 3.4 | 5.9 | 1.1 | 1.50 | 859.0 | 1030.0 |
| 3-4     | Selenga valley, fallow | Anthrosol | Cca  | 8.7 | 0.7 | 1.2 | 0.1 | 0.80 | 270.2 | 73.5 |
|         |              |          | W       | 7.7 | 6.7 | 11.6 | 11.9 | 3.10 | 572.4 | 290.0 |
|         |              |          | P       | 7.6 | 1.3 | 2.2 | 10.2 | 2.15 | 573.5 | 475.0 |
|         |              |          | C       | 7.9 | 0.7 | 1.2 | 3.7 | 0.93 | 480.3 | 161.0 |
| 5-6     | 1 km from st. Stepnoi Dvorets, Selenga delta, cropland | Anthrosol | P     | 6.6 | 1.6 | 2.8 | 3.6 | 1.65 | 429.1 | 132.0 |
|         |              |          | C       | 6.9 | 0.8 | 1.4 | 0.8 | 0.60 | 435.4 | 79.7 |
|         |              |          | PC      | 6.6 | 1.6 | 2.8 | 10.7 | 1.36 | 436.8 | 113.0 |
| 6       | 2nd terrace of the Selenga | Gray     | C       | 7.4 | 0.7 | 1.2 | 0.7 | 0.50 | 430.8 | 61.5 |
|         |              |          | AY      | 5.1 | 3.4 | 5.9 | 10.2 | 15.0 | 578.1 | 249.0 |
|         |              |          | AEL     | 5.4 | 1.7 | 2.9 | 0.1 | 0.60 | 305.1 | 160.0 |
|         |              |          | BEL     | 5.5 | 2.0 | 3.5 | 0.2 | 0.65 | 302.4 | 174.0 |
| 11.1    | Shumikha by-channel floodplain, cropland, 1st year | Fluvisol mollic-gleyic | T     | 7.6 | 7.5 | -    | 0.1 | 1.00 | 218.4 | 36.0 |
| 2       |              |          | H       | 8.1 | 7.5 | 12.9 | 13.2 | 2.94 | 131.4 | 63.5 |
| 15.1    | Left-bank Yabloanka by-channel floodplain, Selenga river, cropland, 3rd year | Anthrosol mollic-gleyic | PH    | 7.5 | 6.8 | 11.7 | 12.6 | 3.08 | 136.3 | 42.5 |
| 6       |              |          | H       | 5.8 | 5.4 | 9.3 | 23.1 | 2.65 | 331.2 | 21.0 |
|         |              |          | G       | 6.5 | 0.8 | 1.4 | 0.7 | 0.64 | 119.2 | 8.5 |
|         |              |          | CG      | 6.4 | 0.6 | 1.0 | 7.5 | 2.15 | 197.4 | 16.5 |
Fluvisol mollic-gleyic, Anthrosol mollic-gleyic and recently used soils. Low contents of nitrate and ammonium nitrogen are observed in soils which have long been used as croplands (sites nos. 5-6).

| Site no. | Soil          | Horizon | Granulometric composition, % | Phys. loam cont. | Name acc gran. comp. |
|----------|---------------|---------|-----------------------------|-------------------|----------------------|
|          |               |         | 1-0.25 | 0.25-0.05 | 0.05-0.01 | 0.01-0.005 | 0.005-0.001 | <0.001 |                   |               |
| 1-2      | Anthrosol     | AYpu    | 3.8    | 38.2      | 37.2      | 3.2       | 5.6       | 12.0    | 20.8               | l. l.          |
|          |               | P       | 3.2    | 31.6      | 44.8      | 3.6       | 6.0       | 10.8    | 20.4               | l. l.          |
|          |               | C       | 9.3    | 57.5      | 18.0      | 1.2       | 3.6       | 10.4    | 15.2               | s. l.          |
| 3        | Chernozem     | AU      | 12.0   | 22.8      | 32.4      | 13.2      | 4.4       | 15.2    | 32.8               | m. l.          |
|          |               | BCA     | 31.5   | 20.9      | 23.6      | 5.6       | 8.4       | 10.0    | 24.0               | l. l.          |
|          |               | Cca     | 8.6    | 57.0      | 18.0      | 3.2       | 3.2       | 10.0    | 16.0               | s. l.          |
| 3-4      | Anthrosol     | W       | 12.3   | 64.9      | 6.0       | 2.8       | 5.0       | 8.2     | 18.0               | s. l.          |
|          |               | P       | 12.0   | 70.8      | 6.8       | 2.8       | 2.0       | 5.6     | 10.4               | s. l.          |
|          |               | C       | 10.6   | 71.0      | 8.4       | 1.2       | 3.2       | 5.6     | 10.0               | s. l.          |
| 5-6      | Anthrosol     | P       | 1.8    | 54.2      | 23.2      | 5.6       | 5.2       | 10.0    | 20.8               | l. l.          |
|          |               | C       | 5.0    | 72.0      | 10.4      | 1.8       | 1.4       | 5.6     | 8.8                | sand           |
|          |               | PC      | 2.1    | 52.3      | 22.4      | 5.2       | 5.6       | 12.4    | 23.2               | l. l.          |
|          |               | C       | 5.0    | 76.2      | 10.4      | 1.6       | 1.2       | 5.6     | 8.4                | sand           |
| 6        | Gray          | AY      | 49.7   | 18.7      | 9.6       | 4.8       | 4.8       | 12.2    | 22.0               | l. l.          |
|          |               | AEL     | 13.4   | 21.4      | 44.8      | 3.5       | 6.1       | 10.8    | 20.4               | l. l.          |
|          |               | BEL     | 13.8   | 28.1      | 37.3      | 3.2       | 5.5       | 12.1    | 20.8               | l. l.          |
|          |               | BT      | 42.8   | 26.0      | 8.4       | 6.4       | 5.2       | 11.2    | 22.8               | l. l.          |
|          |               | C       | 46.3   | 26.9      | 8.0       | 4.8       | 5.6       | 8.4     | 18.8               | s. l.          |
| 11.12    | Fluvisol      | T       | -      | -         | -         | -         | -         | -      | -                  | -              |
|          | mollic-gleyic | H       | 3.0    | 32.2      | 44.7      | 3.5       | 6.5       | 10.1    | 20.1               | l. l.          |
|          |               | G       | 7.9    | 50.1      | 15.2      | 6.0       | 9.6       | 11.2    | 26.8               | l. l.          |
| 15.16    | Anthrosol     | PH      | 3.2    | 31.9      | 42.3      | 5.9       | 6.3       | 10.4    | 20.2               | l. l.          |
|          | mollic-gleyic | H       | 3.5    | 31.6      | 44.8      | 3.5       | 6.1       | 10.5    | 20.1               | l. l.          |
|          |               | G       | 8.8    | 56.8      | 18.0      | 3.3       | 3.1       | 10.0    | 16.0               | s. l.          |
|          |               | CG      | 61.5   | 25.3      | 3.2       | 2.8       | 2.4       | 4.8     | 10.0               | s. l.          |

Note: l. l. – light loam, m. l. – medium loam, s. l. – sandy loam.

According to the scale of the FBGU Center of Agrochemical Service Irkutskii, the content of nitrate nitrogen is characterized as: very low, <4; low, 4-8; medium, 8-15; above medium, 15-20; high, 20-25, and very high, >250 mg/kg [8].

4. Conclusion
The research revealed that the soils of fallow lands and croplands which were previously under forest (sites nos. 1-2 and 5-6) are low in fertility and need application of nitrogenous and potassic fertilizers. The soils that have been put to agricultural use recently need application of phosphorus and potassic fertilizers. A shortage of them is due to a predominance of organic matter and to low content of mineral substances in soils. Concentrations of ammonium and nitrate nitrogen in them are sufficient for plant nutrition. Chernozems and Gray soils of natural landscapes, and also Anthrosols which were previously under steppe (former Chernozems) are in good and satisfactory agronomic condition. However, as our investigations showed, after deforestation and when used as croplands Gray soils degrade rapidly and lose their fertility. Steppe soils and former Chernozems (for instance, sites no. 3-4) show a good sustainability to agricultural use.
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