Spatio-temporal heterogeneity of soil cover in Baikal area and its impact on the development of agriculture in the region

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Abstract. The soil cover of the territory of Baikal region is characterized by a significant variety, and the structure of soil cover – by a high complexity due to complex geological history of the region, to the influence of tectonic processes of the Baikal rift zone, to the wide spread of young mountain systems, island permafrost and other factors. Distribution of loess rocks at the territory of the forest-steppe zone of Baikal region contributes to the genesis of fertile soils, but increases the heterogeneity of soil cover, which should be considered in agricultural land use.

1. Introduction
At the present stage of land reform development, the most important issues are the management of land resources and primarily - agricultural land. At the question of food security relating (to) soil, the special attention need to be focused at aspect of its availability, which propose to use of a complex approach for sustainable food production by sustainable agricultural management [1]. This depends of many factors: on the availability of natural resources (such as available land surface, topography, soil distribution and soil quality, availability of water, biodiversity and activity of natural biota and climatic conditions [2]. The necessary tool and basis for sustainable land use and development of territories is their physical and geographical zoning [3].

To increase the crop areas and more rational use of them, it is necessary to study in-depth the heterogeneity of soil cover, soil typology, genesis and evolution of soils, the features of the impact on soil properties of various factors, which determine criteria for decision-making on modernization of technological methods of land use and regulation for cadastral cost of lands. All this determines the goal and relevance of the study.

2. Objects and methods
The object of this study is the soil cover of the Baikal area, its heterogeneity and its impact on the development of agriculture at the region. The study was carried out based on the authors' own field and laboratory studies, as well as on the analysis of literary material with using of soil-morphological, pedo-lithological, genetic-classification, comparative-historical and comparative-geographical, etc. approaches and methods of research, also – methods of decoding aerospace images of remote sensing of the Earth, analysis of soil cover structures, factors and conditions of soil formation. The main area of investigation was the Irkutsk-Cheremkhovo plain, Tulun, Irkutsk and Bratsk districts of Irkutsk region (figure 1).
3. Physical and geographical features of Baikal region

The Irkutsk region is one of the largest regions of the Russian Federation (774 846 km$^2$ of the territory of Russia). By area it occupies the 5th place among 83 subjects of Russian Federation and the 2nd - in the Siberian Federal district (figure 1).

The location of Irkutsk district at the center of Asian continent, at the junction of two large tectonic structures - the Siberian platform and the ancient folded frame – the Baikal rift zone (BRZ), at zone of sharply continental climate, along with influence of the Siberian anticyclone - causes a great diversity of physical-geographical conditions of the territory development and heterogeneity of its soil cover.

During the Pleistocene time Western Baikal area was at zone of continuous distribution of permafrost, with a capacity of 200 m and more. At present time, the islands of degraded permafrost (up to 50-60 m; temperature 0$^\circ$-1$^\circ$ С), are preserved on the flat territory. Intermittent and continuous permafrost is preserved only at the highlands. In river valleys and depressions permafrost capacity reaches up to 20-25 m, at the steppes of the Olchon region – up to 45-80 m (figure 2).

![Figure 1. Physical and geographical features of Baikal region; a – mainly investigated area of Irkutsk-Cheremkhovo plain, Irkutsk and Bratsk districts of Irkutsk area.](image1)

![Figure 2. Schematic map of permafrost zoning of Baikal area: A - province of perennial frozen rocks of southern part of Siberian plateform; B - province of perennial frozen rocks of Baikal mounted-folded zone.](image2)

In Holocene, after thawing thick ice cracks there was formed post-cryogenic hillock-pit relief with the excess of the hillock above pit ~1 m or more. 70-80% of the territory is located at areas with hillock-pit relief (~ 50% of them falls to arable lands).

Natural resource zoning of Baikal Siberia identifies of 2 main areas for the territory of Irkutsk region [4-6]: 1) the Angaro-Lensky area of the Siberian platform with three subareas: Irkutsk-Tulunsky (of Irkutsk depression of pre-Sayan uplift deflection), Bratsk-Ust-Ilimsky (of Katangskaya saddle and Fraternal ledge) and the NEPA-Boubinsky (of Angara-Lensky step and NEPA-Boubinsky antecline); 2) the Sayan-Baikalsky area of Baikal fold system (BFS) with 4 subareas: Eastern-Sayan sky folded area; Baikalsky (of regional geanticlinal raising); North-Baikalsky (of North-Eastern mountain branch) and Vitimsky (of South-Eastern mountain branch).

The geology of the most agricultural-developed territory of the forest-steppe zone of the Baikal region is represented by a wide spread and their output to the surface of loamy sediments (including sandstones, conglomerates and siltstones, coal-bearing, carbon free) of the Jurassic age and red-colored carbonate-silicate (rarely gypsum-bearing) siltstones of sedimentary genesis of upper Cambrian. The pre-Baikal foothill deflection is represented by Jurassic sediments and Paleogene and Neogene sediments of marsh and lake facies. The eluvial-deluvial surface’ deposits of these rocks at the slopes
become an object of intensive erosion processes. The activity of the Sayano–Baikal rift zone is manifested in high seismicity. Frequent earthquakes with high vibration amplitude (from 9 and more points) are recorded here.

The relief of the forest-steppe zone, which is part of the structure of Lena-Angarsk wavy-sloping plateau, have been dissected by deep ancient river valleys and is represented by the alternation of anticlinal ridges and synclinal depressions with a large amplitude of the relative height fluctuations (up to 300 m). The processes of denudation alignment of the relief, which was beginning from Cretaceous-Paleogene time, led to the development of gentle valleys, hollow and other forms of meso- and micro-relief of Neogene-Quaternary time. The activity of aeolian-slopes-water-erosion processes is manifested in the forms of wind blowing fragments, dunes, deluvial plumes, ravines and gullies, which are well diagnosed on aerospace images (figure 3) and reducing the quality of agricultural lands.

4. **Heterogeneity of the soil cover of Baikal area and its impact on agriculture in the region**

Due to the high tectonic activity of subsequent periods, the mountain systems of the south part of Eastern Siberia were finally formed, which led to the development of mountain-valley glaciations here. The rapid growth at the mountains above a mantle plume within Sayan mountains has led to the periodic formation of large glaciers here, the capacity of which can reach 3 km [7]. Each era of the cold climate was accompanied by a multi-scale glaciations around the mountain framing of the lake Baikal, including Sayan mountains [8]. In the second half of Pliocene there was the formation of Altai mountain country [9]. The arid climate of the Pliocene was contributed to the replacement of broad-leaved forests of Turgay flora by small-leaved biocenosises; to formation of steppe and semi-desert vegetation and accumulation of powerful thicknesses of dusty sediments in most of the Irkutsk region.

The cold and dry climate of the Pleistocene (Sartan time) was caused of deep permafrost cracking of the valley 'soil cover and formation of "cores" of vein ice [10-12]. The degradation and thaw out of ice during the subsequent climate warming led to xerophytization of biocenosises and to formation of the hillock-deepening relief [13-15], which is well manifested at the air-space images of the studied territory by the characteristic "mesh" structure of the surface (figure 3 (a, b)).

![Figure 3](image3.png)

**Figure 3.** Space images of relief and soil cover' structures of the Lena-Angarsky forest-steppe on the example of the Balagansky district of the Irkutsk region (see explanations at the text).

Postglacial warmings of the Pleistocene and Holocene have been contributed to the sediment accumulation of loess material with complex water-glacial and aeolian genesis. At the middle and lower parts of the slopes of gently rolling landforms, the deposits of Cambrian siltstones are often blocked by loess and loess-like carbonate loams with a thickness of 4-5 m (in some places - up to 15 m). "These loess deposits, which are covering of large areas of the Irkutsk region, contributes to the formation of fertile chernozems and gray soils on them. 70-80% of the territory is located in areas with hillock-pit relief (~ 50% of them falls to arable lands).
Soil formation at Baikal region was particularly affected by climate change in Holocene-Pleistocene, which is resulting in "imposition" of modern processes of soil formation into the profiles of more ancient soils and formation of the buried horizons.

All these processes contributed to the formation of spatio-temporal heterogeneity of the soil cover of Baikal region, including its uplands, hillock-deepening, erosional and gley components. The erosion' traces at upper parts of the slopes' territories of hilly-ridge terrain are well diagnosed at air space photos. They are reflected as forming washout hollows of slope relief (figure 3 (c, d)), as a gully-hollow network (figure 3 (e, f)), as a characteristic waviness (like "shagreen skin") at the slopes (figure 3 (j)), and as mesh pattern of micro-complexes (figure 3 (h, i)), also as a redistribution of humus soils’ substances, connected with their drift down the slope by melt, rain waters and deflation processes, which is especially typical for arable lands.

The heterogeneity and spotting of the soil cover of the territory is also associated with the spread of karst phenomena and karst failures, especially at the places of distribution of carbonate rocks of Cambrian, loess and loess-like loams. Thus, the soil cover of the Baikal region is characterized by a significant variety (figure 4).

Figure 4. Map of soils and soil complexes of Irkutsk region [18].

Soil complexes:
1. Podzols+Albrluvosol
2. Umbric Albeluvisols+Podzoluvisols+Luvisols
3. Cambisols+Cambic Umbrisols
4. Cryosols+Histosols
5. Gray Luvic Phaeozems + Mollic Umbrisols
6. Luvisols
7. Kastanozems
8. Gleysols+Stagnosols+Histosols
9. Fluvisols+Gleic Phaeozems+Molic Gleisols
10. Ferralic (Folic) Podzols
11. Umbric (Molic) Leptosols +Regosols

Soil Types:
a. Podzol
b. Albeluvisol
c. Endocalcaric Cambusol
d. Umbric Cryosol
e. Gray Luvic Phaeozem
f. Histic Gleysol
g. Umbric Callic Fluvisol
h. Luvic Chernozem
i. Molic Leptosol

The structure of the soil cover is of high spatial-temporal heterogeneity and complexity [16-18] due to various geological history of the region, to wide spread of young mountain systems, of islands of permafrost (especially in valleys and depressions), to the influence of seismic and tectonic processes of BRZ, influence of loess deposits, karst processes, dissection of terrain, hillock-pit relief and other factors. Physical and chemical properties of humus horizons of soils, which are mostly used in agriculture, are shown in table 1.
Table 1. Indicators of physical and chemical properties in humus horizons of some types of arable soils of the Lena-Angarsky forest-steppe (average data/variation boundaries).

| Soil type according to classification WRB (RU 2004) | Number of soil cuts | Depth, cm | pH<sub>H2O</sub> | Humus % | Ca<sup>2+</sup>, mg-equiv/100g | Mg<sup>2+</sup>, mg-equiv/100g | Σ fractions (mm), %: <0.001; 0.001-0.005; 0.005-0.01 | CO<sub>2</sub>, % |
|--------------------------------------------------|---------------------|-----------|----------------|---------|-------------------------------|-------------------------------|-----------------------------------------------------------------|------------|
| Chernozem (Mollic Epi-Calcic)                    |                    |           |                |         |                               |                               |                                                                 |            |
| Bal (17-12)                                      |                     |           |                |         |                               |                               |                                                                 |            |
| AU (0-21)                                        | 46                  | 22-38     | 8.5            | 4.7     | 31.8                          | 6.0                           | 43                                                               | 5.8        |
| AUBIc (21-29)                                    |                     |           |                |         |                               |                               |                                                                 |            |
| BMKdc (29-54)                                    |                     |           |                |         |                               |                               |                                                                 |            |
| BMKdc (54-61/74)                                 |                     |           |                |         |                               |                               |                                                                 |            |
| [AJdc] (61-66/74)                                |                     |           |                |         |                               |                               |                                                                 |            |
| [BMKdc,q] (74-95)                                |                     |           |                |         |                               |                               |                                                                 |            |
| [BCq,dc,ro] (95-..)                              |                     |           |                |         |                               |                               |                                                                 |            |
| Chernozem (Mollic Epi-Calcik (Uric)              |                     |           |                |         |                               |                               |                                                                 |            |
| Bal (17-4)                                       |                     |           |                |         |                               |                               |                                                                 |            |
| PUpa,ic (0-10)                                   |                     |           |                |         |                               |                               |                                                                 |            |
| PU(ic) (10-30)                                   |                     |           |                |         |                               |                               |                                                                 |            |
| AU(ic) (31-35)                                   |                     |           |                |         |                               |                               |                                                                 |            |
| AU (30-40)                                       |                     |           |                |         |                               |                               |                                                                 |            |
| BCA1,dc (45-55)                                  |                     |           |                |         |                               |                               |                                                                 |            |
| BCAmc (55-73)                                    |                     |           |                |         |                               |                               |                                                                 |            |
| BCca (73-85)                                     |                     |           |                |         |                               |                               |                                                                 |            |
| Cca (85-95)                                      |                     |           |                |         |                               |                               |                                                                 |            |
| Chernozem (Umbric Epi-Calci)                    |                     |           |                |         |                               |                               |                                                                 |            |
| Bal (17-8)                                       |                     |           |                |         |                               |                               |                                                                 |            |
| AY (3-9)                                         |                     |           |                |         |                               |                               |                                                                 |            |
| AYel (9-18)                                      |                     |           |                |         |                               |                               |                                                                 |            |
| BM(f) (18-36)                                    |                     |           |                |         |                               |                               |                                                                 |            |
| BC(t) (36-52)                                    |                     |           |                |         |                               |                               |                                                                 |            |
| [AJdc] (52-70)                                   |                     |           |                |         |                               |                               |                                                                 |            |
| [BMKdc] (70-80)                                  |                     |           |                |         |                               |                               |                                                                 |            |
| [BCm,dcc] (80-104)                               |                     |           |                |         |                               |                               |                                                                 |            |
| [CDca] (104-118)                                 |                     |           |                |         |                               |                               |                                                                 |            |
| [D] (118-125+)                                   |                     |           |                |         |                               |                               |                                                                 |            |
| Umbrisols (Cambic Taptoksantik) (Bal-17/8)       |                     |           |                |         |                               |                               |                                                                 |            |
| AY (3-9)                                         |                     |           |                |         |                               |                               |                                                                 |            |
| AYel (9-18)                                      |                     |           |                |         |                               |                               |                                                                 |            |
| BM(f) (18-36)                                    |                     |           |                |         |                               |                               |                                                                 |            |
| BC(t) (36-52)                                    |                     |           |                |         |                               |                               |                                                                 |            |
| [AJdc] (52-70)                                   |                     |           |                |         |                               |                               |                                                                 |            |
| [BMKdc] (70-80)                                  |                     |           |                |         |                               |                               |                                                                 |            |
| [BCm,dcc] (80-104)                               |                     |           |                |         |                               |                               |                                                                 |            |
| [CDca] (104-118)                                 |                     |           |                |         |                               |                               |                                                                 |            |
| [D] (118-125+)                                   |                     |           |                |         |                               |                               |                                                                 |            |
| Cambisol Umbric Epi-Calcaric (Bal-17/13)          |                     |           |                |         |                               |                               |                                                                 |            |
| AY (3-9)                                         |                     |           |                |         |                               |                               |                                                                 |            |
| AYel (9-18)                                      |                     |           |                |         |                               |                               |                                                                 |            |
| BM(f) (18-36)                                    |                     |           |                |         |                               |                               |                                                                 |            |
| BC(t) (36-52)                                    |                     |           |                |         |                               |                               |                                                                 |            |
| [AJdc] (52-70)                                   |                     |           |                |         |                               |                               |                                                                 |            |
| [BMKdc] (70-80)                                  |                     |           |                |         |                               |                               |                                                                 |            |
| [BCm,dcc] (80-104)                               |                     |           |                |         |                               |                               |                                                                 |            |
| [CDca] (104-118)                                 |                     |           |                |         |                               |                               |                                                                 |            |
| [D] (118-125+)                                   |                     |           |                |         |                               |                               |                                                                 |            |

Figure 5. Granulometric fractions’ composition (mm) of forest-steppe soils of Baikal region.
The most agricultural-developed area of Irkutsk-Tulun sub-district of Baikal region is represented by subtaiga, steppe and forest-steppe landscapes. Soil formation here occurs mainly on loess and on loose loess-like loamy carbonate deposits with sufficient heat supply and significant participation of herbaceous vegetation, low moisture, which causes the formation of forest’ complexes of Gray Luvic Phaeozems and Mollic Umbrosols (Gray and Dark Gray soils) with Cambisols and Cambic Umbrosols (Gray metamorphic soils and Burozems) [19, 20].

The steppe areas are occupied by Luvic-Chernic Chernozems (Chernozems typical micellar, clay-illuvial and textural-carbonate) and Epigleic Phaeozems (Chernozem-like (meadow-chernozem) soils) with a small proportion of solonetz’ and saline’ soils along the river valleys.

As we can see, the soils of the forest-steppe area of Baikal region are characterized by a fairly high level of fertility. Natural factors, limited of the agricultural development, include; sharply continental climate, the presence of permafrost, the dissection and hillock-hollow landforms of relief, heterogeneity and high complexity of soil cover. Agriculture is mostly developed at the southern part of the region on the plains and floodplains. Moreover, at areas with hilly-hollow relief there are located of 70-80% of agricultural lands, of which 50% is arable lands. So, the level of soil fertility of Baikal forest-steppe area has been affected by sharply continental climate, presence of permafrost, fragmentation, hillock- hole landforms, heterogeneity and high complexity of the soil cover.

The hard-loamy-clay granulometric composition of studying soils contributes to the formation of soil’ fertility, to form their exchange capacity and structure, but simultaneously it contributes to the development of erosion processes of loose sediments and the formation, thus, heterogeneity and complexity of soil cover of the study area.

Paleo-cryogenic phenomena are manifested at a small depth from the modern surface and determine the properties of soils: physical characteristics of soils; the migration of moisture; the migration of soluble and mobile substances.

Frost-resistant structures have a reduced density of addition, so they serve as channels for vertical discharge of atmospheric precipitation. It is difficulty to smooth out of the diversity of soils (within hillock- pit complex) and the differences in their fertility by existing agronomic techniques.

In most developed (respecting agriculture) southern areas of Baikal region there are about 70-80% agricultural lands (of which 50% are arable lands), which are located on floodplain and lowland areas with hilly-hole relief. The main soil’ types [21-24] of arable lands and their main properties and distribution are represented in table 2.

As part of the arable lands’ fund, the most common are Gray Mollic Umbrosols (Gray residual carbonate soils) – 47.7 %; Cambic-Epi-Calcic Umbrosils (Burozems and gray metamorphic soils) are amount 35.5%. The share of Mollic Calcic Chernozems (Chernozems texture-carbonate) accounts for 7.4% of the area size, of Voronic Gleyic Chernozems (Chernozems-like (meadow-chernozem) soils) – for 3.2 %, of Fluvisols (Alluvial soils of floodplains) – for 2.4 %, of Albeluvisols (Sod-podzolic soils) – for 1.9 %, Gleyic Phaeozems (Dark humus-gley soils of meadows) – for 1.6%, of others – for 0.3 % of the total area of arable lands [25].

Baikal region is not good for agriculture. Factors, which are limited on development of agricultural production are agro-climatic features of Baikal region: severe long winter (175-200 days); Σ, >10°=1300-1770°C; Σ precipitation per year = 210-450 mm; late spring and early autumn frosts; slow melting of the soil due to deep freeze; low soil temperature, especially during the "sowing – germination" period, which reduces the mobilization of soil nutrients; negative impact of low soil temperatures on plant nutrition at the beginning of vegetation. At the soil ‘temperature about 5 -10°C there is the worst consumption of nitrogen and phosphorus by plants, more intensively - of potassium.

Meanwhile, the region has one of the lowest indicators of population availability of arable lands. If on average in Russia it accounts for 0.89 hectares of arable land per inhabitant; in the Irkutsk region – it’s only 0.46 hectares. The state of more than 20% of agricultural lands of the region is assessed as unsatisfactory. The intensive and unsystematic using of lands leads to decrease in land’ fertility.

The main area of agricultural land is located along the Trans-Siberian railway through the valleys of the Angara and Lena rivers. The highest level of agricultural use corresponds to the lands of the Ust-
Ordyn Buryat district, where the share of agricultural land accounts to more than 53 % and to 4 areas with the most favorable climatic conditions and with high level of labor resources: Irkutsky, Angarsky, Usolsky, Cheremkhovsky.

Table 2. The main soil’ types of arable lands and their properties.

| Soil’ types WRB (RU(2004)) | Stotal thousand hectares | S%, arable lands | Distribution of soil types by landforms of the relief, agrochemical parameters, level of fertility |
|-----------------------------|--------------------------|-----------------|------------------------------------------------------------------------------------------------|
| Phaeozems and Albeluvisols: total | 760 | 47 | Forest-steepe zone |
| Albeluvisols (Sod-podzolic) | 109 | 7 | Forest zone. Tops of ridges, top of slopes; low level of natural fertility; slightly acidic and acidic, low level of P\textsubscript{2}O\textsubscript{5}, K\textsubscript{2}O (available); (*)\textsuperscript{a} |
| Phaeozems (Greyic) (Grey (forest)) | 381 | 24 | Gently sloping ridges, low hills and plains. High level of natural fertility (slightly acidic, 4-8 % of humus, medium and heavy loam); (*) |
| Phaeozems (Mollic-Epi-Calcic) (Dark grey residual carbonate) | 270 | 36 | The bottom of the ridges, low-lying areas of terraces; high level of natural fertility (4-8 % of humus); (*) |
| Umbrisols Cambic-(Mollic)-EpiCalcic (Gray metamorphic and Burozems (residual carbonate)) | 578 | 37 | Forest-steepe-zone; the upper parts of hillsides. Soils are prone to dislodging at the period of waterlogging and dust covering during the dry period; high level of natural fertility, (weakly alkaline, heavy loam, 4-6 % of humus, high carbonate); (*) |
| Chernozems (Mollic-Calcic) (Chernozems texture-carbonate) | 130 | 8 | Steepe zone. Soil rocks - sedimentary, loess-like of proluvial-deluvial and alluvial genesis. Soils are prone to dusting, dislodging and to forming of a crust. High carbonate, neutral/weakly alkaline; high level of humus (5-10%) and of natural fertility; (*) |
| Chernozems Voronic-Gleyic (Chernozem-like (meadow-chernozems) | 75 | 5 | The lower parts of the slopes and ravines. Soil is thawed in late spring, with early autumn frosts. Large capacity of humus horizon (up to 80 sm), high level of natural fertility; high carbonate, P\textsubscript{2}O\textsubscript{5} and K\textsubscript{2}O (available); neutral/ weakly alkaline. |
| Albeluvisols Cutanic (Sod-podzolic soils); Phaeozems Gleyic (dark humus-gleyic soils of meadows); Fluvisols Umbric (alluvial sod-grey-humus) and others | 59 | 4 | Soils do not have a significant impact for making of agricultural products and are used for growing forage crops of late sowing. |

\textsuperscript{a}Notice: (*) - exposed to wind and water erosion

Natural-agricultural industrial zoning of the Baikal region distinguishes of 3 zones:
1. The subtaiga-taiga forest zone is area of insufficient heat supply of agricultural crops. $\sum_{\text{precipitation per year}} = 350-450$ mm. Soils: Albeluvisols (Sod-podzolic); Greyic Phaeozems (Grey (forest)); Cambic-(Mollic)-EpiCalcic Umbrisols (Gray metamorphic and Burozems (residual carbonated)). The area of arable land is of 289 thousand hectares.
2. Forest-steppe zone has relatively more favorable climatic conditions: \( \Sigma \text{precipitation per year} \) is of 300-400 mm; deficit of moisture in spring and early summer. Soils: Greyic Phaeozems (Grey (forest) - 59%; Mollic-Epi-Calcic Phaeozems (Dark grey residual carbonated) - 20 %, Mollic-Calcic Chernozems (Chernozems texture-carbonated) - 8%, Albeluvisols (Sod-podzolic) – 1%. The area of arable land is of 834 thousand hectares.

3. Steep zone. This is the main agricultural zone of the region, which produces 60% of the regional agricultural production. Soils: Mollic-Calcic Chernozems (Chernozems texture-carbonated), kashtanozems (with solonchaks and solonetzes). The area of arable land is of 504 thousand hectares.

Between 1990 and 2015, there was a significant increase in arable lands with low (4 \%) humus content (up to 790.5 thousand hectares or 47 \%). The area of acidic soils reached 594.4 thousand hectares (35.1 \%) of arable land, including strongly acidic soils, requiring of liming - 146.6 thousand hectares.

During the process of implementation of agrarian reforms of the Russian Federation of 1990 at Baikal region there was a significant reduction of lands area, including agricultural. There were next reasons of this: 1) increase of territories of settlements and expansion of industrial construction; 2) creation of 4 hydroelectric power stations on Angara river, mineral extraction (1995-2005); 3) voluntary abandonment of agricultural enterprises from the lands, given to them earlier (because of their unsatisfactory economic condition and fertility decline); 4) location of the territory at zone of risky agriculture: the need for large investments to the economy, seed production, chemicals and technologies to get a decent return from the land that only large agricultural holdings can afford.

As shown in Table 3, the most areas of arable lands has medium and low indicators of agrochemical properties of the region. And also there is another massive problem for the region with influence into soils of acidity: huge areas are exposed to acidification (table 3).

| Indicators        | Soil area, a thousand hectares |
|-------------------|--------------------------------|
|                   | Very low| Low | Medium | Above the average | High | Very high |
| Humus             | 98.6    | 585.9 | 449.1  | 288.3            | 83.7 | 29.4      |
| Mobile phosphorus | 35.1    | 146.1 | 619.2  | 349.6            | 255.1| 129.7     |
| Exchange potassium| 18.3    | 448.5 | 655.4  | 278.0            | 108.8| 26.4      |
| Degree of acidity | 2.40    | 16.0  | 111.2  | 374.6            | 309.6| 721.6     |

As part of the lands of the Irkutsk region (the area of which is equal to 77485 thousand hectares), agricultural developed lands are amounting of 3.6 \%, and arable lands are amount 2.2 \% [26].

Our analysis of the data (table 4) received by FSBI Center of agrochemical service "Irkutsky" [27] have shown that at the most developed by agricultural production Irkutsk-Tulun district of the Irkutsk region, only 2387.6 thousand hectares are occupied by agricultural lands, including arable land (which are amount 16116 thousand hectares), of which today only 56.2\% are used for agricultural production.
Table 4. The structure of agricultural land in Irkutsk-Tulun district of the Irkutsk region.

| Region          | Arable land | Arable land used | Unused arable land | Arable land, suitable for introduction in agricultural turnover |
|-----------------|-------------|------------------|--------------------|---------------------------------------------------------------|
|                 | thousand hectares | thousand hectares | % of arable land | Subtotal: including, thousand hectares | % of arable waterlogged /flooded | eroded /afforest. /shrubby | thousand hectares | % of arable |
| Irkutsky zone   | 921.27      | 471.01           | 51.1               | 450.26 | 48.9     | 1.8          | 116.7             | 89.48       | 242.28        |
| Tulunsky zone   | 690.32      | 434.23           | 62.9               | 256.09 | 37.1     | 6.1          | 17.9              | 120.52      | 111.57        |
| Subtotal:       | 1611.29     | 905.24           | 56.2               | 706.35 | 43.8     | 7.9          | 134.6             | 210.0       | 353.85        |

The analysis of the structure of agricultural lands of the most developed areas of Irkutsk-Cheremkhovo plain demonstrates significant areas of arable lands, which are currently unused due to problems of waterlogging, flooding, erosion and deflation, overgrowing with bushes, etc. (table 5) and are often a consequence of the heterogeneity of the soil cover.

Table 5. Indicators of arable lands’ degradation of Baikal region.

| Natural zone | Area of arable land, a thousand hectares | Unused | Flooded | Eroded | Forestry/bushy | Suitable for agriculture |
|--------------|------------------------------------------|--------|---------|--------|----------------|-------------------------|
| Forest-steppe| 315.8                                    | 0.8    | 37.8    | 109.1  | 151.1          |                         |
| Steepe       | 192.9                                    | 62.1   | 27.6    | 103.3  |                |                         |
| Taiga        | 197.7                                    | 7.1    | 17.7    | 73.3   | 102.2          |                         |
| TOTAL        | 706.4                                    | 7.9    | 117.6   | 210.0  | 356.6          |                         |

Soil washout on arable land reaches an average of 5-10 t/ha per year [28]. Unsystematic forest uprooting and soil plowing, intensive grazing and non-compliance with anti-erosion measures contributed to the strengthening of erosion processes.

Considering the complexity of the soil cover, the impact of heterogeneity of the fields’ relief on the soils’ properties and their fertility, we can say that the most cost-effective technology of agriculture at the region is a comprehensive high-tech agricultural management system of "Coordinate agriculture", which includes global positioning technology (GPS, GLONASS, Galileo), special programs for agricultural management based on geographic information systems (GIS), Yield Monitor Technologies, Variable Rate Technology, earth remote sensing (ERS) and other technologies’ solutions, that allow not only to maximize profits, but also to significantly to improve the ecological quality of production through the redistribution of norms and plans for fertilization.

5. Conclusions
The analysis of the soil cover of the Baikal region allows us to conclude the following:
1. the complex geological and temporal history of investigated area led to the formation of a wide soils’ diversity at the region, of many types of spatial heterogeneity and complexity of soil cover;
2. the relief and lithology of Baikal region on the background of the influence of permafrost and climate - are the factors of the greatest contribution to formation of soil cover structure;
3. the regional features of the soil cover of the most developed agricultural lands of Irkutsk region, confined to the Irkutsky and Lena-Angarsky forest-steppe zones, are largely determined by the wide
spread of Cambrian siltstones, loess and loess-like rocks. These rocks due to their material composition
and physical-chemical properties, carbonation content neutralize of the podzolic process of forest’ soils,
create an optimal water-air regime and conditions, favorable to humus accumulation in soils. All this
leads to formation of fertile soils: Molic-Calcic Chernozems (Chernozems texture-carbonated),
kaushtanozems (with solonchaks and solonetzes); Greyic Phaeozems (Grey forest); Mollic-Epi-Calcic
Phaeozems (Dark grey residual carbonated); Cambic-(Mollic)-EpiCalcic Umbrisols (Gray
metamorphic and Burzozems (carbonated);

4. The fund of arable lands of the most developed agricultural areas of Baikal region have been quite
significantly (~50%) reduced by the heterogeneity and complexity of soil cover, along with the
processes of erosion, waterlogging, afforestation, acidification, etc. This suggests the needless for the
development and implementation of scientific-based methods of landscape-adaptive farming, including
technology of comprehensive high-tech agricultural management system of "Coordinate agriculture",
considering the heterogeneity and regional specificity of the soil cover of the region.

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