

Soil Resources of the Republic of Kazakhstan: Current Status, Problems and Solutions

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Abstract This chapter includes information on the current status of the soil landscape of Kazakhstan and an analysis of materials based on our own research published during the last two decades, as well as literature on land degradation, salinisation, soil contamination and land resource use. It has been found that a current tendency can be observed towards intensive land degradation and desertification, salinisation (including secondary salinisation and soil contamination by oil, petroleum products, chemicals and radioactive substances), de-humification, decreasing soil fertility and deterioration of the ecological status of soil resources. In Kazakhstan this problem is complex because of the vast territory and variety of both natural conditions and anthropogenic impacts on soil. The sustainable development of agriculture in Kazakhstan and ensuring food and environmental safety are closely related to the rational and efficient use of soil. In this regard, it is necessary to develop appropriate laws and regulations, programmes and related activities and to take measures to prevent rapid land degradation, desertification and deterioration of the environmental situation, and to start to restore soil fertility.

Keywords Kazakhstan · Soil · Degradation · Soil fertility

1 Soil Inventory

The soil surface of Kazakhstan is characterized by a distinct horizontal and vertical zoning which is linked with the significant length of the plains stretching from north to south, high altitudes in the mountains, and changes in the bioclimatic

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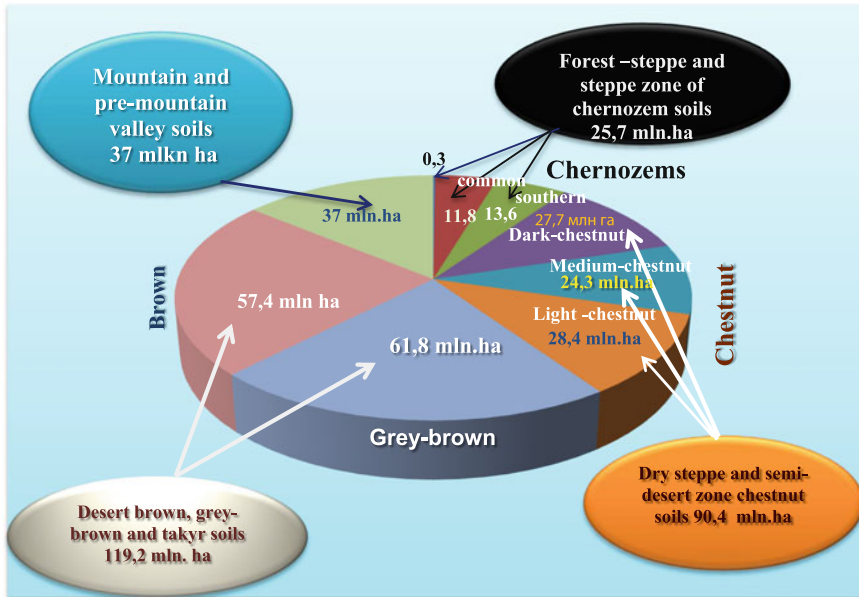


Fig. 1 Soil surface of the Republic of Kazakhstan (Saparov et al. 2006b). Read *comma* as point

conditions of soil formation. The flat area occupies 86 % of the Republic's territory.

In Kazakhstan, there are 25.7 million hectares (M. ha) of black soils (Chernozems), 90.4 M. ha of chestnut soils (Kastanozems), 119.2 M. ha of brown and grey-brown soils (Calcisols), and 37 M. ha of mountain soils (Faizov et al. 2006, Fig. 1).

The flat territory of the Republic is divided into natural zones and subzones:

- Moderately wet forest steppe with grey forest soils.
- Moderately arid and arid steppe zone with black soils.
- Moderately dry, dry and desert-steppe zone with chestnut soils.
- Desert zone with brown and grey-brown soils.

According to bioclimatic indices and basic and auxiliary soil formation processes, the moderately wet forest steppe zone with grey forest soils, and the moderately arid and arid steppe zone with black soils, are divided into three subzones:

- Moderately wet southern forest steppe with grey forest soils, black soils (Chernozems) and meadow-black soils (Meadow Chernozems);
- Moderately arid steppe with common black soils (Ordinary Chernozems);
- Arid steppe with southern black soils (Southern Chernozems).

In the structure of the soil landscape, the black soils and meadow-black soils occupy about 40 %, grey forest soils and salty soils 20, semi-hydromorphic and hydromorphic soils more than 20, salty and saline marsh soils 19 % of the territory. On the background of zonal soils, the common black soil complexes with saline soils comprise about 17 %, semi-hydromorphic and hydromorphic soils 10 %, saline soils 5 %, and saline soils and saline marsh soils 4 % of the area. Zonal southern black soils occupy 65 % of the subzone area, of which 22 % are their complexes with saline marsh soils, 10 % semi-hydromorphic and hydromorphic soils and 3 % saline soils and saline marsh soils.

In the zone of moderately wet forest steppe with grey forest soils and black soils, processes of de-humification and decreases in natural fertility have been observed. In the moderately arid steppe zone with black soils (common and southern) intensive processes of dehumification and erosion are observed, particularly strongly on calcareous soils. The moderately dry, dry and desert-steppe zone with chestnut soils occupies more than 30 % of the territory of Kazakhstan. The soil landscape in this zone is characterized by complex soils, with alkaline, calcareous and saline soils widespread, and more than 40 % is occupied by a variety of complexes of soils with saline soils. The basis of the soil is dark chestnut soils that are spread over the low Kazakh hills, the trans-Ural and pre-Ural plateau and the low mountains of Mugaldzhar and some parts of the Caspian, as well as the Turgay and pre-Ural plateau and the Irtysh plain. This is a zone of rainfed agriculture, i.e. four or five years out of ten are dry, and there is no yield.

The subzone of desert steppe with light chestnut soils occupies the extreme southern level of the chestnut soils zone from the Caspian depression in the west to the foothills of Altay and Tarbagatai in the east. The main background of the soil landscape in the subzone is light-chestnut saline and saline marsh soils. The usual light chestnut, calcareous soils and weakly developed soils are less common. In the structure of the soil landscape, the zonal light chestnut soils occupy 63.3 % of the subzone area, saline soils 20.2 %, semi-hydromorphic soils 5.2 %, hydromorphic soils about 4 %, saline marsh soils 1.6 % and sands 1.2 %.

In the moderately dry, dry and desert-steppe zone of chestnut soils, where the variety of saline soil complexes are widely spread, intense degradation, desertification, salinisation and alkalisation is observed, and in irrigated areas secondary salinisation is observed. The desert zone of brown and grey-brown soils is the southern level of the latitudinal bioclimatic zones of Kazakhstan, which covers the un-drained areas of the south Caspian lowlands, the plateaus of Mangyshlak, Ustyurt and Betpakdala, the Aral Sea areas, Shu-Moinkum, the Balkhash-Alakol depression, the sloping foothill landscapes of the Tien Shan, Zhongariya, Altay and Saur-Tarbagatai. Their total area makes up 44 % of the country and nearly 15 % of the area of typical desertified land surface (Faizov 1980; Babaev et al. 1986).

Deserts are the most arid regions of Kazakhstan, where soil-forming processes take place in conditions of severe water shortage, and high levels of soil degradation and desertification. The main natural reasons for these processes are a flat

terrain, a high degree of arid climate, salinity, carbonate content, a lack of structure and low natural soil fertility (Saparov and Faizov 2006).

The influence of anthropogenic factors is seen almost in all natural landscapes, especially in the Aral Sea region, where degradation and desertification processes are becoming more widespread. In the most fertile delta-alluvial plain of the Syr-Darya river, the area of desertified land is 1.1 M. ha, and in the dried-up bottom of Aral Sea it is 1.5 M. ha, of which saline marsh soils occupy 0.8 M. ha. In contrast to other natural zones, these vast areas are occupied by sands (17.5 M. ha), saline soils (2.6 M. ha) and takyr plains (0.3 M. ha). The total area of saline soils in the desert zone with brown and grey-brown soils exceeds 60 M. ha, and alkaline complexes are present in 22 M. ha.

Mountain soils occupy the mountain ranges of south and south-eastern Kazakhstan, and amount to 13.6 % of the whole territory of Kazakhstan. Moreover, 5 M. ha of mountain soils are located in the low mountain areas of central and western Kazakhstan. The main and most general factor regulating mountain soils is the strong vertical zoning. Mountain soils are formed under different hydro-thermal conditions and do not form complexes with saline soils. They are divided into three major regions depending on the combination of soil formation conditions and composition of soil landscape in the vertical zones and belts: Altay, north Tien Shan and west Tien Shan. Each mountain region has its own specific vertical soil zoning structure.

The soil landscape of Kazakhstan is the wealth of the Republic and the basis for ensuring food security. At the same time, some of the country's rich soil resources are not used effectively or efficiently.

2 Problems of Soil Quality

Analysis of the current status of the soil landscape has shown that intensive land degradation and desertification processes can be observed, with deterioration of the soil and environmental conditions of the country taking place. According to the data of the Agency on Land Resources Management, more than 75 % of the territory of Kazakhstan is subjected to degradation and desertification; over 14 % of pastures have reached an extreme degree of degradation or are completely degraded, and it is impossible to use them. Therefore, 15.2 % of lands are classified as "waste" fallow lands. The desertification of large territories is accompanied by soil contamination, waterlogging by surface water and groundwater, and a decrease in general regional biological capacity. According to scientists' preliminary evaluation, the damage caused by the erosion of arable land, secondary soil salinity, land degradation and desertification is estimated as 93 billion tenge, or 6.2 billion USD (RFCA 2010).

On the vast territory of the Republic, there are a number of regions where the combination of various forms of environmentally damaged soils has resulted in a crisis situation. Disastrous environmental conditions can be observed in the Aral

Sea area: zones of intensive soil desertification, salinisation and deflation. The regions of Central and East Kazakhstan, which are the major industrial centres, are the centres of technogenic disturbances and the industrial pollution of soils with toxic chemicals (lead, mercury, chromium, etc.). Every year, about 3–4 M. tonnes of polluting chemicals are emitted to the atmosphere or deposited on the soil surface.

The conditions and use of 59.6 M. ha of land in the Aral Sea area is causing particular concern. As a result of the Aral Sea drying up, major changes have occurred in the current delta of the Syr Darya river and on the dried Aral Sea bed. The negative factor is the process of salt-dust transfer over long distances. At the Kazakhstan part of the Aral Sea, three large sources emitting sand-salt aerosols into the atmosphere have formed and their influence can be observed at a distance of 200–250 km and more. The area of dust distribution and deposition is about 25 M. ha.

Since 1956 researchers at Kazakhstan's U.U. Uspanov Research Institute of Soil Science and Agrochemistry have conducted monitoring studies which have determined that the drying up and desertification of hydromorphic soils at the current delta of the Syr Darya river are accompanied by increased salinisation processes, a sharp decrease in non-saline soils and increases in soil salinity of various degrees, including the formation of saline marsh soils. Saline marsh soils make up more than 50 % of the area.

In the oil regions of Western Kazakhstan and the Torgay plain, on an area of more than 500 thousand ha, there are large sections of soil contaminated with oil and radioactive materials, high levels of salinity with industrial wastewater and technological transformation of the soil landscape, leading to the accumulation of toxic heavy metals (lead, cobalt, nickel, vanadium etc.) and radionuclides (thorium, barium, radium). Lands contaminated with heavy metals and radioactive substances occupy about 21.5 M. ha. These pollutants are spread on 59 % of the area in the Atyrau region, 19 % in Aktobe, 13 % in West Kazakhstan and 9 % in Mangystau.

Scientists from the Institute identified that as a result of oil pollution, deep morphogenetic changes are taking place in the soils, with soils in the zone being transformed and acquiring new properties. In contaminated soils, the most important genetic characteristics are damaged: their natural morphological profile changes along with their chemical and biological properties, and dense bituminous crusts are formed, which are soaked in fuel. Their morphological profile is transformed under the influence of crude oil and their horizon turns a brown-grey and resinous-black colour; it becomes a viscous, sticky and cloddy feature.

After the evaporation of the light fraction of oil, the heavy fractions which remain in the soil, saturated with resins, wax and asphaltene, glue together the granulometric fractions to form a dense mass, and form bituminous crusts ranging from 5–10 to 20–40 cm (Figs. 2, 3): specific technogenic soils with different genetic characteristics than the natural zonal soils are formed. It has been determined that oil-polluted soils are characterized by an increased content of gross and

Fig. 2 Bituminous crusts

mobile forms of lead 1–6 times higher than the maximum allowable concentration (MAC), 7–12 times higher for molybdenum and 2–3 times higher for cobalt.

In some cases, the presence of vanadium and nickel and low concentrations of copper, zinc and cadmium are observed. In the coastal zone, an increased amount of boron was revealed, caused by alkaline and saline sea sediments (Saparov et al. 2006a, b, 2010; Saparov and Mamyshev 2008). The soil is becoming an accumulator and storage medium for toxic chemicals. In addition, a geochemical flow goes into the Caspian Sea, which could cause a global environmental disaster. The industrial zone featuring oilfields is contaminated with hydrogen sulphide, sulphur dioxide and other toxic substances (Figs. 4, 5).

According to the nature of the initial soil salinity, the areas of the Caspian basin are classified as chloride and sulphate-chloride types of salt accumulation, the Aral Sea basin as the chloride-sulphate type and Lake Balkhash as the soda-sulphate type. On some parts of the plateau and layer plains in Mangyshlak, Ustyurt and Betpakdala, there are gypsum deposits. The loose sediments are spread at large distances from the parent rocks and differ in age, genesis and mineral composition.

Everyone knows about the serious consequences of nuclear tests at the Semipalatinsk, “Kapustin Yar” and “Lira” test grounds (among others). At the former Semipalatinsk nuclear test ground, about 2 M. ha of agricultural lands have been subjected to radioactive contamination. In the technogenic area of Shymkent City, soil is contaminated with mobile forms of lead and cadmium, with maximum concentrations of lead from 200 times the maximum allowable concentration to 1,500 MAC. A similar situation is observed for specific elements in the East Kazakhstan, Karaganda and Pavlodar regions.

In Kazakhstan, large areas (more than 30.5 M. ha) are subject to erosion processes. The degree of their occurrence varies and depends on climatic conditions, the physical and physical–mechanical properties of the soil and parent rock, slope,

Fig. 3 Oil pit**Fig. 4** Contamination with sulphur

degree of disturbance of vegetation, and soil cultivation methods. Erosion processes at the vast massifs of Karakum, Kyzylkum, Moinkum, and the Sary-Is-hikotraukum sands are very active, as well as in regions where light texture and calcareous soils are common. Areas of land subjected to wind erosion occupy 25.5 M. ha, and those subject to water erosion more than 5 M. ha, of which 1 M. ha are arable land. The largest areas of water erosion can be observed in the South Kazakhstan region, with 958.7 thousand (K) ha, of which eroded arable land makes up 223.6 K. ha. In the Almaty region, there are 801.9 K. ha, in the Mangistau region 802.8 K. ha, and in Akmola 559.4 K. Ha including 286.2 K. ha of eroded arable land. In the Aktobe region, there are 488.3 K. ha, and in East Kazakhstan 419.0 K. ha, of which 134.5 K. ha are eroded arable land.

Fig. 5 Sulphur storage

Erosion processes are also developing intensively in the Akmola, South Kazakhstan and Almaty regions. In 8 districts of the Akmola region, there are slightly eroded soils (where the thickness of the humus horizon has decreased by 30 %), medium-eroded soils (by 50 %), and heavily eroded soils (characterized by the lack of an arable horizon).

In Southern Kazakhstan, in recent years, the processes of erosion on irrigated fields and pastures have developed rapidly: every year 19 million tonnes of soil are washed off with 400 K. tonnes of humus. Every year about 2.5–2.6 million tonnes of manure would be needed to cover these losses.

In the irrigated fields of Mangyshlak consistent fine, strongly spotted and solid secondary soil salinisation can be observed. Progressive salinisation of irrigated land is taking place in the Arys-Turkestan, Tashutkul, Bakanas and other irrigated areas. Secondary salinisation of irrigated lands has increased rapidly.

Intensive use of agricultural lands of the country without consideration of the agro-ecological potential of the territory and scientifically justified land cultivation systems has led to a significant decrease in soil fertility. Monitoring studies carried out by scientists at Kazakhstan's U.U. Uspanov Research Institute of Soil Science and Agrochemistry have determined changes in the content of humus in the major soil types in Kazakhstan and, accordingly, decreases in the potential soil fertility. The loss of humus after the cultivation of virgin and fallow lands was one-third of the original content, or 45–48 % including the most valuable humic acids and hydrolyzed nitrogen, and up to 60 % in irrigated conditions. The annual losses of humus in agriculture in Kazakhstan are 1.2–1.6 t/ha.

These results suggest that the processes of de-humification, classified as stage 1 (low degree) cover 4.5 M. ha of arable land, stage 2 (moderate degree) 5.2 M. ha,

Table 1 Application of mineral fertilizers in the Republic of Kazakhstan

Types of fertilizer	Years						
	1986	1995	2000	2005	2006	2007	2008
Mineral fertilizers (kilotonnes)	1,039	36.2	10.7	37.5	41.4	58.9	30.9
Organic fertilizers	33,196.0	1,141.0	17.5	7.8	13.7	7.8	7.4
Applied mineral fertilizers per 1 ha of arable land, kg NPK	29	1.3	0.7	2.0	2.3	3.1	1.5
Share of arable lands treated with fertilizers, %	47	1.5	0.5	3.5	3.6	4.8	4.9
Total arable area, K. ha	35,500	28,679	15,400	18,400	18,400	18,954	20,119

and stage 3 (strong degree) 1.5 M. ha. On irrigated arable land, 0.7 M. ha are subject to de-humification. Due to these significant losses of humus, the plants are not provided with the proper quantity of nutrients.

The main reasons behind humus loss are the inefficient use of land, failing to observe the laws of interaction between nature and society, and, most importantly, neglecting scientifically justified land cultivation systems.

3 Research Activities on Soil Monitoring and Restoring Soil Functions

One of the major factors in the conservation and improvement of soil fertility is a scientifically justified fertilizer application system. In Kazakhstan, the application of fertilizers has significantly decreased, resulting in a decrease in soil fertility and yields. In 1965, 170.4 K. tonnes of fertilizer were supplied and applied, i.e. 3.6 kg of NPK per 1 ha of arable land. As agriculture was intensively developed in the country, the areas of fields where the fertilizers were applied increased by 47 % of their total area. In 1986, the total volume of deliveries of mineral fertilizers amounted to 1,039 K. tonnes, and the quantity of fertilizers per 1 ha of arable land was 29 kg (Table 1). By 1986, yields had increased by 26 % compared with 1965, spring wheat from 6.1 to 10.1 decitonnes (dt)/ha, rice from 19.1 to 45.1 dt/ha, corn from 20.8 to 38.8 dt/ha, sugar beets from 235.8 to 288.0 dt/ha, cotton from 17.9 to 25.8 dt/ha, potatoes from 75.0 to 106.2 dt/ha and vegetables from 66.1 to 170.0 dt/ha (Saparov et al. 2011).

Then, in 1987, the production and supply of mineral fertilizers for agriculture sharply decreased, and this situation lasted until 2000. The total amount of fertilizers used in agriculture decreased to 10.7 K. tonnes, and the intensity of their use decreased from 29.0 to 0.7 kg/ha of NPK. This led to a decrease in yields of 8.8–52.1 % depending on the crops. In comparison with the period 1986–1990, the yield capacity of grain crops during 1996–2000 decreased by 14.4 %, and that of wheat by 8.7 %. Particularly high losses were observed in the yields of sunflower, sugar beet, corn, rice, cotton and vegetables.

Since 2001, there has been a steady tendency towards land cultivation growth in Kazakhstan (Table 1). In 2009, 56.4 K. tonnes of mineral and 125.5 K. tonnes of organic fertilizers were applied, i.e. 10 % of the required amount.

Monitoring of the use of fertilizers in Kazakhstan at a long-term station involving experiments with crop rotations has showed that soil fertility can be not only conserved, but also extensively restored using organic and mineral fertilizers. Thus, scientists from the Kazakh Institute of Land Cultivation and Crop Production determined that in an 8-field crop rotation scheme, using 60 t/ha of complete fertilizer and manure once per rotation, an extensive quantity of humus was restored in the soil. Beginning with the third rotation, humus reserves increased both in the upper and lower layers of soil.

By systematically applying complete mineral fertilizer, the concentration of mobile phosphorus in the soil by the end of the first rotation was increased by 13.1 mg/kg of soil and reached optimal values. At the same time, in the fertilized variants in the upper layer an increase in the concentration of mobile phosphorus was observed after the application of not only the optimum level of mineral fertilizers but also high values of combined mineral and organic fertilizers. Fertilizers providing a positive impact on the nutrient regime of irrigated light chestnut soils have enhanced the increase in the productivity of crop rotation with sugar beet. In the long-term cultivation of crops without fertilizers only low yields were harvested, and the quality of crops in a sugar beet crop rotation was low. The systematic application of mineral fertilizers provided an increase in the yield of sugar beets of almost 3 times the level, 1.6 times for wheat grain, 1.3 times for corn, and 1.5 times for alfalfa hay. After the application of mineral and organic fertilizers the yield of sugar beet increased 3 times, that of wheat 1.6 times, that of corn 1.5 times, and that of alfalfa hay 1.6 times. The quality of production improved significantly: the content of crude protein in the wheat grain increased by 0.8–1.2 %, the concentration of sugar in the roots has increased by 0.9–1.0 %, and the quality of corn grain and alfalfa hay also improved (Saparov et al. 2010).

In a station, experiment conducted by the Kazakh Research Institute of Potato and Vegetable Growing in irrigated dark chestnut soils on the basis of intensive vegetable crop rotation, it was determined that during 18 years (1991–2008) the concentration of humus in the variant without fertilizers decreased by 15.2 %, and in the case of variants with fertilizers (combined use of mineral and organic fertilizers), a tendency was observed for extensive restoration of soil fertility. However, there is an assumption that fertilizers are a potential source of soil contamination with heavy metals.

In view of this, we conducted extended agro-environmental monitoring in the south-east of Kazakhstan from 2001–2005. 11 field experiments applying fertilizers were selected as the object of monitoring, lasting for different durations (15–63 years) and taking place at 6 scientific institutions. Land plots without fertilizer and with full fertilizer application were tested. The soils at these sites were light and common grey soils, meadow-marsh and light chestnut soils, and they differed in the degree of contamination with heavy metals.

Table 2 Inputs of heavy metals (HMs) into the soil through the long-term use of complete mineral fertilizers (1961–2005)

Fertilizer	Application of fertilizers, kg/ha	Input into soil, g/ha						
		Zn	Cu	Fe	Pb	Cd	Cr	Ni
Urea	2,850	37.2	5.0	155	8.0	1.5	–	–
Granulated superphosphate	2,500	253.8	188.0	21,678	559	46	78.9	43
Potassium chloride	3,080	67.4	24.7	2,209	68.5	23	–	–
Input of HM, g/ha of soil	–	358.4	217.7	24,042	635	71	78.9	43
Input of HM, mg/kg of soil	–	0.12	0.07	8.0	0.2	0.02	0.02	0.01

An assessment of the degrees of soil contamination with heavy metals was carried out, identifying the mobile forms in them according to Vazhenin (1987): weak, moderate, medium, increased, high and very high levels of pollution.

To calculate the amount of heavy metals penetrating the soil with the fertilizers, data was used from a long-term station experiment conducted by the Kazakh Institute of Land Cultivation and Crop Production (Table 2).

The research results showed that the highest quantity of heavy metals penetrating the soil, in terms both of the accumulation and the concentration of the impurity, was with phosphorus fertilizers. The figures for potash fertilizers are slightly lower, and penetration of heavy metals in the soil with nitrogen fertilizers is insignificant. The calculation confirms that the application of scientifically justified fertilizer quantities does not lead to the contamination of soil with heavy metals.

There are various ways of solving these problems. A special approach needs to be created for each specific region, taking into account the natural climatic and ecological conditions. To stop and reduce land degradation and desertification, salinisation and pollution it is necessary to implement scientifically justified systems of land cultivation and complex organizational, economic, agrotechnical and hydro-technical activities, forest reclamation schemes etc.:

- Complete inventory of arable lands according to their current state of degradation and desertification, susceptibility to erosion, salinisation, pollution and other negative factors;
- Integrated soil resource management and their protection, introduction of scientifically justified crop rotation schemes, land cultivation systems, industrial and innovative technologies, pasture rotation, surface and radical improvement of soil reclamation and environmental conditions on unproductive degraded agricultural lands, rangelands and their irrigation;
- Rational use of water resources; strengthening efforts to prevent water loss, introducing modern irrigation technologies;
- Establishment of environmental monitoring and improvement of ecological situation by implementing environmental standards and certification in agriculture;
- Development of highly effective technologies for extracting hydrocarbons;
- Conservation of flooded oil wells.

Fig. 6 Forest bands of black saksaul in the Kozjetpes valley



In the Aral Sea area, significant attention is paid to the phyto-reclamation development of the formed land, and in particular soil conservation planting of trees and shrub species (halophytes) which will support the removal of salt, dust and sand, and stop the movement of sand dunes (Figs. 6, 7).

For a rational use of the soil landscape and the improvement of the soil reclamation and environmental status of land resources, one of the major tasks of our time is to develop new, highly relevant methods of soil resource management. In this regard, the relevance and priority of this issue are obvious, and it requires urgent solution and actions.

To solve these problems, it is necessary to develop specific programmes for studying contaminated and disturbed lands, develop laws and make appropriate recommendations for re-cultivation and land restoration. The adopted measures will serve as the basis for sustainable and intensive development of agri-industrial complexes in the Republic and ensuring food security of the country, aimed at implementing a common development policy in the agricultural sector.

Fig. 7 Natural tamarisk plants on sand in the Aral area



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