Modern assessment of soil resources of Kyrgyzstan

A A Shpedt¹,² and Yu V Aksenova³

¹ Krasnoyarsk Research Agricultural Institute, Federal Research Center “Krasnoyarsk Research Center, Siberian Branch of the RAS”, Krasnoyarsk, 660041, Russia
² Siberian Federal University, 79, Svobodnyj ave., Krasnoyarsk, 660041, Russia
³ Omsk State Agrarian University, 1, Institutskaya sq., Omsk, 644008, Russia

E-mail: yuv.aksenova@omgau.org

Abstract. A comparative assessment of the natural potential of mountain-valley soils of Kyrgyzstan was carried out. The assessment score was determined by the soil-ecological index (SEI). The calculation of the SEI for the main soil types showed that the most valuable soils are formed under moderately cool and humid climate and are represented by low-humic chernozems and Turanian dark grey soils, with an estimated score of 41–37. The increase in climate aridity and an increase in the accumulated temperature above 10°C contribute to the formation of less fertile Turanian typical grey soils, northern grey soils, and chestnut soils. The SEI of these soils varies from 25 to 32 points. Grey-brown desert and light brown soils of the Central Tien Shan, developing under conditions of high moisture deficit, have the minimum scores (13, 16 points). SEIs are largely determined by soil and climate indices. The agrochemical index is estimated by a similar score throughout the study area, since all soils are poor in nitrogen and phosphorus, provided with potassium and differ only in humus content. The value of the climate index to a greater extent depended on the moisture supply of the territories. The soil index varied within 1–2 points and significantly decreased only in soils of varying degrees of erosion, salinity and rockiness.

1. Introduction
The land reserve of the Republic of Kyrgyzstan is about 20 million hectares; 10.2 million hectares are occupied by agricultural land. The territories of the intermontane basins and plains are completely transformed into cultural landscapes. Viticulture, horticulture, melon-growing and vegetable-growing are developed here, all plantations of cotton, tobacco, rice and the main crops of cereal and industrial plants are located here. Intensive use of soils as arable and fodder lands led to their unsatisfactory condition, since 88% of lands are subjected to the degradation processes [1, 2]. The decrease in soil fertility in Kyrgyzstan, as well as in other republics, states, large regions [3], is influenced by the progressive development of solonization, salinization [4, 5], overwetting and waterlogging of lands, wind erosion and deflation [6, 7], choking up with stones. Soil degradation causes Kyrgyzstan a great economic damage, reducing crop yields by 20–60% [8].

2. Materials and Methods
The objects of the study were the soils of intermontane troughs and syrt uplands: Turanian light grey soil, Turanian typical grey soil, Turanian dark grey soil, northern light grey soil, northern dark grey soil, light chestnut soil, dark chestnut soil, grey-brown desert soil, light brown soil of the Central Tien Shan,
light chestnut soil of intermountain troughs, dark chestnut soil of intermountain troughs, low-humic chernozem.

The value of land as the main means of agricultural production is determined by its fertility, qualitative and quantitative changes in soil properties under the influence of various degradation processes. To date, many methods have been developed for a comprehensive assessment of soil fertility and valuation of agricultural land, taking into account the totality of their properties and characteristics, crop yields and forage land productivity [9, 10].

Soil-ecological assessment of agricultural land was carried out according to Karmanov [11] on the basis of soil, agrochemical properties and climatic indices, which reflect the total influence of soil fertility, climatic and geomorphological conditions on soil productivity.

The initial data for calculating the soil ecological index (SEI) were taken from the materials of previously conducted soil agrochemical surveys of the territory of Kyrgyzstan [12–14]. To characterize the soils, we used data on the humus content, soil reaction (pH), particle size distribution, the temperature of the warmest and the coldest months, the latitude of the area, amount of precipitation per year, accumulated temperature above 10°C.

3. Results and discussion

The calculation of the SEI of the main soil types of the republic used in agricultural production showed that the most productive and valuable soils are low-humic chernozems and Turanian dark grey soils (Table 1).

| Soil                                           | Index  | soil agrochemical | climatic | soil-ecological (total) |
|------------------------------------------------|--------|-------------------|----------|-------------------------|
| Low-humic chernozem                            | 9.32   | 0.95              | 4.58     | 41                      |
| Turanian dark grey soil                        | 9.30   | 0.95              | 4.20     | 37                      |
| Turanian typical grey soil                     | 9.30   | 0.95              | 3.20     | 28                      |
| Turanian light grey soil                       | 9.02   | 0.95              | 2.33     | 20                      |
| Northern dark grey soil                        | 9.22   | 0.95              | 3.60     | 32                      |
| Northern light grey soil                       | 9.02   | 0.95              | 3.32     | 28                      |
| Dark chestnut soil                             | 8.23   | 0.95              | 4.22     | 33                      |
| Light chestnut soil                            | 8.01   | 0.95              | 3.33     | 25                      |
| Dark chestnut soil of intermountain troughs   | 8.55   | 0.95              | 4.28     | 35                      |
| Light chestnut soil of intermountain troughs  | 8.23   | 0.95              | 3.22     | 25                      |
| Light brown soil of the Central Tien Shan      | 7.29   | 0.95              | 2.27     | 16                      |
| Grey-brown desert soil                         | 6.92   | 0.95              | 2.04     | 13                      |
| Weighted average value                         | 8.54   | 0.95              | 3.30     | 27                      |

Low-humic chernozems are characterized by the highest climatic, soil, and soil-ecological index. Soils are spread over a small area (17 thousand hectares) and occupy a relatively cool and moist part of the territory of the foothill plains, basins and valleys of the Central Tien Shan. The accumulated temperature above 10°C does not exceed 1600–2000°C, the amount of precipitation varies from 400 to 500 mm/year. Previously, such soils were formed under cereal-forbs and meadow-steppe natural vegetation; therefore, they are well provided with humus (5.0–6.0%) and exchange potassium but have a low content of mobile phosphorus. The content of total phosphorus varies within 0.15–0.25%, potassium – 2.1–3.5%, nitrogen – 0.23–0.45%. The absence of carbonates in the humus horizons causes a neutral and slightly alkaline reaction of the medium (pH value is 7.0–7.5 units). These are the most fertile soils used for the production of cereals, fodder crops, and potato.
The SEI of Turanian grey soil is lower than that of low-humic chernozems by 4–20 points, due to a significant decrease in the climate index. These are the soils of the intermontane troughs of Southern Kyrgyzstan, the Chuy and Talas valleys of Northern Kyrgyzstan; their area is 1333.3 thousand hectares. They are formed with periodic moistening during the winter-spring and partially autumn periods (precipitation amount is 250–400 mm/year) and accumulated temperature above 10ºC of 3500–4450ºC. Under more favourable hydrothermal conditions, Turanian dark grey soils develop, as evidenced by the high score of the climatic index. These conditions contribute to some accumulation of humus (2.1–4.6%), but the soil is not adequately supplied with nutrients. With an increase in climate aridity and accumulated temperature above 10ºC to 4250–4450ºC, these soils are replaced by typical and light grey soils. Formed under conditions less favourable for the humification process, soils have very low and low humus content (1.0–2.5%) and a poor provision with nitrogen and phosphorus. These are soils of low fertility, the SEI of which is lower by 9–17 points in comparison with dark grey soils. A common feature of Turanian grey soils is the alkaline and strongly alkaline reaction of the medium (pH value of 7.7–8.7) throughout the entire soil profile associated with the presence of carbonates. Light and typical soil subtypes are involved in arable land for cotton production, fruit cultivation and viticulture. Turanian dark grey soils, as more fertile soils, are occupied by cereals and perennial grasses.

The northern grey soils, marked out in the soil cover of the Chuy and Talas valleys on an area of 312.9 thousand hectares, have a similar score of the soil and soil-ecological index. Soils are formed with a certain lack of moisture (320–350 mm/year) and the accumulated temperature above 10ºC of 3500ºC. In terms of fertility, they are similar to Turanian grey soils. They are characterized by a very low (0.7–1.7%) and low (1.5–2.5%) humus provision, the amount of which increases from the northern light grey soils to the dark subtype. A distinctive feature of the northern light grey soils is the neutral reaction of the medium in the humus layer, which transforms into the alkaline interval near the parent rock (pH 7.0–8.8). In the dark subtypes of these soils, the reaction of the medium is alkaline throughout the entire profile (pH 7.5–8.5). In comparison with low-humic chernozems, northern grey soils can be attributed to soils with an average level of fertility. They are used for the cultivation of sugar beets, corn, perennial grasses, cereals and melons, and are assigned to orchards and vineyards.

Chestnut soils occupy 2238.9 thousand hectares of the foothill plains of Northern Kyrgyzstan and the intermontane troughs of the Central Tien Shan. Dark chestnut soils, including soils of intermontane troughs, are formed in a moderately cool and temperate dry climate, where the accumulated temperature above 10ºC is 1700–2400ºC, and the amount of precipitation varies from 320 to 500 mm/year. The climate index in this area is rated high. This hydrothermal regime contributes to the favourable course of the humification process and the accumulation of humus in soils up to 3.5–6.0%. Soils are insufficiently provided with elements of mineral nutrition. The amount of mobile phosphorus in the arable layer is low, potassium content is from high to very high. Reducing precipitation to 250–400 mm/year and increasing the accumulated temperature above 10ºC to 2700ºC contributes to an increase in climate dryness and the predominance of the process of mineralization of organic matter over humus formation. The increase in climate aridization is expressed in the reduction of the climate index by 1 point. Such hydrothermal conditions contribute to the development of light chestnut soils. The amount of humus in these soils ranges from 2.0 to 4.5%. Provision of arable horizons with mobile phosphorus is low, with potassium – from high to very high. Skeletal and light loamy soil varieties contain an insufficient amount of exchange potassium. Carbonates are usually leached from the upper horizons or are contained there in small amounts, so the reaction of the medium can vary from neutral to alkaline (pH 7.0–8.5). The SEI of chestnut soil subtypes is comparable to the SEI of the Turanian and northern grey soils, but their soil index is on average lower by 1 point. Corn, sugar beet, fruit, grain and vegetable crops, perennial grasses, cereals and melons, are cultivated on the soils.

The grey-brown desert and light brown central Tien Shan soils are rated with the minimum score. The grey-brown desert soils occupy 120.8 thousand hectares and are confined to rocky deserts, which are a foothill plain. Light brown soils of the Central Tien Shan are distributed on 915.1 thousand hectares in the intermontane troughs, basins and valleys of the Central Tien Shan. Soils develop at relatively low sums of active temperatures above 10ºC (1900–2350ºC) and a pronounced deficit of precipitation (100–
250 mm/year). Adverse climatic conditions reduce the climate index score to 2.0–2.3. Forming under conditions of a large moisture deficit, insignificant intake of organic matter and accelerated processes of its mineralization, soils have a low level of fertility. The grey-brown desert soils are poor in organic matter and nutrients, therefore their soil index was 7 points: the content of humus does not exceed 0.5–1.5%, of gross nitrogen – 0.07–0.08%, of phosphorus – 0.03–0.04% and potassium – 1.0–3.0%. The number of mobile forms of phosphorus and nitrate nitrogen is very low. The reaction of the medium throughout the soil profile varies in the alkaline range (pH = 8.0–8.5) and is associated with the presence of carbonates.

Light brown central Tien Shan soils are characterized by a very low humus content (1.0–2.0%), but they are more provided with elements of mineral nutrition: the amount of nitrogen is 0.10–0.25%, of phosphorus – 0.20–0.30%, of potassium – 2.0–2.5%. The presence of carbonates (5–10%) shifts the soil reaction in the alkaline and strongly alkaline intervals (pH = 8.2–8.8).

The presence of large ranges, intermontane troughs and basins, sharp continentality and dryness of the climate, the activity of denudation processes, the diversity of parent rocks, the wide distribution of surface and groundwater, their nature of movement and accumulation depending on geomorphological and hydrogeological conditions determine the reclamation and cultural condition of the land.

In the territory of Kyrgyzstan, there are some saline and solonetzic soils, solonchaks and solonetzes; in the places of groundwater pinching out and temporary excess moisture there are wetlands. Extensive expanses of rocky soils are also noted. Eroded soils are widespread on the slopes and foothills of mountain ranges, alluvial fans, river terraces.

Among agricultural lands, saline soils occupy a large proportion, their area reaches 1170.3 thousand hectares. The origin of saline soils on the territory of Kyrgyzstan is associated with the wide distribution of various saline deposits and mineralized groundwater, which lies high to the surface. In addition to the salinization process, the solonetz process is actively proceeding in soils. Salinization significantly reduces soil productivity and value. The quality of low-humic chernozems is estimated at 41 points. With a weak degree of salinity, its score is lower by 14 points, and under conditions of strong salinity – by 30 points. The value of light chestnut saline soils reduces to 8–25 points, dark chestnut saline soils – to 25–35 points. The scoring of grey soils of different subtypes in the presence of salts decreases from 20–37 to 7–27 points. The total SEI of grey-brown desert soils decreases by 0.5–8.0 points depending on the degree of salinity.

The area of stony soils in the agricultural zone is about 3809 thousand hectares. At present, about 110 thousand hectares of low- and medium-stony soils have been developed. In their genesis, the leading role belongs to exogenous processes, which are actively manifested under conditions of dissected relief, runoff of surface water, heavy rainfall (often of a rainstorm character) and contribute to the formation of skeletal-stony soil-forming material. Grey soils of varying degrees of rockiness, depending on the subtypes, are estimated at 12–30 points. Chestnut soils, including soils of intermontane troughs, reduce their productivity by 1–13 points, light chestnut soils – by 1–7 points, and low-humic chernozems – by 10–18 points. The presence of rockiness reduces the value of grey-brown desert soils and light brown central Tien Shan soils by 2–6 points.

Erosion processes in the study area are widespread and are manifested in the form of water erosion and deflation. The strong ruggedness of the relief, large elevation differences, slopes of various steepness and exposure determine the intensified development of slope denudation processes and the formation of intense lateral in-soil and subsoil geochemical outflow. Denudation processes constantly remove the upper layers of erosion and soil formation products, which determines the low thickness of the soil profile. Thus, under the influence of water erosion, the scoring of grey soils is lower in comparison with non-eroded grey soils by 6–26 points depending on the degree of erosion. Light chestnut eroded soils are estimated at 12–22 points, dark chestnut eroded soils – at 16–27 points. The SEI of low-humic chernozems decreases by 14–25 points, of grey-brown desert and light brown soils of the Central Tien Shan – by 1–5 points.

The wind regime in mountain basins and troughs is the most intense. Under the influence of the relief, as the main factor in the wind regime, mountain-valley winds develop, characterized by a regular
daily change of direction, high speeds and destructive force. Under the influence of wind activity, soils of varying degrees of deflation are formed, with lower productivity and quality assessment. For example, the SEI of low-humic deflated chernozems is lower by 9–18 points compared with non-deflated counterparts. Grey soils of varying degrees of deflation are estimated at 14–31 points, chestnut soils – at 15–30 points, grey-brown desert and light brown central Tien Shan soils – at 9–15 points.

4. Conclusion
The analysis of the indicators of the agrochemical state of the studied soils showed that they have approximately the same soil reaction, provision with humus, mobile phosphorus and potassium, therefore, the agrochemical soil cover index is estimated by the same score. Estimated points for the climatic index vary over a wide range (2.04–4.58) due to different hydrothermal conditions of the territory associated with the influence of the highlands, remoteness from significant water bodies, snowfields and the presence of nearby deserts. Estimated points of the soil index differ at the level of soil type. The difference between the scores of the soil index is in the range from 0.77 to 2.46 points. The climate index made a significant contribution to the final SEI. The weighted average SEI of soils in Kyrgyzstan is 27 points. The most valuable soils are low-humic chernozems and Turanian dark grey soils. Grey-brown desert and light-brown Tien Shan soils are classified as low-productivity soils in terms of SEI. Soils with an average level of fertility include Turanian typical grey soils, northern grey soils, and chestnut soils.

References
[1] Umarova M 2016 State of use of land and water resources of the Kyrgyz Republic International Scientific Review 3(13) 87–94
[2] Hoppe F, Zhusui Kyzy T, Usupbaev A and Schickhoff U 2016 Rangeland degradation assessment in Kyrgyzstan: vegetation and soils as indicators of grazing pressure in Naryn Oblast Journal of Mountain Science 13 1567–1583
[3] Shpedt A A, Aksenova Yu V, Shayakhmetov M R, Zhulanova V N, Rassypnov V A and Butyrin M V 2019 Soil and ecological evaluation of agrochernozems of Siberia International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies 10(3) 309–318
[4] Rukhovich D I, Simakova M S, Kulyanitsa A L et al 2017 The influence of soil salinization on land use changes in Azov district of Rostov oblast Eurasian Soil Science 50 276–295
[5] Gorji T, Sertel E and Tanik A 2017 Monitoring soil salinity via remote sensing technology under data scarce conditions: a case study from Turkey Ecological Indicators 74 384–391
[6] Chen Z, Wang L, Wei A, Gao J, Lu Y and Zhou J 2019 Land-use change from arable lands to orchards reduced soil erosion and increased nutrient loss in a small catchment Science of the Total Environment 648 1097–1104
[7] Niacsu L., Sfica L., Ursu A., Ichim P., Bobric D E and Breaban I G 2019 Wind erosion on arable lands, associated with extreme blizzard conditions within the hilly area of Eastern Romania Environmental Research 169 86–101
[8] Umarova M 2013 The role of land resources in the agricultural and industrial sector of the Kyrgyz Republic Economic, State and Society in the 21st Century (Moscow: RGTEU) pp 158–165
[9] Tsvetnov E V, Marakhova N A, Makarov O A, Strokov A S and Abdulkhanoova D R 2019 Experience in approbation of societal land value as a basis for the ecological and economic assessment of damage from land degradation Eurasian Soil Science 52 1298–1305
[10] Molchanov E N, Savin I Y, Yakovlev A S, Bulgakov D S and Makarov O A 2015 National approaches to evaluation of the degree of soil degradation Eurasian Soil Science 48 1268–1277
[11] Shishov L L, Durmanov D N, Karmanov I I and Efremov V V Theoretical foundations and ways of regulating soil fertility (Moscow: Agropromizdat)
[12] Mamytov A M 1996 Soil resources and issues of the land cadastre of the Kyrgyz Republic (Bishkek: Kyrgyzstan)
[13] Mamytov A M, Osadchy G R, Matienko G S and Samusenko V F 1980 *Features of soil formation and properties of mountain soils of the Tien Shan* (Frunze: Ilim)

[14] Mamytov A M 1963 *Soils of the Central Tien Shan* (Frunze: Academy of Sciences of the Kyrgyz SSR)