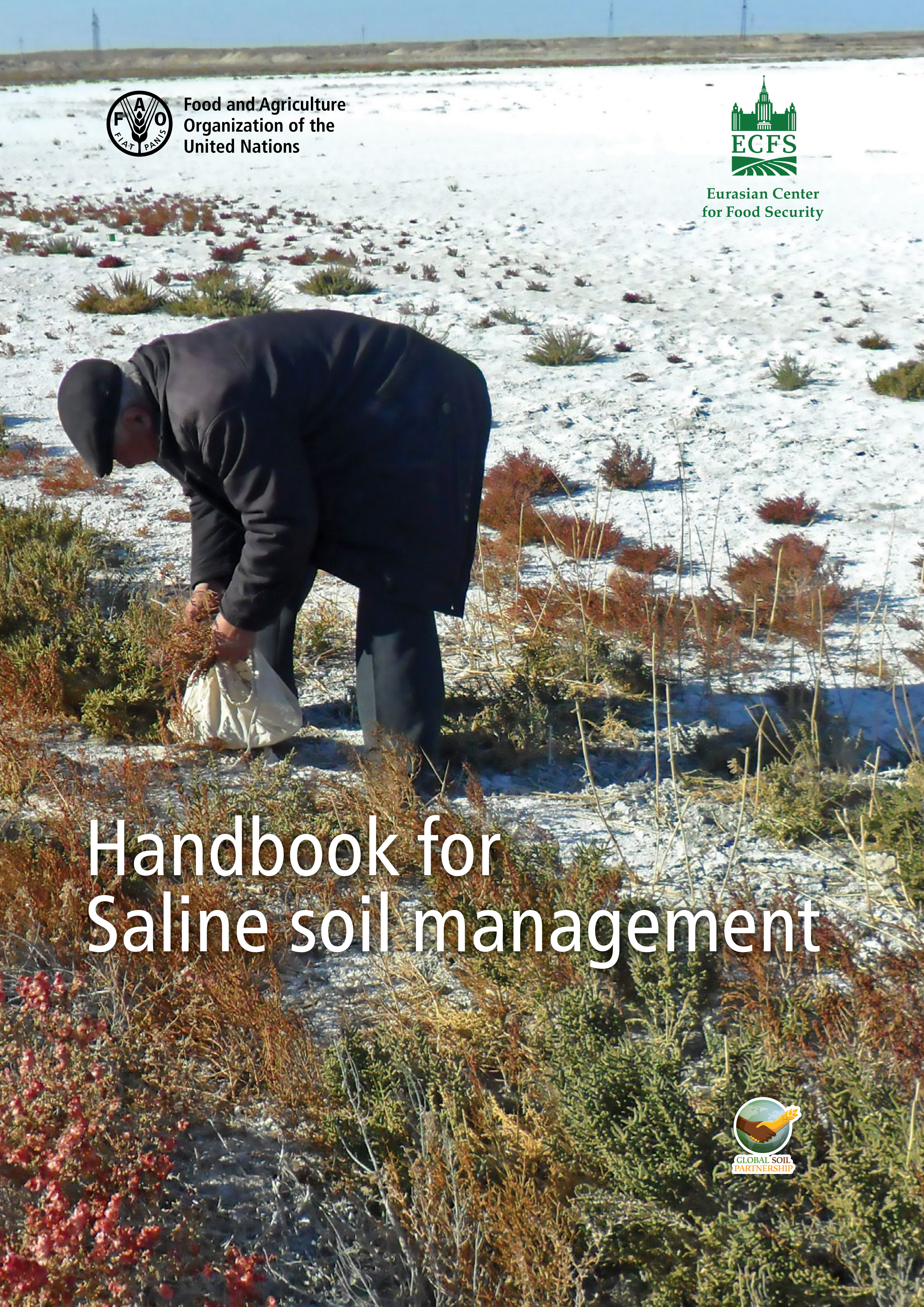

Food and Agriculture Organization of the United Nations

Eurasian Center for Food Security

# Handbook for Saline soil management

GLOBAL SOIL PARTNERSHIP

# Handbook for saline soil management

Editors: R. Vargas, E.I. Pankova, S.A. Balyuk, P.V. Krasilnikov and G.M. Khasankhanova

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*Cover photo: Gulchekhra Khasankhanova*

# Contents

# Foreword

This handbook has been prepared for the training workshop on innovative methods of amelioration and use of salt-affected soils, which takes place in Kharkiv, Ukraine, in September 2017. This workshop is conducted within the framework of the Implementation Plan of the Eurasian Soil Partnership, which is a sub-regional affiliation of the Global Soil Partnership. The main goals of the Global Soil Partnership (GSP) and Regional Soil Partnerships (RSPs) include the development of global and regional plans of action for the sustainable management and monitoring of limited soil resources as a key element, as well as the maintenance of food security and ecological services of soils. The RSPs rely on the existing regional networks that connect the national and local networks, partners, projects and measures to ensure that the interests of all member countries of the partnership are taken into account. A RSP should give directives for the development of regional targets, priorities and ìrequred mechanisms of implementation and also undertake regular assessments of progress in reaching goals and accomplishing the tasks.

The Eurasian Region covers Eastern Europe, Central Asia and Caucasus and includes the following countries: Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkey, Turkmenistan, Ukraine and Uzbekistan. The Eurasian Region is diverse in terms of climatic conditions, soils, flora and fauna, land use and human activities. Soil degradation is a serious problem within this region, with its most destructive consequences including salinization, erosion, loss of soil organic matter, nutrients and biodiversity as well as soil compaction.

Soil salinization presents a serious challenge that requires co-ordination between countries that share common water and land resources. International co-operation is also needed to attract and manage investment into water and land resources. It should be emphasized that salinization is both the cause and the result of other agricultural problems. Combating salinization should, together with other measures for achieving the sustainable intensification of agriculture, be considered as a basis for food security.

This handbook was prepared by authors from almost all the countries that are included in the sub-regional Eurasian Soil Partnership together with representatives from leading scientific and industrial organizations dealing with soil salinization. We hope that our work will be useful for solving some of the important problems within the region and help with the implementation of innovative technologies for the prevention of soil salinization and amelioration of salt-affected soils.

# Part I.
# Soil salinity management in the Eurasian Region

The aim of the workshop

By the end of the training the participants should be able to:

1. Understand diagnostics, criteria, factors, scale and extent of soil salinity.
2. Be able to recognize and evaluate impacts, risks and challenges and predict the development of salinization and alkalinization processes in soils
3. Assess and identify methods of mapping and monitoring saline and alkaline soils
4. Be able to identify and select suitable management and amelioration options and make decisions for preventing and mitigating against soil salinization and alkalinization
5. Have gained familiarity with innovative methods and sustainable management techniques for saline soils, which lead to enhanced agricultural productivity and farm profitability.

# Chapter 1.
# Salt-affected soils of the Eurasian Region: diagnostics, criteria and distribution

**E.I. Pankova, L.A.Vorobieva (Russia), S.A. Balyuk (Ukraine), G.M. Khasankhanova (Uzbekistan), M.V. Konyushkova and I.A.Yamnova (Russia)**

## 1.1. Definitions

The group of salt-affected soils includes soils containing soluble salts or their ions in at least one of their horizons in quantities that are above the threshold of toxicity – the maximal permissible concentration of salts that does not suppress plant growth [10].

According to the USDA Agriculture Handbook [20], salt-affected soils are characterized by a specific electrical conductivity (EC) of saturated soil-paste extracts above 4 mSm/cm (t=25°). More recently [4] soils became considered salt-affected starting at a lower EC level of 2 mSm/ sm, as several fruit, vegetable and ornamental crops suffer from salinity within the EC interval of 2 to 4 mSm/cm.

Classifications and groupings of salt-affected soils within the region under consideration are based on the Classification and Diagnostics of Soils of the USSR, 1977[10] and analytical data on saturated extracts (USDA Agriculture Handbook. 1954) [20]. These classifications and groupings are presented in Tables 1.1-1.3 and Annex A.

## 1.2. Soil and water salinity diagnostics and evaluation methods

Soils are regarded as salt-affected, if they have salt concentrations above the thresholds of toxicity that include the following: 1) a concentration of salts in the soil solution of 3-5 g/l [11]; 2) a sum of toxic salts measured in water extracts of 0,05-0,15% [1]; 3) specific electrical conductivity of saturated soil-paste extracts of 2-4 mSm/cm (USDA Agriculture Handbook, 1954) [20]. The suitability of such soils for different crops is determined by attributing them to specific soil groups differentiated by their salinity levels and respective levels of the tolerance of different crops [4].

Salt-affected soils are subdivided into two groups: 1) Saline soils without Natric/Solonetzic/Sodic horizon and 2) Alkaline soils with a well-developed Natric/Solonetzic/Sodic horizon, which is the diagnostic horizon of this group. The former group includes Solonchaks and other saline soils without the solonetzic horizon, the latter – Solonetz and solonetzized soils.

Solonchaks are soils that contain high concentrations of toxic (soluble) salts within their surface layer: more than 0,5% in the case if soda-dominated salinity and more than 1% in the case of chloride-sulphate salinity. Such concentrations prevent the growth and development of most agricultural crops [9, 10]. The surface layer implies a whole plough layer (15-30 cm) of arable soils and the top 15-cm-thick layer of virgin soils (Fig. 1.1). The surface salt crust that is usually present in Solonchaks has an average salt content of 10 - 20% and often higher.

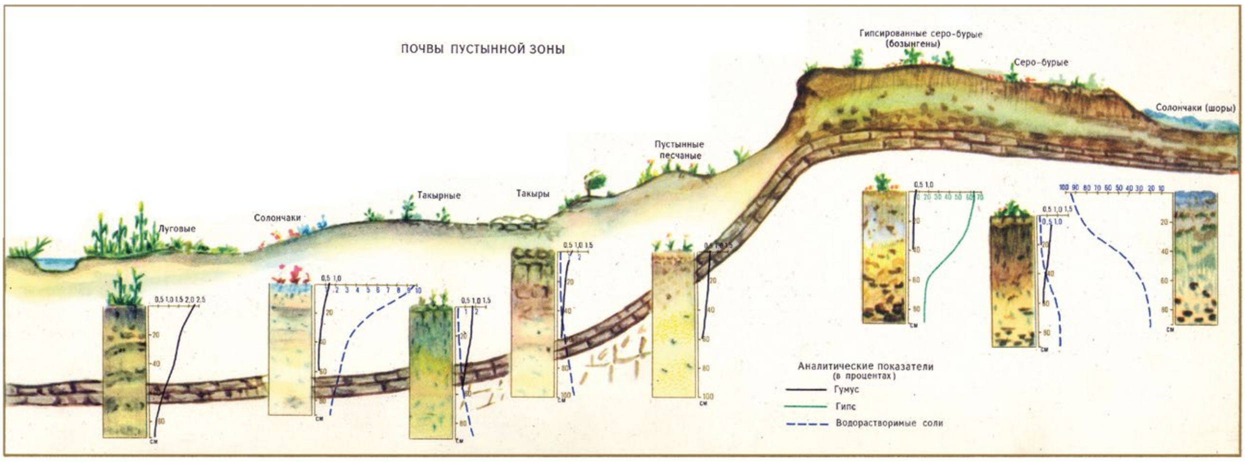



***Fig.1.1. Soil profiles (by the example of the desert zone of Uzbekistan). Source: The Atlas of Uzbekistan, 1985***

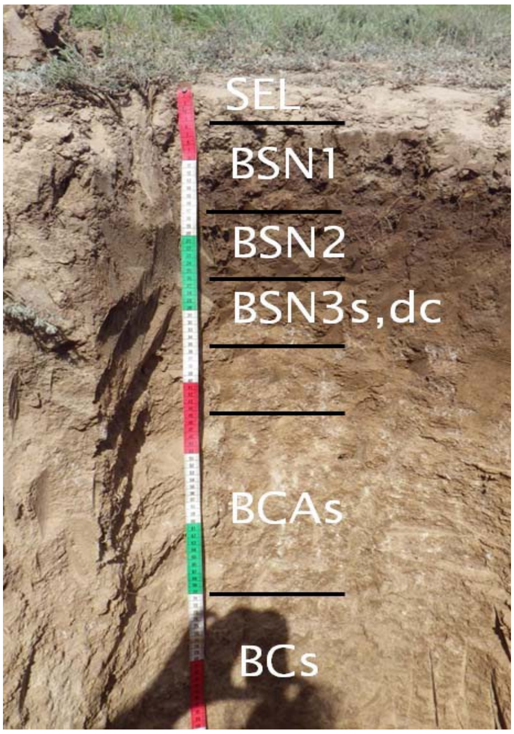
All other soil types that contain salts also belong to the rank of salt-affected soils (e.g., deeply saline chestnut soils). Depending on the depth of the upper boundary of the salt- containing horizon, the soils are subdivided into the following groups: saline at the top (with the boundary occurring within the upper 30 cm of soil), saline in the middle (30 - 100 cm) and lower (100-200 cm) layers. The surface of such soils can sometimes bear a seasonal salt film, which does not provide a substance for classifying them as Solonchaks, because the mean content of salts within the surface 15 cm of soil does not exceed 1% (or 0.5% in the case of soda-dominated salinity).

Solonetz and solonetzized soils have a vertically differentiated distribution of clay within their profile that consists of the solonetzic eluvial horizon and the Natric/Solonetzic illuvial horizon with specific physicochemical properties, being a diagnostic feature (Fig. 1.2). Classifications, assessment criteria and distribution of salt-affected soils are presented in Annex A.

Analyses of the soil:water extract of 1:5 and soil solutions represent a traditional method of soil salinity assessment in the countries of the Eurasian Region [1]. At an international level, there is a widely used salinity assessment method based on the specific electrical conductivity of saturated soil-paste extracts, as developed by the USDA Salinity Laboratory in the 1950s [20]. However, the preparation of pastes and their extracts is a labour- intensive process and is, therefore, often replaced by measurements in water suspensions of soils (1:2.5, 1:5, 1:10) with subsequent re-calculation using empirical coefficients [15]:

$$EC_{SE} = (250 \bullet EC2.5) / WC_{SE} \quad (1.1)$$

where $EC_{SE}$ is the electrical conductivity of saturated soil-paste extract, EC2.5 - electrical conductivity of soil: water suspension of 1:2.5, $WC_{SE}$ – the moisture content in soil paste, g/100 g, according to Table 1.4.




***SEL*** – solonetzic eluvial horizon

***BSN*** – solonetzic B horizon

***BCA*** – horizon of carbonate accumulations

***BC*** – transient horizon between B and C hor

s – salic features

dc – dispersed carbonates

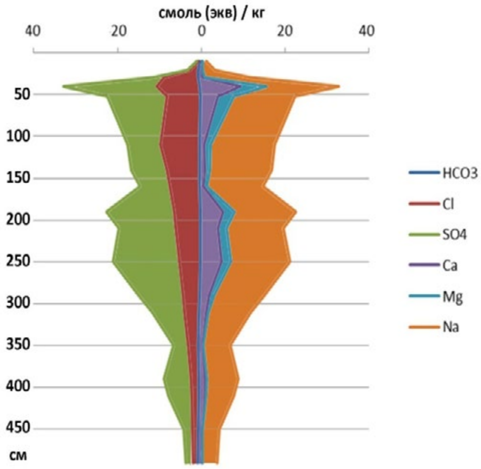



***Fig. 1.2. Morphology and salt distribution within the profile of Episalic Solonetz. The West Kazakhstan, village of Borsi; 50.10808 N, 47.4963 E.***

### *Table 1.1. Soil salinity grades depending on the chemistry of salinization (Bazilevich and Pankova, 1972)*

| Soil salinity grades | Salinization chemistry (by dominant ion concentrations, mmol (equiv.) / 100 g of soil) | | | | | |
|---|---|---|---|---|---|---|
| | Neutral salinization (pH<8.5) | | | Alkaline salinization (pH>8,5) | | |
| | Chloride, sulphate-chloride | Chloride- sulphate | Sulphate | Soda and soda-chloride | Sulphate-soda and soda-sulphate | Sulphate-chloride-carbonate |
| | $HCO_3$<Ca+Mg | $HCO_3$<Ca+Mg | $HCO_3$<Ca+Mg | $HCO_3$>Ca+Mg | $HCO_3$>Ca+Mg | $HCO_3$<Ca+Mg |
| Toxicity treshhold (non-saline soils) | <0,1<br><0,05 | <0,2<br><0,1 | <0,3(1,0)**<br><0,15 | <0,1<br><0,1 | <0,15<br><0,15 | <0,2<br><0,15 |
| Low | 0,1-0,2<br>0,05-0,12 | 0,2-0,4(0,6)<br>0,1-0,25 | 0,3(1,0)-0,6(1,2)<br>0,15-0,3 | 0,1-0,2<br>0,1-0,15 | 0,15-0,25<br>0,15-0,25 | 0,2-0,4<br>0,15-0,3 |
| Medium | 0,2-0,4<br>0,12-0,35 | 0,4(0,6)-0,6(0,9)<br>0,25-0,5 | 0,6(1,2)-0,8(1,5)<br>0,3-0,6 | 0,2-0,3<br>0,15-0,3 | 0,25-0,4<br>0,25-0,4 | 0,4-0,5<br>0,3-0,5 |
| High | 0,4-0,8<br>0,35-0,7 | 0,6(0,9)-1,0(1,4)<br>0,5-1,0 | 0,8(1,5)-1,5(2,0)<br>0,6-1,5 | 0,3-0,5<br>0,3-0,5 | 0,4-0,6<br>0,4-0,6 | Does not occur |
| Very high | >0,8<br>>0,7 | >1,0(1,4)**<br>>1,0 | >1,5(2,0)<br>>1,5 | >0,5<br>>0,5 | >0,6<br>>0,6 | " |

***Note**: above line - the total amount of salts, below line - the sum of toxic salts, %, in water extract 1:5. The sums of toxic salts were calculated according to [1, 7].*

Numbers in brackets characterize salinity levels in gypsum-containing soils with more than 1% of $CaSO_4 \cdot 2H_2O$.

## Table 1.2. Classification of alkaline and non-alkaline saline soils based on analyses of saturated soil-paste extracts [20]

| Soil groups | EC | ESP** | pH | SAR | Main ions and their concentrations | Gypsum* | Carbonates of earth metals* |
|---|---|---|---|---|---|---|---|
| Non-saline, non-alkaline | <4 | <15 | <7< | low | | +, - | +, - |
| Saline > 4 | >4 | <15 | <8.5 | medium | $Cl^-$, $SO_4^{2-}$,$HCO_3^-$ - low, $CO_3^{2-}$ - absent, $Na^+$>$Ca^{2+}$ +$Mg^{2+}$ | + | + |
| Non-saline, alkaline | medium | >15 | Usually >8.5 | high | $Na^+$ , may be present in form of $NaHCO_3^{2-}$ - $NaCO_3$ | Rare + | |
| Saline, alkaline >4 | >4 | >15 | Usually <8.5 | | Like in the 2nd group, but with higher content of sodium | | |

***Note***: ** + present, - absent * * the relative amount of the sodium ion expressed as a percentage (%) of the CEC or the sum of exchangeable bases*

## Table1.3. Soil salinity assessment based on the electrical conductivity of saturated soil-paste extracts [20], the data on gypsum-containing Greyzems and analyses of water extract 1:5 (the sum of toxic salts and sodium ion concentration), according to Kopikova and Skulkin, 1990 [12]

| The impact of salinity on crp yields | Degree of salinization | Criteria by USDA (1954), ECe, mCm/cm | Criteria according to [12] | | |
|---|---|---|---|---|---|
| | | | ECe, mCm/cm | The sum of toxic salts % | Na+ cmol(equiv.)/kg |
| Insignificant influenceofsalinity | Absent | Up to 2 | 0-3 | 0-0.15 | 0-1 |
| Limited yields of very sensitive crops | Low | 2-4 | 3-5 | 0.15-0.30 | 1-3 |
| Limited yields of many crops | Medium | 4-8 | 5-10 | 0.30-0.60 | 3-6 |
| Satisfactory yields of many salt-resistant crops most | High | 8-16 | 10-16 | 0.60-1 | 6-11 |
| Satisfactory yields of very few salt-resistant crops most | Very high | >16 | >16 | >1 | >11 |

## Table1.4. The water content of saturated extracts (WCSE) depending on the particle-size distribution and humus content (in mineral soils) [15]

| Particle-size-distribution | Humus content | | | | | |
|---|---|---|---|---|---|---|
| | < 0.5% | 0.5-1% | 1-2% | 2-4% | 4-8% | 8-15% |
| Gravel, CS | 5 | 6 | 8 | 13 | 21 | 35 |
| MS | 8 | 9 | 11 | 16 | 24 | 38 |
| FS | 10 | 11 | 13 | 18 | 26 | 40 |
| LS, $SL_{<10\% \text{ of clay}}$ | 14 | 15 | 17 | 22 | 30 | 45 |
| SiL | 17 | 18 | 20 | 25 | 34 | 49 |
| Si | 19 | 20 | 22 | 27 | 36 | 51 |
| $SL_{10-20\% \text{ of clay}}$ | 22 | 23 | 26 | 31 | 39 | 55 |
| L | 25 | 26 | 29 | 34 | 42 | 58 |
| $SiL_{10-27\% \text{of clay}}$ | 28 | 29 | 32 | 37 | 46 | 62 |
| SCL | 32 | 33 | 36 | 41 | 50 | 67 |
| CL, SiCL | 44 | 46 | 48 | 53 | 63 | 80 |
| SC | 51 | 53 | 55 | 60 | 70 | 88 |
| SiC, $C_{40-60\% \text{ of clay}}$ | 63 | 65 | 68 | 73 | 83 | 102 |
| $HC_{<60\% \text{ of clay}}$ | 105 | 107 | 110 | 116 | 126 | 147 |

In Ukraine, water quality and its suitability for irrigation are regulated by the national standards of irrigation water quality, agricultural criteria and also regulations and standards of nature protection and conservation. Criteria for assessing irrigation water quality, the risks of salinization, solonetzization and alkalinization of soils and the risks of salt toxicity for plants growing on soils with different buffer capacities are presented in Annex B [2, 3, 5, 6].

Six groups of soils with different particle-size distributions were assigned specific threshold levels of salts in chloride ion equivalents on the basis of published data and results of long-term studies by S.A. Balyuk and colleagues from the Laboratory of Fertility of Irrigated and Solonetzized soils of the Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky (Kharkiv). The irrigation water quality assessment used to determine the risk of irrigation salinity is set out in Table 1.5. The irrigation water quality assessment to determine the risk of soil alkalinization is presented in Table 1.6.

### Table 1.5. The irrigation water quality assessment to determine the risk of irrigation salinity occurrence in soils

| The concentration of toxic ions expressed as equivalents of chloride ions in soils with different particle-size composition within a layer of 0-100 cm, meq/dm$^3$ | | | | | | Water quality class |
|---|---|---|---|---|---|---|
| Sand | Loamy sand | Sandy loam | Loam | Clay loam | Clay | |
| less than 30 | less than 26 | less than 22 | less than 18 | less than 14 | less than 10 | I |
| from 30 to 40 | from 26 to 36 | from 22 to 32 | from 18 to 28 | from 14 to 24 | from 10 to 20 | II |
| more than 40 | more than 36 | more than 32 | more than 28 | more than 24 | more than 20 | III |

***Note***: *Calculations of the sum of toxic salts in irrigation water as equivalents of chloride ions and the classification of soils by their particle-size composition are presented according to [5, 6].*

### Table 1.6. The irrigation water quality assessment to determine the risk of soil alkalinization

| Water quality parameter | Water quality class | | |
|---|---|---|---|
| | I | II | III |
| | | Irrigation of acidic soils | |
| pH | <8,2 | from 8,2 to 9,0 | > 9,0 |
| The content of $CO_3^{2-}$, meq/dm$^3$ | <0,3 | from 0,3 to 0,9 | > 0,9 |
| The level of toxic alkalinity $HCO_3^{2-}$ $CA^{2+}$ , meq/dm3 | < 2,5 | from 2,5 to 8,0 | > 8,0 |
| | | Irrigation of neutral soils | |
| pH | < 8,0 | from 8,0 to 8,8 | > 8,8 |
| The content of $CO_3^{2-}$ , meq/dm$^3$ | absent | from 0,2 to 0,6 | > 0,6 |
| The level of toxic alkalinity $HCO_3^{2-}$ $CA^{2+}$, meq/dm$^3$ | < 2,0 | from 2,0 to 7,0 | > 7,0 |
| | | Irrigation of alkaline soils | |
| pH | < 7,5 | from 7,5 to 8,5 | > 8,5 |
| The content of $CO_3^{2-}$, meq/dm$^3$ | absent | from 0,1 to 0,3 | > 0,3 |
| The level of toxic alkalinity $HCO_3^{2-}$ $CA^{2+}$, meq/dm$^3$ | <1,5 | from 1,5 to 6,0 | > 6,0 |

***Note***: *1). pH, $CO_3^{2}$- and $HCO_3^{2}$- should be determined at water temperatures from 17 °C to 20 °C and the partial pressure of $CO^2$ in the air at 3040 Pa; 2). The method of toxic alkalinity calculation and the soil pH classes are described in [5].*

The three classes of water are distinguished as follows: I – no risk of irrigation salinity occurrence in soils and the use of water without limitations according to science-based irrigation rates; II – risks of occurrence of weak and medium irrigation salinity within the 0-100 cm layer and water use requiring the application of technical and agricultural amelioration measures ; III – risk of occurrence of strong irrigation salinity of soil and water use only possible on the condition that its quality is improved by different techniques to fit Classes I - II (Annex B. Part II).

## 1.3. Main causes, sources and effects of salinity

### Main types and sources of salts

There are 2 main types of soil salinity:

- primary salinity due to natural causes
- secondary salinity due to irrational land use and inappropriate agricultural practices

Primary salinity occurs naturally in soils and waters. Natural salt accumulation processes are associated with certain types of relief, geomorphological and hydrogeological conditions. The latter imply a high groundwater table, impeded drainage or even an absence of drainage with only evaporation and transpiration processes to control the groundwater table. In arid climates, relic salt accumulations tend to be preserved and modern salt accumulation processes are in progress occur within the accumulative types of landscapes under hydromorphic condition.

Secondary salinity occurs as a consequence of excessive water inputs via irrigation and leaching of soils in the absence of appropriate drainage systems, which causes a rapid raising of the groundwater table. At the present time, the development of secondary salinization represents an important problem in sustaining the health of arid ecosystems (FAO SPUSH, 2001) [21] .

The main sources of soil salinity are salts originally present within parent materials, mineralized ground and surface waters as well as wind-blown deposits.

An assessment of the causes of salinity within a specific area requires consideration of the following factors:

- The presence of salt-containing deposits or saline parent materials. Modern soil salinity is often caused by the influence of strongly saline sediments and, especially, deposits of rock salt and salt domes.
- Aeolian transport of salts from the sea surface (salt spray) and also from the surface of Solonchaks. This process is extensively developed in both coastal areas and inland, e.g., Western Siberia and the areas of the Aral Sea and Lake Balkhash.
- Hydrogenic salt accumulation is an important source of salts in soils within the areas of groundwater springs and shallow groundwater tables.

- Biogenic salt accumulation associated with the ability of plants to accumulate certain salts and later return these to soils as plant litter undergoes decomposition.
- Use of highly mineralized irrigation water can cause strong soil salinization within irrigated fields.

Research into genesis and sources of salinity should involve another important consideration. Salts that enter a soil can undergo significant changes. They can be present in soil solution, undergo precipitation or exchange reactions, which implies the development of processes of salt transformation, vertical re-distribution and interaction with the solid and liquid phases of soils, i.e., salts take part in soil formation.

## Causes of soil salinity

Soil salinity is multi-factorial phenomenon, i.e., caused by various factors or combinations of factors. Salinization is a complex process that can develop in different ways in different areas of the Eurasian Region, often caused to a significant extent by the over-exploitation of natural resources, in particular, unsustainable and inappropriate methods of agriculture and land use, and incorrectly managed water resources, the consequences of which become aggravated by climate change with extreme droughts and other challenges.

Balyuk and colleagues point out that causes of secondary salinity of soils in Ukraine can also include the following: (i) an unfavourable chemical composition of irrigation water, with the contents of sodium and potassium salts in their equivalent concentrations exceeding the contents of salts of calcium, magnesium, iron and other bi- and trivalent cations; (ii) the raising of groundwater towards the surface layer having an equally adverse chemical composition can cause persistent secondary salinization and (iii) leaching of saline soils as well as paddy rice cultivation on naturally saline soils (initial years).

Research by V.A. Kovda, E.I. Pankova, I.P. Aidarov and other scientists [11, 14] showed that the relic and modern salinity of soils and waters in the Central Asia are caused by the combined influence of climate, topography, geomorphology, bedrock geology and history of the development of the Turan Province. The manifestations of the salinization process are predetermined by the two types of landscapes: i) landscapes with natural (relic) soil salinity and ii) landscapes with the secondary accumulation of salts. Gentle slopes and an absence of natural drainage of the groundwater in combination with irrigation result in changes in the state of soluble salts including the mobilization and upward migration of ancient salt accumulations. The main causes of secondary salinity in Central Asia include excessive irrigation, significant losses of water from the channels on irrigated fields and imperfect drainage systems that result in a rapid rising of the groundwater and salt accumulation within the root zone. The inadequate maintenance of drainage networks triggers the mobilization of salts from deep aquifers.

Bucknall et al. [19] point out that over 70% of salts carried by trans-boundary rivers originate from drainage systems that discharge 10-25% of their water back to the rivers (with the remaining amount used on land). Water unsuitable for agricultural use or drinking, with a salinity of 1.5-1.8 g/l and a hardness double that of the maximal permissible level, is still supplied to consumers in the lower reaches of the Amu Darya River. The main systems of land use in such regions are recognized as being at risk from the combined impact of natural and man-made phenomena [11, 13, 14].

## Impacts and risks of soil salinity

The productivity of agricultural lands in arid and semi-arid environments is affected by the accumulation of salts and the loss of soil organic matter (SOM). The latter leads to the loss of soil fertility and deterioration of its agrophysical, biological and other properties. Salinization processes have a serious impact on soil functions such as its ability to act as a buffer and filter against pollutants, its participation in the water and nitrogen cycles and its ecosystem services in supporting the health of the environment and biodiversity.

Soil salinization impacts on the agricultural productivity by causing disruptions to the processes of nitrogen uptake and plant growth development. The loss of biological activity of soils is associated with the decline of food supplies for soil microflora necessary for ecosystem functioning. The abandonment of arable soils is associated with high risks for soil and environment health and significant ecological stress. An increase in soil salinity further deteriorates soil ecosystem services and decreases revenues for farmers and smallholders. The loss of natural vegetation and forests is the ultimate consequence of salinization of arid agricultural lands.

In cases of the occurrence of a shallow groundwater table, salinization affects the soil's infiltration capacity, which creates flood risks at different scales. Flooding can lead to the damage of roads, dams, agricultural fields and wetlands as well as the destruction of buildings.

Salt accumulation can cause damage to infrastructure including roads, buildings and other constructions. If the groundwater table occurs at a depth of less than 1-2 m, the presence of salts in the ground can cause a significant decrease in road tarmac durability. Salts also cause the corrosion of asphalt, concrete and brick constructions.

Soil salinization results in significant limitations to agricultural crop production and, therefore, negatively affects food security. The salinity-induced losses of yields within dry territories vary from 18 - 26% to 43% [25], which can undermine the quality of life for local people and aggravate damage caused by land degradation and climate change. The annual loss of agricultural productivity is estimated to be 31 million USD, while the financial loss due to land abandonment following soil salinization, infrastructure deterioration and a lack of water for soil leaching is estimated at 12 million USD (World Bank, 2009).

The current trends of climate change with increases in the frequencies and severities of droughts represent a serious threat and create significant risks for fragile ecosystems in arid and semiarid areas. Droughts accelerate and spread the processes of salt mobilization and accumulation within the upper horizons of soils. More frequent droughts with extremely high temperatures and low humidity are especially dangerous in combination with a lack of water for land irrigation, which causes the suppression of seedling growth, partial or complete losses of yields over vast areas of soils affected by salinization. For example, a severe drought in the lower reaches of the Amu Darya River in 2000-2001 caused losses of yield of 14-17% in cereal crops and from 45- 52% to 75% in other crops. Orchards and vineyards are especially prone to yield loss due to soil salinization and a lack of water. A lack of water also affects the productivity of cattle, as the poorer quality of fodder crops causes a decrease in animal weight gain [8].

Efforts to prevent soil salinity should be directed at changing the land use and management towards decreasing the risks of soil salinization in fragile agricultural environments during certain periods of time. The assessment of risks of irrigation salinity can be useful in designing management techniques for different ecosystems. Comparing such risks can help in prioritizing the management options.

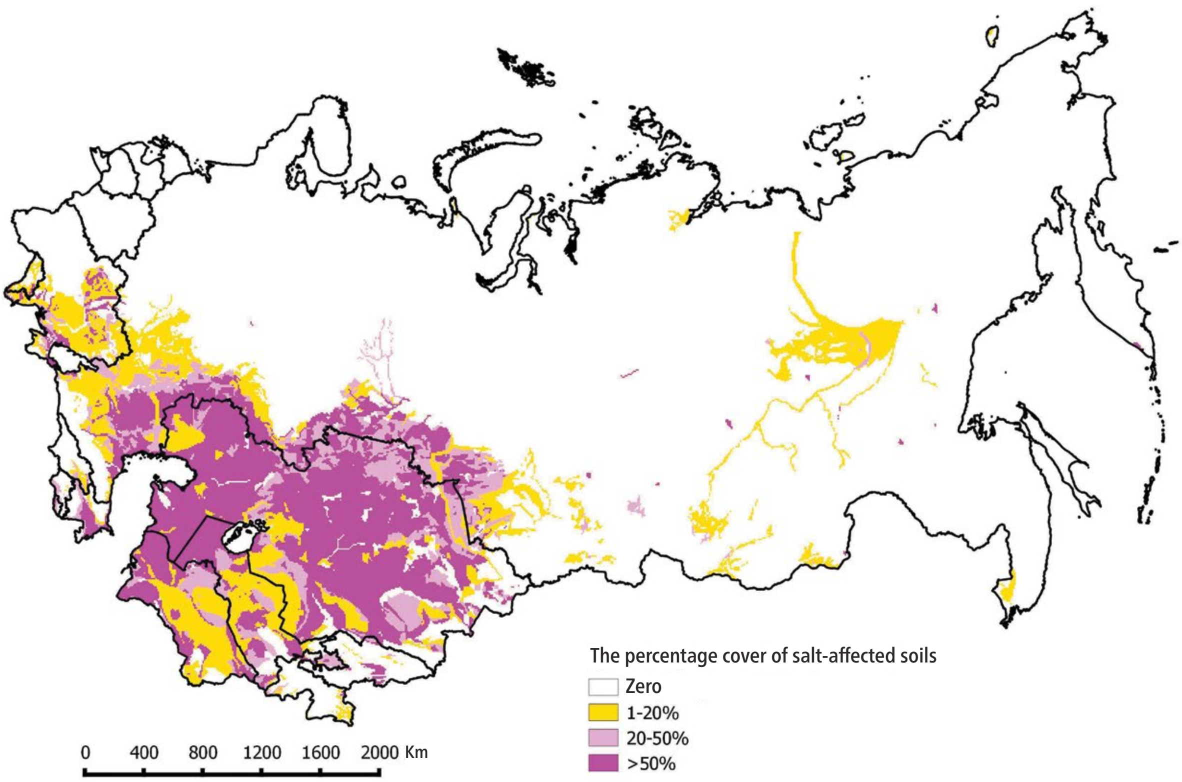
## 1.4. Distribution of salt-affected soils within the Eurasian Region

Salt-affected soils occur in almost all countries of the Eurasian Region (Fig. 1.3). Soils with sulphate-dominated salinity are most widespread (Fig. 1.4). According to calculations based on the digital map of saline soils of the Eurasian Region [16], the total area of salt-affected lands is estimated at about 242 million hectares. Such lands are found mainly in Kazakhstan, Russia, Turkmenistan, Uzbekistan, Ukraine and Azerbaijan. There are very few saline soils in Armenia, Georgia, the Kyrgyz Republic and Moldova. The data on saline and alkaline soils in the Eurasian Region countries are presented in Annex A. Brief notes on some countries are given below.

In Azerbaijan (B.G. Aliev and S.A. Safarli, 2016) salinization affects about 633.8 thousand ha (43.8%) of irrigated lands, of which 429.8 thousand ha (68%) and 139.8 thousand ha (22%) are assigned weak and medium grades of soil salinity and about 66.2 thousand ha (0.4%) are strongly saline soils, the latter being found mostly within the Kura-Aras Lowland.

In Georgia (E. Sanadze, 2016) there are two large groups of salt-affected soils, Solonchaks and Solonetz, with a total area of 112.6 thousand ha (1.6% of the country). These are found mostly within the zone of dry subtropics on plains, especially in Alazani, Eldari and other regions.

In the Republic of Moldova (B.M. Ropot, Yu.G. Rozloga and other specialists) the main areas of distribution of saline soils are located on the floodplains of internal and transboundary rivers, where 180 out of the total of 250 thousand ha of saline soils are involved in agricultural use. As a result of river damming, the floodplain environments are gradually turning into steppe, which is accompanied firstly by the acceleration of evaporation-induced salt formation within the groundwater – soil system and then by the intensification of soil solonetzization processes. An analysis of hydrogeological data shows that about a half of the area of cultivated alluvial soils of the Republic has an unsatisfactory agricultural state, with the soils being affected by the processes of salinization, solonetzization and slitization (reversible cementation of clay soils).




| Страна | Азербайджан | Армения | Грузия | Казахстан | Кыргызстан | Молдова | Россия | Таджикистан | Туркменистан | Украина | Узбекистан | Всего |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Площадь засоленных почв, млн. га (по цифровой карте) | 2,4 | 0,2 | 0,3 | 140,3 | 1,2 | 0,3 | 57,3 | 0,6 | 17,3 | 6,6 | 15,6 | 242,2 |

***Fig. 1.3. The distribution of salt-affected soils within the Eurasian Region [16]***

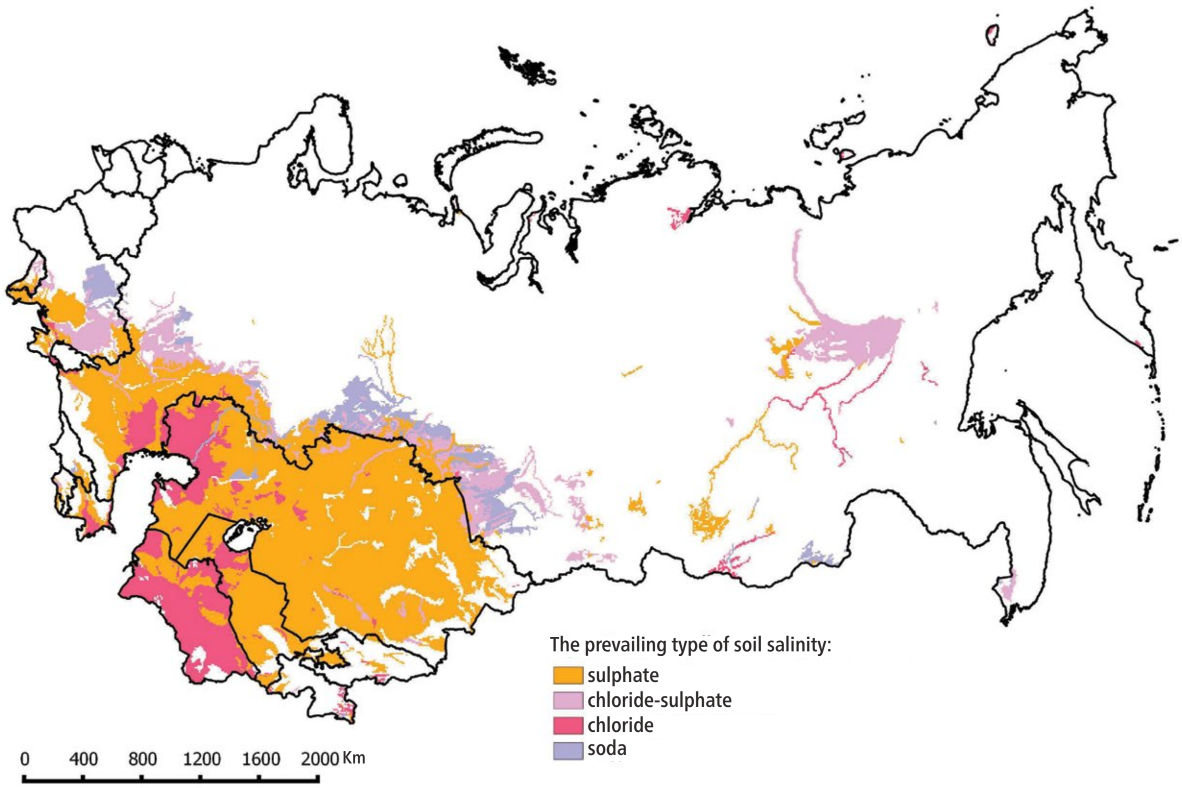



*Fig. 1.4. The prevalent chemistry of salt-affected soils within the Eurasian Region [17]*

In the Russian Federation [7] about 21% of the total area of agricultural lands are categorized as salt-affected, among which there are 6.3 million ha (about 9%) of saline (non-alkaline) soils and more than 23 million ha (12.5%) of soils of Solonetz complexes. Salt-affected soils are most widespread in the south of Russia in semidesert, dry steppe, steppe and forest-steppe environments.

In some regions, e.g., the Astrakhan region, the Republic of Kalmykia, the Republic of Dagestan, the Novosibirsk region, etc., saline and akaline soils occupy up to 30% or more of the total arable land area. Alkaline soils are widespread in the south of Western Siberia, while saline soils occur in the south-eastern part of Siberia within small locations such as topographic depressions and river valleys. They are especially common on irrigated lands towards the south, where primary salinity and the risk of secondary salinity are common problems.

In Ukraine (S.A. Balyuk and E.N. Drozd) salt-affected soils occupy a relatively small proportion (around 7%) of arable land, but in an agricultural sense they require special attention for several reasons [22]. Natural salt-affected soils of Ukraine are located within two tectonic depressions – the Dnieper-Don (forest-steppe zone) and the Black Sea (steppe) depressions, where generally imperfect land drainage causes the accumulation of salts within the root zone and the development of secondary salinization processes. According to hydrology-amelioration monitoring data, formerly irrigated lands occupy a total area of 2.18 million ha, but currently irrigated lands – only 600-700 thousand ha (25-30% of irrigated lands).

Saline soils without a morphologically distinct solonetzic horizon occupy a total area of 1.92 million ha, while alkaline soils with a morphologically distinct solonetzic horizon occupy 2.8 million ha.

The total arable land area includes between 50-100 and 200 thousand hectares of secondary saline soils in different years.

These findings have been confirmed by analysis outputs from the global database of GLADIS (FAO LADA, 2005) as follows. In dry parts of the region, most soil types undergo salinization and degradation due to the poor condition of vegetation and soil cover and the ecosystem sensitivity to salinization, water erosion, climate change and droughts. At the present time, salt-affected and waterlogged soils occupy up to 40-60% of irrigated lands in Central Asia [23]. The World Bank (2005) states that over 69.4% of agricultural lands in the Central Asia are affected by salinization [8, 13, 24].

Thus, there are important problems in the use and amelioration of salt-affected soils in all countries of the Eurasian Region, which require decision making on the development of joint programmes for action to achieve an integrated management, conservation and rational use of natural resources with an emphasis on the sustainable management of salt-affected soils and waters. To achieve targets there is a vital need to strengthen the scientific base and to mobilize resources to support the wider implementation of innovative approaches and technologies for sustainable management of land resources and realization of national and subregional programmes on the improvement and amelioration of salt-affected soils involving the application of technical, scientific, water-ameliorative, land-ameliorative and agricultural engineering measures.

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# Chapter 2.
# Methods of studying, mapping and monitoring saline and alkaline soils

This chapter focuses on the main methods that are widely applied within the Eurasian Region and internationally in studying and assessing salt accumulation trends as well as the mapping and monitoring of salt-affected soils. Methodological aspects of the assessment, mapping and monitoring of saline and alkaline soils are presented in Annex C; a brief overview of approaches and methodologies of soil assessment and monitoring is given below.

## 2.1. Methods of studying and mapping of saline and alkaline soils: ground survey and remote sensing techniques, aerial photography and GIS-mapping

**S.A. Balyuk, V.B. Solovei, M.A. Solokha and S.P. Truskavetsky (Ukraine)**

The study and mapping of alkaline and saline soils can be particularly complex. The distribution of salt-affected soils is reflected by variations in the groundwater table and mineralization in combination with the influence of microtopography. The spatial heterogeneity of alkaline and saline soils can be seen by tonal contrasts in images over open surfaces (due to variations in the humus content and the presence of siliceous powdering and salt efflorescences) and also over vegetated surfaces (due to plant growth suppression by soil salinity and alkalinity and differences in sensitivity of native and cultural crops to moisture levels associated with fluctuations in the groundwater table). This serves as a basis for the wide application of remote sensing in combination with traditional ground surveys in the study and mapping of saline and alkaline soils [6, 8].

The use of space-borne Multispectral Imaging (MSI) followed by digital image processing and classification is a highly efficient modern technique for mapping saline and alkaline soils.

The study of alkaline and saline soils involves three stages – preparation, field work and laboratory research.

The ***preparation stage*** includes the following tasks:

- the collection and organization of information on environmental conditions, existing maps and analytical data;
- drafting a list of soil varieties, as judged by the anticipated structure of the soil cover;
- the compilation of a draft map of soil cover based on remote sensing data, using high resolution images, or aerial photography including the use of an unmanned aerial vehicle (UAV), etc.

### *Aerial photography from an unmanned aerial vehicle (UAV)*

The sequence of data collection on soil conditions of a study site using the UAV includes the following operations and procedures:

- capturing aerial images using the UAV (i.e., preparing a drone with a camera for flight, making corrections for wind, sun, cloud, the influence of windbreaks and man-made objects); timing the aerial imaging for the hours between 9.00 to 16.00;
- adjusting the height of the UAV flight to 80 to 100 m above test field(s), with the route
- involving several circular assents and descends above the test field(s);
- image data processing as required for the study purpose, re-processing the images obtained for further analyses or preparing an ortophotoplan for solving problems of precision agriculture;
- re-processing of the images obtained involving adjustments of brightness and contrast to uniform levels and selecting the optimal orientation of the analysed image;
- an ortophotoplan preparation involves merging the obtained aerial images.

### *Compilation of a draft map based on satellite imagery*

The most widely known parameters of satellite images of saline and alkaline soils of arid environments of the dry steppe include a relatively light tone of images in most ranges of the spectrum and a complex pattern of images. A reliable indirect method of mapping involves the use of phyto-indicators of salt-affected soils based on the MSI data from high- and ultra-high-resolution images (e.g., Spot, Landsat, Terra, Pleiades) [8].

The MSI-based mapping of saline and alkaline soils follows a generally accepted algorithm that includes several stages. At the initial image-processing stage, one should perform a successive systematic, radiometric, atmospheric and geometric correction of the image, with radiometric calibration and increases in image contrast and spatial filtration. At the stage of statistical analysis of the image, the optimal number of classes is determined for the next stage – the image classification. Digital processing and classification result in the creation of a draft map that reflects the relative positioning of the areas studied. The latter are delineated by geographical coordinates and distinguished by their surface optical parameters.

### *The field work stage of the study (ground survey)*

The field work stage of the study involves the verification of the draft map (remote sensing data output) on the ground. This stage also involves a field survey to confirm soil- environment interaction and the list of soil varieties.

The field survey involves the inspection of soil pits and cores within contours delineated on the drafted soil map. The soils of Solonetz and Solonchak complexes are identified on the basis of the morphological structure of their profiles [16, 17] followed by laboratory analysis to confirm their genesis and taxonomic position [4].

***The laboratory research stage.***

At the laboratory research stage, the samples taken from saline and alkaline soils are analysed giving special attention to determinations of the humus content, particle-size distribution, cation exchange capacity, sodium absorption ratio and the cation-anion composition of water extract. The data obtained should then allow the confirmation soil varieties and a finalized list of soil designations and also enable completion of the soil map and the legend to serve as a basis for further recommendations regarding amelioration of saline and alkaline soils.

## 2.2. Methods of assessment of modern processes of salt accumulation in soils using salt concentration measurements

**S.A. Balyuk (Ukraine) and I.P. Aidarov (Russia)**

Soil tests provide reliable and long-term data on soil salinity and alkalinity and serve as a method of assessment of modern processes of salt accumulation in soils. Measurements of salt concentrations in soils allow the analysis of spatial development of salinization and alkalinization processes on currently and formerly irrigated fields and adjacent lands [5, 7].

Measurements of salt concentrations in soils allow the determination of the following:

a) the chemistry (chemical type) of soil salinity based on the concentrations of salt anions and cations;

b) the degree of soil salinity (based on determinations of the total amounts of salts and toxic salts in water extracts of soils and sediments characterized by different types of salinity);

c) the depth of the upper boundary of the first salt-containing horizon;

d) the mean content of the reserves of salts;

e) the hydrochemical type (based on anion and cation concentrations) and the salinity of the groundwater (fresh - up to 1g /$dm^3$; weakly saline -1-3; moderately saline -3-5; strongly saline -5-10; very strongly saline -10-35; brine - more than 35 g / $dm^3$ [7]);

f) the irrigation water quality and the risk of irrigation salinity occurrence [7].

The information gained is used for creating data bases and maps of soil salinization.

The development of strategies for controlling water and salt regimes of irrigated lands requires the knowledge of the scale and trends of natural processes of salt accumulation under different hydrogeological and hydrochemical conditions that existed in soils before irrigation started [1]. Specific calculation techniques [1, 3] for the evaluation of contents and distribution of salts in a soil at a specific moment of time. A change in at least one of the factors leads to a change in salt regime.

In cases of fluctuating groundwater tables and other parameters, the salt accumulation trends can be assessed via simultaneous soil tests over a wide area.

The assessment procedure involves statistical processing of the data to reveal the distribution patterns of random values of toxic salt (or ion) concentrations within a two-meter-thick layer of soil, which excludes the influence of seasonal fluctuations in salt composition. Practical calculations can be conducted using a simpler method for mass processing of data [2], which is widely used in hydrology and amelioration.

An example of statistical calculations for practical exercises is given in Annex C.2.

## 2.3. Organizing and conducting soil monitoring in conjunction with European experience

**V.V. Medvedev (Ukraine)**

Soil cover monitoring has been conducted in Europe for more than a quarter of a century, since the 1990s. At the present time, such monitoring is widely supported in European countries and it is generally accepted that high- quality soil information systems are vital in creating and maintaining good quality of life and a clean environment (Fig. 2.1.). On the basis of the results of monitoring, the European Union has ratified several legislative documents on soils including directives for maximal permissible levels of heavy metals, industrial pollution control, the use of solid and liquid industrial waste in agriculture, etc.

In 2006 the European Union ratified the thematic strategy of soil conservation and recommended it for use in national politics in all the EU countries [ 12 ].

**Box 2.1. Soil monitoring system [11]**

According to the European standards, the soil monitoring is a spatial-temporal system of observations of soil properties within permanent plots involving the use of a wide range of indicators with the following objectives: creating informative- analytical databases, regionalization, identification of problem areas, prediction of soil development, planning soil conservation measures, attraction of subsidies to farmers, connection with the media, etc.

The organization of a monitoring system relies on the following principles: independence from government, simple direct interactions between a regional laboratory and the Main Informational and Analytical Centre, discussed and agreed legislative base, coordination of environmental data, finance from the state budget and systematic progress reports to administration and the public.

There is an urgent need for support to improve and modernize the system of monitoring of soil cover in the Eurasian Region countries using the most recent developments in programming, mathematics and mapping in harmony with European experience.

***Types of monitoring.*** The countries that participate in this seminar are advised to create a permanent system of background, industrial and scientific monitoring.

***Background (control)*** – an initial assessment of the study site that gives a conventional baseline measurement. Such background monitoring provides data on soil properties in their natural state, which can later be compared to those in ploughed soils and allow for the detection of trends and intensities of man-induced soil transformation. If it is not possible to have reference to the natural state of a site, the first set of measurements should be used as baseline information.

***Industrial*** – the main form of current observations on soils in space and time.

***Scientific*** – data of a high quality and quantity can contribute to the effectiveness of the industrial monitoring and, importantly, help to create more reliable forecasts. Scientific monitoring should be based on specially designed field experiments, equilibrium and lysimentric studies, simulation and mathematical models. The industrial and background monitoring should be conducted by specialized industrial organizations and the scientific monitoring – by appropriate scientific institutions.

***Sites for monitoring*** – land areas with definite boundaries, permanent in time and space, GIS-positioned and registered (certified). The number of monitoring sites should be able to adequately represent the diversity of soil, landscape, climatic, geomorphological, hydrological and lithological conditions and land use systems and to support mapping at different scales to evaluate the state of soils using their individual and combined characteristics.

***The development of observation network.*** Practice of European countries involves the use of two types of monitoring networks – regular and irregular. The regular network is used in Austria (a network of several thousand permanent monitoring plots at a distance of 11 km and, some locations, 4 and 1 km from each other), Romania (960 plots in the intersections a 16x16 km network), France (2100 plots in the intersections of a 16x16 km network) and Sweden (2400 plots in the intersections of different-sized networks depending on topography). The irregular networks is used in Norway and Great Britain (13 plots each), Italy (27 plots), Germany (around 800 plots) and the Czech Republic (257 plots). This irregular type of monitoring network makes it possible to give representative (proportional) estimates of the state of the soil cover structure and the local characteristics of topography, climate and land use.

There are no comparative studies on the advantages and disadvantages of the two above- described types of monitoring networks. However, according to the EU standard (ISO 16133:2004(E)), it is recommended that each country individually chooses the type of monitoring network to use depending on its own experience in monitoring studies.

***Methods of monitoring***. The most widely used parameters of monitoring (in almost all countries) include concentrations of heavy metals, nitrates, pH, total carbon, particle-size distribution and cation exchange capacity. Less used parameters include soil density, aggregate composition, porosity, electrical conductivity and chemical composition of soil solutions. The least used parameters include fraction composition of organic carbon, microbiological parameters, soil respiration and enzymes.

The progress of monitoring studies has been supported by the development of measuring equipment. Many producers of field and laboratory measurement devices have appeared on the market, in particular, Dutch «Eijkelkamp», English «ADC», French «Lambrinus» and German «Trum». These producers have recently achieved noteworthy successes in construction, production and distribution of equipment for studying soils, plants, waters, solutions, emissions, processes of energy and matter exchange and transformation, etc. [12].

# 2.4. Soil salinity monitoring by the use of remote sensing (following the example of irrigated territories of Central Asia)

**E.I. Pankova, D.A. Soloviev, D.I. Rukhovich and I.Yu. Savin (Russia)**

The main requirements for organising remote sensing monitoring of irrigated salt- affected soils were defined by specialists from the Dokuchaev Soil Science Institute (Moscow, Russia) as a result of their long- term research in Uzbekistan. Despite the fact that most of this research was conducted in the 1990s, the data obtained are still relevant and serve as a basis for the present paper. The establishment of a monitoring system on irrigated soils is still one of the primary challenges of the ecological and agricultural sciences.

**Box 2.2. What do we mean by *ecological monitoring?***

The term ecological monitoring can be defined as a continuous testing, controlling and forecasting the state of the environment including soils and their properties on the basis of modern research techniques including ground-verified remote sensing data [15]. The main tasks and concepts of ecological monitoring have been defined in UNESCO's Man and the Biosphere Programme and many other publications.

### *The general concept of soil monitoring*

An evaluation of the state of cotton crops using remote sensing data and the analysis of the spatial distribution, sizes and numbers of cotton wilt patches using data collected in the late summer and early autumn serves as a basis for the estimation of soil salinization dynamics. As demonstrated earlier [9, 19, 20], the main factor causing cotton wilt is the presence of salts within the uppermost 1 m of soil. The larger and the more frequent the cotton-wilt patches, the stronger the salinization. Therefore, as a cotton-wilt patch by itself is insufficient evidence of strong salinization of soils, it is necessary to analyse the general extent and distribution of such patches. In cases when an image shows small areas (less than 20 m in diameter) and a sparse distribution of cotton-wilt patches (<20% of the total area), such patches have medium saline soils, while the rest of the field has non-saline or weakly saline soils. In cases when an image shows large areas (50-100 m in diameter) and a dense distribution of cotton-wilt patches (>50% of the total area), such patches have strongly and very strongly saline soils, while the rest of the field has medium and strongly saline soils with crops remaining unaffected (Table 2.1). Previous experience has shown that images from just two observation cycles fail to provide enough information for making a reliable judgment on salinization trends. It is necessary to organize regular annual observations on changes in soil salinity using remote sensing techniques and also to introduce mapping of salinization dynamics into practice [15].

*Table 2.1. The probability (% of the total number of samples) of different degrees of soil salinization within a mapping unit [15].*

| Image pattern* | Component | Degrees of soil salinization: Absent or low | Medium | High | Very high | Soil salinization within a component |
|---|---|---|---|---|---|---|
| Uniform dark | dark | 93 | 7 | - | - | Non-saline, rarely moderately saline |
| With small mottles | dark | 83 | 17 | - | - | Mostly weakly saline, rarely moderately saline |
| | light | 33 | 67 | - | - | Moderately and weakly saline |
| With medium mottles | dark | | 86 | 14 | - | Mostly moderately, rarely strongly saline |
| | light | | 7 | 66 | 27 | Stronly and very strongly saline, rarely moderately saline |
| With large mottles | dark | | 67 | 33 | - | Moderately and strongly saline |
| | light | | | 50 | 50 | Strongly and very strongly saline |
| Uniform light | | | | 17 | 83 | Very strongly saline, rarely strongly saline |

** Light – cotton crop is in poor condition; dark – cotton crop is in good condition.*

The ***largest scale*** of monitoring corresponds to the evaluation and control of soil condition throughout Central Asia, i.e., in all countries of this region. Irrigated areas of the region are concentrated within the basins of two large rivers: Amu Darya and Syr Darya. The water regimes, the total concentration (mineralization) and the composition of salts present in these rivers have significantly changed over recent decades and methods and agrotechnical measures of soil amelioration developed in the middle of the last century are now out of date. It is clear that such shortcomings are having a negative impact on agricultural productivity within Central Asia and these require updating. An overall re-assessment of the agricultural state of soils and the development of new regional amelioration policies are required.

Monitoring at the ***regional scale*** involves the analysis of regional lithological and geomorphological characteristics that predetermine specific measures of soil amelioration, the types of irrigation and drainage systems, etc. It is also important to take into account the demographic situation within the region.

Monitoring at the ***local scale*** is conducted within local farms, fields or groups of fields. Human impact represents the main factor of change in the agricultural state of these sites, with soil amelioration and landscape transformation conditions being the most dynamic parameters of such change. Clearly, the regional dynamics of soil quality are slower than local changes occurring within separate fields, which is reflected in differences in methodological approaches to salinization assessment at different scales. Local-scale monitoring involves the annual evaluation of the agricultural state of soils followed by a rapid decision making process in cases of drastic deterioration of the soil quality.

At larger scales of monitoring, less frequent observations are required, however, with a more complex analysis of factors and mechanisms of salinization dynamics. Such research should rely on the latest science and technological developments including remote sensing data and new data processing techniques. The soil monitoring system should be developed with the ideological and financial support of the state and the international community.

## The theoretical and methodological background to monitoring

Monitoring was developed as a new tool of natural sciences in the early 1970s in response to two main factors: 1) increasing environmental problems and 2) technological advances that allowed for the development of new and efficient means to control the state of the environment.

According to the authors [15], the aim of monitoring is to effectively manage the environment under the conditions of the dynamic development of local communities. The main tasks of monitoring include observation, control and prognosis of the state of the environment.

A prospective monitoring site should be highly sensitive to any change in the environment. Standard methods should be used with an obligatory statistical analysis of monitoring data. Special attention should be paid to the synchronicity and comparability of monitoring data and to the development of appropriate software (mathematical) and the technical basis for monitoring [10].

Research conducted within a framework of ecological monitoring should be aimed at obtaining information needed for developing forecasts and recommendations regarding the control of natural and human-induced processes. A general scheme for the remote sensing monitoring of the salinization of irrigated lands is presented in Fig. 2.1.

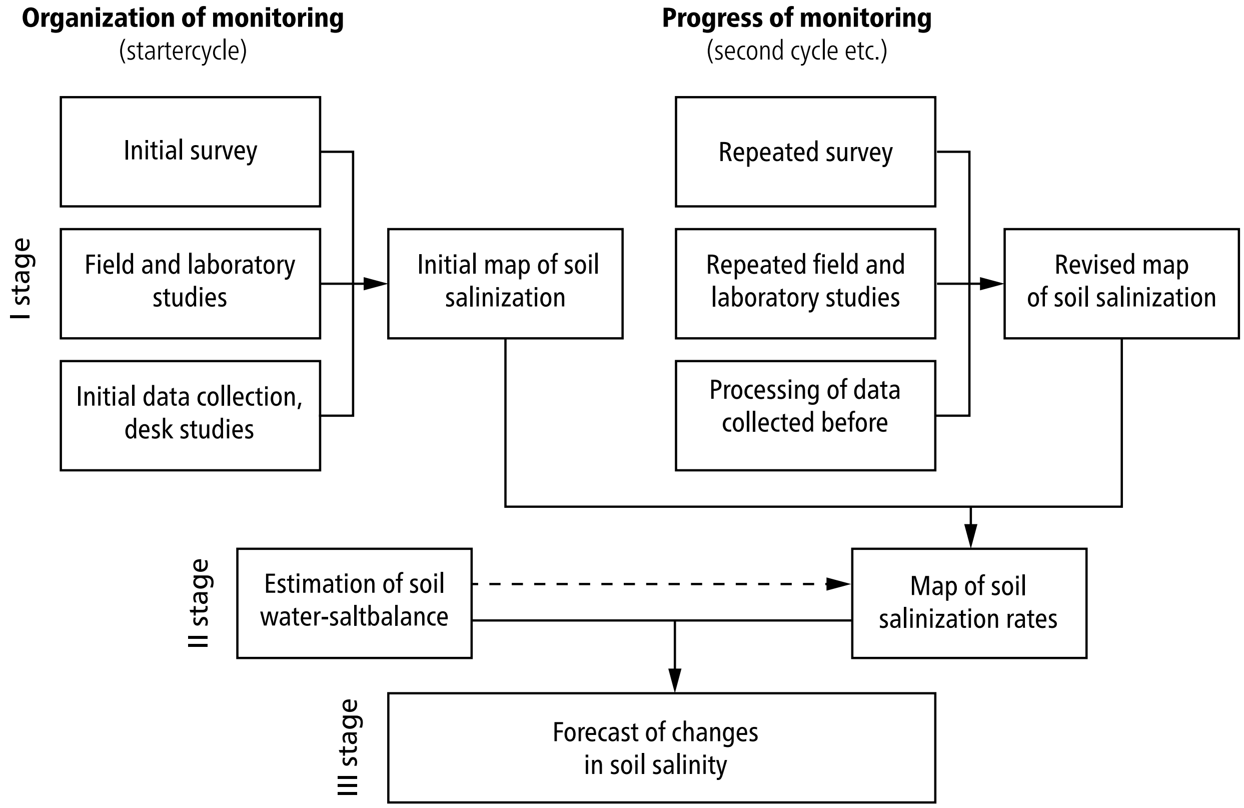


*Fig. 2.1. A general scheme of remote sensing monitoring of salinization of irrigated soils [15]*

The organization of remote sensing monitoring of soil salinization can be divided into three stages:

1. The inventorization of salt-affected soils based on the remote sensing data and the analysis of information on the actual state of salt-affected soils at the time of research.
2. The study of seasonal and long-term dynamics of soil salinization and the estimation of salinization-desalinization rates.
3. The determination of causes of soil salinization dynamics, the prognosis of development of salinization-desalinization processes and the development of recommendations for management of those processes.

Our studies have shown that the first of the aforementioned stages has already been achieved and its practical applications can be seen on specific sites of irrigation systems in Central Asia. The principles of the second stage have been set out and it can be realized in the near future with the development of appropriate tools. The third stage is the most complicated and requires the further involvement of specialists on soil amelioration, hydrogeology, mathematics and other disciplines to tackle existing problems.

It is assumed that all information that can be used in the future is being entered and saved into the database, which will be available for later use in the evaluation, planning and decision making in the course of work progress. The main approaches to the site-specific organization of monitoring systems on salt-affected soils at different work stages (establishment of soil monitoring system, choosing optimal timings for remote sensing, organizing ground surveys, etc.) are published in detail [15].

# 2.5. Experiences of the Eurasian Region countries in soil monitoring

## 2.5.1. Organization of research and assessment of the state of irrigated lands in Ukraine

**S.A. Balyuk, A.A. Nosonenko and M.A. Zakharova (Ukraine)**

In this country, water and soil amelioration monitoring and research is organized by the State Water Resources Agency of Ukraine. The monitoring of salt-affected and irrigated soils is based on observations and assessments of their condition parameters, which include hydrological and soil properties, irrigation water quality and crop yields. All these parameters should be determined simultaneously on specific key sites, which should be chosen and recorded in a manner that allows for the comparison of ecological and agricultural characteristics of formerly and currently irrigated and non-irrigated lands.

The determination of parameters within a unified interconnected system of 'irrigation and ground waters – soils – plants' is the only way to obtain the most accurate and full understanding of the influences of groundwater (in hydromorphic and semi-hydromorphic situations) and irrigation water on pedogenic processes and soil properties as well as the growth and development of crops and the quality of agricultural produce. This method was developed and tested by the Laboratory of Fertility of Irrigated and Solonetzized soils of the Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky (Kharkiv) [13].

The aim of this method is to produce a spatial assessment of the character and degree of soil degradation processes on formerly and currently irrigated non- irrigated and adjacent lands as well as the impact of these processes on soil fertility parameters (agrophysical, agrochemical, physicochemical and toxicological), crop yields and the quality of produce. The practical implementation of this method should precede the planning of ecological-agricultural monitoring systems within large irrigated areas to optimize the choice of key sites (plots, points) for monitoring and for the correct delineations of land areas that differ in their ecological- agricultural state.

Organizational issues, the survey and assessment criteria and indicators of the ecological-agricultural state of irrigated land in Ukraine are outlined in **Annex C.3.**

## 2.5.2. Main criteria and indicators for monitoring of soils as a natural resource

**I.P. Aidarov (Russia)**

The monitoring of soils as a natural resource should cover all irrigated and non-irrigated sites within river basins independently of their legal status and land use systems and include agricultural territories, water areas, nature conservation sites, etc.

This type of monitoring is targeted to integrate all kinds of natural ecosystems, all kinds of natural resources and all kinds of amelioration systems (hydrotechnical, agrotechnical, agrochemical, agro-sylvicultural, chemical, etc.).

The monitoring should also include assessments of criteria, indicators and parameters, which are used in existing models and methodologies for planning land amelioration. On the basis of the data obtained, new improved methods of quantitative evaluation of dynamics of natural processes can be developed. The existing methods and models for designing the land amelioration system are presented later in Chapter 3.

Monitoring soils as a natural object should include an assessment of the health of natural ecosystems under conditions of irrigation. A need for such monitoring is associated with an interaction between ecology and economy. The former studies bio-abiotic interactions, while the latter involves the management of such interactions [2, 3]. The degradation of natural ecosystems leads to a reduction in their environmental and agricultural role in climate change, the condition of water and soil resources and public health.

Monitoring of the ecosystem condition should include the following:

- assessment of changes in the regional water turnover and the frequencies of droughts and dry desiccatingwinds;
- assessment of changes in the natural structure and composition of biotic and abiotic systems;
- evaluationoftheactualecologicalvalueofthosesystems;
- evaluationoftheecosystemstabilitylevel;
- costassessmentofthelossofecosystemservices(ecologicaldamages).

Main criteria and indicators for the monitoring of soil as a natural resource are presented in **Annex C.4.**

### 2.5.3. Soil salinization monitoring inUzbekistan

**R.K.KuzievandA.Ismonov(Uzbekistan)**

A unified national system for the monitoring of agricultural soils can ensure the supply of accurate and complete information on the current condition of the agricultural lands of the republic. Such a system is needed for the provision of informational support to the state administration that is responsible for the rational land use and for agricultural production for the profit of farmers and the public. A unified system of soil monitoring within agricultural areas allows the state of soils to be controlled and the problems to be efficiently solved. At the highest hierarchical level of the unified monitoring system (decision making stage), there is a possibility for targeted management of the sources of negative processes[18].

Soil and water monitoring is carried out by the State Committee of the Republic of Uzbekistan on Land Resources, Geodesy, Cartography and State Register (Goskomzemgeodezcadastr) and the Ministry of Agriculture of Uzbekistan with the assistance from the State Committee of the Republic of Uzbekistan for Architecture and Construction, the Centre of Hydrometeorological Service at the Cabinet of Ministers of the Republic of Uzbekistan, the State Committee of the Republic of Uzbekistan for Geology and Mineral Resources and other interested parts of administration. Monitoring data are collected by regional 'Hydrological- Melioration Expeditions' by the Ministry of Agriculture and Water Resources of Uzbekistan and also by soil researchers from scientific organizations and institutes of the Academy of Sciences.

The organization and execution of monitoring are based on the main principles of coordinated and systematic observations within time periods matching the characteristic geomorphological and hydrological situations and the use of unified techniques of parameter determination over the whole area of the Republic of Uzbekistan [14].

The Land Monitoring Methodology was developed in the Republic of Uzbekistan in 2001. It is designed for monitoring the state of the land resources with the aim of timely identification and assessment of changes followed by prevention and mitigation of negative processes. It serves as a guidebook for conducting field, laboratory and desk studies to obtain knowledge and achieve generalization, systematization and automatization of work. Soil monitoring tasks include the organization and execution of systematic soil quality assessments, the timely detection of changes and their impacts on soil fertility and the development of measures for the prevention and mitigation of negative consequences.

The monitoring system is designed for all lands of the Republic of Uzbekistan independently of their legal status, potential and actual use. The monitoring system is subdivided into subsystems corresponding to the land use categories.

The choice of key sites for soil monitoring is based on the principle of adequate representation of all soil-climatic zones, subzones and provinces with typical natural and agricultural landscapes of the republic. Key sites with certain dominant soils are chosen on the basis of regional land use maps of 1:10000 and 1:25000 scales with corresponding legends.

The whole process of organizing and conducting the monitoring of agricultural soils is subdivided into three periods: preparation, field work and laboratory/computer work.

A network of monitoring sites called 'permanent ecological plots' (PEP) allows for the reliable assessment of the quality of irrigated soils and land resources in general together with the analysis of existing trends of changes and the forecast of further changes. Monitoring is also aimed at the observation of salinization regimes of soils and groundwater, determination of the character of changes, assessments of the ameliorative status and fertility of soils and the prognosis of their further development.

The Land Monitoring Methodology is based on soil salinity tests that are performed on permanent and semi-pemanent ecological plots (sites) followed by soil geographic, comparative geographic and laboratory analyses and the summarizing of the results. The comparative geographic method is applied to the assessment of the parameters of the groundwater and soil salinization.

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# Chapter 3. Assessing and forecasting the development of soil salinization and alkalinization processes

**I.P. Aidarov (Russia)**

According to the concept of sustainable development, agricultural practices should encompass the conservation and restoration of land, the efficient use of natural resources and stable production to satisfy the needs of both present and future generations. In the area of natural resource management, the sustainable development of agriculture requires a multifaceted approach to research and decision making. Therefore, a transition to sustainable development should be based on the study on ecological problems and socio-economic issues, which implies a detailed analysis of causal relationships between natural and agricultural factors and long-term consequences of agricultural impact on natural resources as well as the development of methods for a quantitative assessment of land quality [2].

An analysis of the current state of agricultural lands and the causes of its deterioration requires consideration of, at least, three aspects of human-nature interaction, which are as follows: (i) *ecological*, connected with a loss of biodiversity and natural ecosystem stability that forms the basis for natural resource formation and ecological stability of agrocenoses (agricultural plant communities); (ii) *socio-economic*, connected with a depletion of natural resources, decreases in both efficiency and stability of agricultural production and food security issues; and (iii) *methodological*, associated with the development of quantitative methods for the assessment of long-term consequences of land use and the design of complex soil amelioration measures.

All the above requires analyses of ecological-agricultural interactions and their influence on natural ecosystems. The planning of combined land amelioration measures requires development of simulation modeling and methods for the long-term forecasts of changes in the quality of irrigated lands, because management is impossible without such forecasts.

## 3.1. Methods and models for assessing the state of irrigated lands

Methods and models designed for assessing the state of land and, most importantly, for the forecasts of changes in the state of natural resources due to human impact are still underdeveloped. At the same time, it is generally recognized that forecasting man-made changes in the state of agricultural lands is a basis for the development of natural resource conservation and management practices. Due to the fact that soil is the primary resource in the agricultural production and that it is intimately connected with biodiversity of terrestrial and aquatic ecosystems, the development of soil management methods should involve the analysis of soil at several levels including the interactions of soil components and the role of soils in terrestrial ecosystems and the whole biosphere [2].

## 3.2. Methods and models required for natural resource management

*The relationship between soil characteristics and bioclimatic conditions within different natural zones.*

This geographic model is based on the concepts of soil geographic zones and soil-forming processes. An integrated index for the assessment of zonal soils is calculated as follows:

$$\overline{R} = \frac{R}{L(O_c + O_p)} \quad (3.1)$$

where: R – radiation balance, kj/cm$^2$; $O_c$ and $O_p$ total precipitation and irrigation norm, cm; L – latent heat of vaporization, kj/cm$^3$.

An advantage of the integrated $(\overline{R})$ index application is the possibility to assess the ground-level atmosphere layer, the water and salt regimes of soils and the rates of biological processes. The use of the integrated $(\overline{R})$ index inv\olves a similar approach as for the Dokuchaev humidity index (Fig. 3.1).

The geographical model presented in Figure 3.1 contains a large volume of unbiased information that is needed for not only assessing the state of zonal soils and landscapes under natural conditions, but also for suggesting ways and means for controlling the state of irrigated lands.

***This model can be applied in assessments of the following:***

- the water-physical, physicochemical, biological and other properties of zonal soils and natural ecosystems;
- methods for controlling the moisture, chemistry and other soil regimes.
- If $\overline{R} < 1$ , then water regime of soils should be controlled by drainage and pH regime – by liming. If $> 1$ , then irrigation and gypsum application are needed for the respective purposes. It is most difficult to control fertile chernozems and chestnut soils of steppe and dry steppe zones, where a change in either direction inevitably leads to deterioration of soil condition;
- the trends and rates of changes in properties and fertility of soils that result from agricultural land use and changes in the R value.

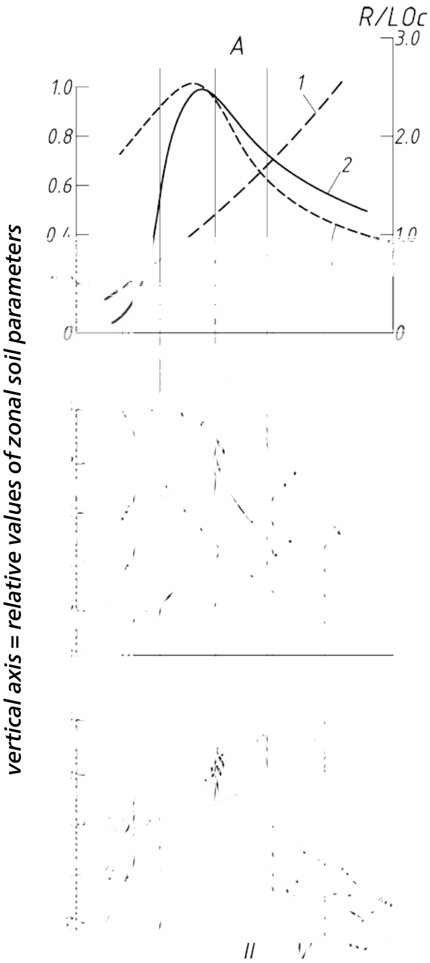


***Fig. 3.1. Factors of pedogenesis (A), water-physical properties (B) and physiochemical properties of soils (C).***

*Designations: I – humid zone; II – steppe zone; III – dry steppe zone; IV – semidesert and desert zones; 1 – value* $\overline{R}$*; 2 – litter to biomass ratio; 3 – energy of soil formation; 4 – the content of particles < 0,001 mm; 5 – soil moisture; 6 – soil aeration; 7 – the content of water-resistant peds; 8 – nutrient availability; 9 – the ration of humic to fulvic acids; 10 – soil exchange complex value; 11 – humus content; 12 - pH value*

The inability to assess the rates of changes in soil properties and fertility is a major shortcoming of this model.

## 3.3. Models and methods for the assessment of moisture and salt regimes of irrigated lands

An assessment of the dynamics of moisture and salt regimes of irrigated soils requires knowledge of the quantitative relationships between water and salt transport, environmental conditions and land use. At the same time, the use of complex multi-factor equations of mass transfer in soils requires determinations of numerous parameters. Therefore, the use of simpler mathematical models based on most significant parameters is preferred for making forecasts. An assessment of the dynamics of moisture regime of lands with a free natural drainage and a deep (> 5-10 m) growndwater table can be done by the following simple method [1, 2]. A prognostic moisture regime of soils is determined from a balance equation and an equation connecting moisture exchange processes between the root zone, atmosphere and subsoil [1].

$$\overline{W}_2 = \overline{W}_1 + \frac{\Delta t}{r_0(m_0 - W_0)}(O_c + O_p - E - g) \quad (3.2)$$

$$g = K_B \overline{W}_{cp}^{3,5} \quad (3.3)$$

where $\overline{W}_{1,2}$ - relative humidity of soil in the beginning and the end of the assessement period $\overline{W} = \frac{W - W_0}{m_0 - W_0}$ ; m0 – porosity, % of volume; $W_0$ – maximal molecular moisture capacity, % of volume; W – soil moisture content, % of volume;

r0 – rooting depth, mm; Δt –assessment period, days; $K_B$ – $\overline{W}_{cp}$ ;

g - water exchange between ; soil and lower layers, mm.

Advantages of the suggested method of moisture regime prognosis include the simplicity of calculations and the small number of input parameters, which can be easily determined in the course of soil research. Amplitude of moisture within the root zone can be set for any species of agricultural and natural grassland vegetation. The value of total evaporation can be determined with a good precision from the biological characteristics of plants, air temperature and humidity and the total water input. In cases of a shallow occurrence of the groundwater table, equations (3.2) and (3.3) are supplemented by groundwater balance equations [1].

Mean content of salts within the layer $0 < x \leq L$ can be calculated with the use of nomogram (Fig. 3.2), where the solid lines correspond to desalinization process, with downward water fluxes ( $\bar{t}$ > 0); the dotted lines correspond to salinization process, with upward water fluxes ( $\bar{t}$ < 0); Pe - Peclet dimensionless number;

$\bar{c} = \frac{(c - c_1)}{(c_0 - c_1)}$ ; $c_0$ – initial salt content in soils,

%; $c_1$ – irrigation water salinity, ($c_1$ 0); c – salt content in soils by the end of the assessment period, %.

The salt regime of soils with a high cation exchange capacity (more than 15-20 meq/100 g) is determined from the sum of toxic salts and the concentrations of calcium, sodium and magnesium in soil solution and soil exchange complex. In this case, the model should incorporate convection-diffusion processes and ion exchange sorption balance.

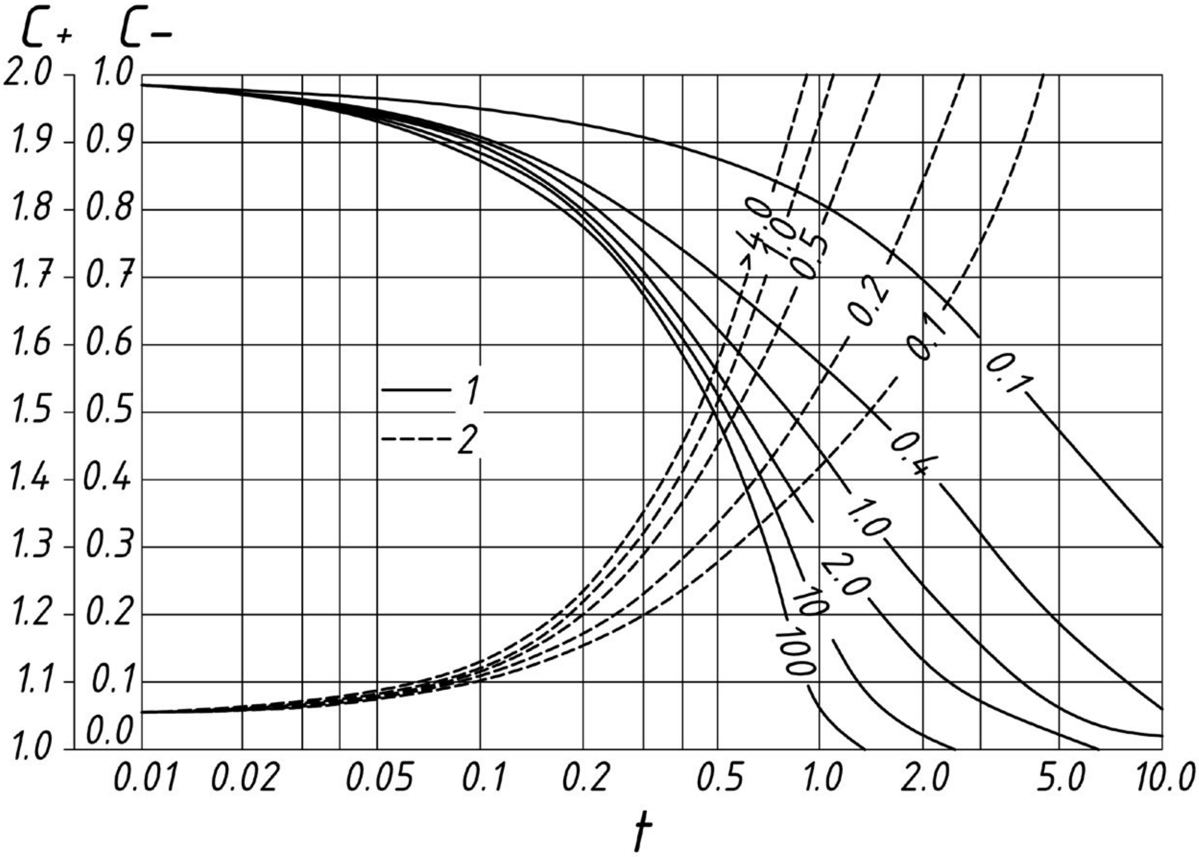


*Fig. 3.2*

*A nomogram for calculating changes in the mean content of salts within a layer 0 < x ≤ L, %;; $t = \frac{O_{p+O_c-E}}{xm_o}$ ; $O_p$ and $O_c$ – the total of water inputs; E – the total evaporation; x and m0 – the thickness and porosity of the specified layer of soil; the numbers on the curves show the values of non-dimentional parameter Pe = x/m0λ*

The distribution of salts within a soil profile is estimated using the following equations [1]:

$$\overline{c} = \frac{c}{c_2} = exp\left[2Pe(1-\frac{1}{\overline{V}})(1-\overline{X})\right] \quad \text{with } c_1 = 0 \qquad (3.4)$$

$$\overline{c} = \frac{c}{c_1} = -\frac{\overline{c}_1}{\overline{V}-1} + (1+\frac{\overline{c}_1}{\overline{V}-1})exp\left[2Pe(1-\frac{1}{\overline{V}})(1-\overline{X})\right] \quad \text{with } c_1 > 0 \qquad (3.5)$$

where: c, $c_1$ and $c_2$ – calculated mineralization, mineralization of irrigation and ground waters, g/l; $\overline{V}$ - ratio of upward and downward fluxes of moisture in soil; x and $x_1$ - the; $\overline{x} = \frac{x}{x_1}$ specified layer of soil and groundwater depth, m.

The dynamics of salt regime in soils can be predicted upon 2-3 trial crop rotations. Calculations are carried out for certain periods of each year: the growing season, the autumn-winter season and the spring season. If a soil undergoes freezing, then the autumn-winter season can be excluded from calculations. The value $\overline{V}$ is determined on the basis of the results of water regime predictions for the same periods of the year.

$$\overline{V} = \frac{E + T_p}{O_c + O_p} \quad (3.6)$$

where: $E + T_p$ – the total evaporation, mm; $O_c + O_p$ – the atmospheric precipitation and the irrigation norm, mm.

If the required salt regime is disrupted, then the $O_n$ value increases due to the percolative regime.

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# Chapter 4.
# The rational use of saline and alkaline soils (with examples from Ukraine)

In this chapter the main approaches and principles of integrated management of water and land resources are described and amelioration measures are classified. Technological, innovative, informational and methodological issues of the use and conservation of salt-affected soils as well as synergistic aspects of their amelioration and management are presented. The general objective is to improve self-regulation mechanisms of ecosystems, sustainability of natural resources and the combined effects of ameliorative management and land use measures for solving problems and achieving a green economy.

## 4.1. Classification of amelioration measures

**P.S. Truskavetsky (Urkaine)**

It is very important to choose the correct methodological approach to the classification of soil amelioration mea sures.

All amelioration measures known in Ukraine to date are grouped into three hierarchical levels termed as follows: the highest level – the Groups, the intermediate level – the Types and the lowest level – the Techniques of amelioration (Table 4.1).

***Table 4.1. Classification of ameliorative measures in Ukraine***

| Hierarchical levels | | |
|---|---|---|
| Groups | Types | Techniques |
| Hydrotechnical amelioration | Irrigation systems | Sprinkling<br>Surface irrigation (furrow, bands, flooding)<br>Subsurface irrigation<br>Drip irrigation |
| | Irrigation and drainage systems | Irrigation combined with horizontal drainage<br>Irrigation combined with vertical drainage |
| Chemical amelioration | Application of gypsum, Acidification treatments, etc. | Overall application<br>Scattering<br>Compensating<br>Local<br>Combined |
| Agrotechnical amelioration | Surface-water regulating reclamation | Levelling<br>Furrowing<br>Ridging |
| | Subsurface-water regulating reclamation | Deep tilling<br>Slitting<br>Moling |
| Phytobiological amelioration | Grass plantation | Inclusion of phytomeliorants into crop rotations<br>Green manure (cover crops)<br>Organic carbon sequestration<br>Grassing |
| Agro-technical amelioration (Culturetechnics) | Amelioration (cultivation) of the land surface | Removal of shrubs and trees, stumps and stones<br>Removal of humps, levelling |

| | | |
|---|---|---|
| Structural amelioration | Structural amendment of the solid phase of the plough layer | Sand application<br>Clay application |
| | Structural amendment of the solid phase of the plough layer | Ditching<br>Deep ploughing<br>Vertical wells |

## 4.2. Integrated management of water and soil resources of salt-affected land

**O.I. Zhovtonog and L.I. Vorotyntseva (Ukraine)**

The application of a systemic approach, principles and methods of an integrated management system is very important for providing a balanced and sustainable development of agriculture on salt-affected soils and for effective and rational land use.

Integrated approaches to water resource management are widely practiced in the world as, for example, the EU Water Framework Directive. Some of those approaches are vital for solving problems of water resource use in the context of food production and environment conservation, as they allow the solution of a whole range of social, ecological and economic issues [6, 23, 24]. Therefore, attention is focused on coordinated management of water, land and associated resources aimed at the achievement of high levels of social and economic development without destabilizing key elements of ecosystems [2, 3, 22].

The integrated management of water resources is a process that facilitates the coordinated management of water, land and associated resources with the aim of maximizing economic achievements and social welfare, without comproming the sustainability of vital ecosystems [22, 23].

The modern concept of integrated management of water and land resources implies water management for socio-economic development and ecosystem conservation. The management of land and water resources and ecosystems should be unified to benefit the livelihoods of people and for sustainable development. The successful application of such an approach within salt-affected lands can be achieved through professional management, science-based planning, forecast of trends of soil processes and support of coordinated multi-disciplinary interactions of interested parties.

An ecologically balanced use of salt-affected areas should take into account local bioclimatic and socio-economic factors in order to enable planning, sustainable development of agricultural production, its further diversification as well as improving the living standards of rural populations and making effective management decisions. Particular attention should be given to social issues to achieve improvements in the living standards and increases in the income of rural populations as well as the creation of jobs and development of small and medium-sized enterprises.

The development and implementation of plans for the integrated management of water and land resources within salt-affected lands includes the following stages: project organization, the development of alternative land use plans, the selection of the best economically substantiated integrated plan, the economical assessment of potential expenditure and income, the ratification of a final plan, identification of sources of finance, plan realization and assessment of results.

Initially, detailed research and assessment of the state of natural ecosystems and socio-economic issues within the territory is required. Such research and assessment should focus on soil cover (soil quality), water resources (agricultural and ecological criteria for irrigation water use), water use infrastructure and land use plans. On the basis of the results obtained, a database on local natural and agricultural conditions is created, GIS-mapping is carried out and alternative plans of water and land resource management within salt-affected lands are drawn up by interested parties. These plans are then subjected to an ecological-economic assessment, with the best economically substantiated plan selected.

The integration of different interests and viewpoints during the course of project implementation and the encouragement of initiatives from the bottom up are very important considerations in an integrated management system of water and land resources within salt-affected areas.

Therefore, the introduction of principles and plans of integrated management can provide for the rational and coordinated management of water and land resources within salt-affected areas under conditions of climate change and support water conservation and for the adaptive use of salt-affected soils with specific properties to obtain the maximum economic yield.

## 4.3. Innovation and investment to support the management and use of salt-affected soils

**A.V. Kucher and O.V. Anisimova (Ukraine)**

Innovation and investment to support land amelioration is a range of measures that involves the use of means, mechanisms, methods, tools and techniques of innovation and investment management aimed at mobilizing and encouraging further investment and innovation in the areas of organization, technology, agrochemistry and nature conservation for increasing the efficient use and management of ameliorated lands.

Conceptually, the innovation policy should be combined with the investment policy to provide a simultaneous promotion of investments and innovations, as the former serves as a basis for the latter. At the same time, innovation incentives stimulate further demand for investments. The integration of innovation and investment activities and the attraction of additional finance to the development of innovative technologies should be considered as the most important aspect in the efficient and sustainable development of amelioration practices.

State control over innovation and investment policies in the area of soil amelioration in Ukraine involves the following priority measures [9]:

- the creation of an infrastructure of an innovations market and the development of technology transfer systems, in particular, by focusing on the development of innovations in the management of financial and material resources by different organizations such as science parks and scientific research institutes in cooperation with small and medium-sized enterprises under business incubation programmes and a coherent innovation policy based on the principles of planning and forecasting innovations;
- the implementation of an organizational-economical mechanism designed specifically for supporting new ecological ideas, providing a demand for innovations in the areas of amelioration and the greening of the ameliorated land use systems;

- the development of a system of economic incentives in soil conservation and innovation enterprises (tax deductions for entrepreneurs that bring patent licenses for ecological innovations in the area of amelioration and implemented soil protection technologies);
- the provision of tax deductions for enterprises under various forms of ownership and management, where they invest their own capital into scientific research and development of ecological innovations in the area of land amelioration;
- the creation of mechanisms of favourable loans to encourage practical applications of innovations in the area of land amelioration, e.g., by concessional loans to enterprises that implement innovative amelioration projects;
- the establishment of a credit insurance fund for innovative developments, the provision of the state insurance for risks in innovation development and the creation of special innovation-investment banks to concentrate capital in the area of amelioration;
- the improvement of an organizational-economic mechanism for the interaction between the recipients of direct foreign investments to encourage non-fiscal incentives such as economic liberalization in the agricultural sphere and strengthening the institutional support system, in particular, improving the performance of agents that attract foreign investments.

It is clear that actual possibilities for the practical realization of ameliorative measures on salt-affected lands depend mainly on the availability of investment resources. For example, according to estimated calculations for Ukraine, the annual application of gypsum to the Solonetz area of about 0.1 million hectares requires an investment of almost 5.6 million USD and the ameliorative deep ploughing of the Solonetz area of 0.04 million hectares requires about 2.7 million USD. High ecological standards and economic efficiency can be achieved on ameliorated lands on the basis of a broad-scale use of innovations and a realization of the innovation-investment model in agricultural sector.

The main sources of finance for the priority aspects of innovative land amelioration development in Ukraine include the following: a) self-funding of agricultural enterprises and associated organizations, b) the state budget of Ukraine and local budgets at all levels, c) nature conservation funds at all levels, d) bank loans and finance lease, e) domestic and foreign investments and international technical support and f) other non-budget funds in accordance with current legislation.

Additional investments can come from sources such as global and regional funds, common investment institutions, international financial and credit institutions and government loans from developed countries.

Considering the limited availability of investment resources in the state, it is suggested that agricultural enterprises should be encouraged to seek their own funds for conducting amelioration of salt-affected soils in combination with their conservation and rational use, with a partial reimbursement of amelioration expenses. For example, both gypsum application and deep ploughing of salt-affected soils should require a 10% reimbursement of expenses from the government.

The efficiency of investment and innovation support for land amelioration can be improved by the active involvement of state funds into the public-private partnership, where the state uses mechanisms to attract private capital for innovative development.

In self-funding enterprises profits and depreciation remain chief sources of investments into innovative amelioration development. At the same time, many agricultural enterprises have recently been unprofitable, while depreciation has reduced its potential to improve financial resources. Therefore, mobilization of financial resources requires both internal and external investments that can only be achieved through creating more favourable business climate together with use of institutional media to attract domestic investors and foreign funds.

Bank lending plays an important part in financing investment-innovation projects in the area of land amelioration. In this respect, it is important to solve state-level problems of reducing the cost of bank loans, extending the periods of credit, increasing the credit supply and availability and diversity of international use of credit offsets. The best support of amelioration projects can be provided via long-term concessional lending with partial or complete repayments of interest rates from the state budget.

As long as agricultural enterprises have limited budgets and little potential for the self- financing of ameliorative projects, there will be a need for investigating untraditional sources on finance. For instance, leasing can be a promising and effective solution to the problem. Financial leasing is more economical than bank credits and includes commodity lending that allows for the restoration and purchase of productive assets without great financial strain. Therefore, in a near future it is advisable to implement public leasing to support the refurbishment of existing enterprises with new ameliorative machinery.

The stimulation of processes for creating effective sources of investment can be achieved through the creation of new agricultural producer networks with relevant joint-stock companies, agricultural venture businesses and agrocomplexes that can be more efficient in attracting both domestic and foreign investments into land amelioration [4].

It could be helpful to make the following institutional arrangements: 1) to form holding companies on the basis of national water management enterprises as an effective way to increase the investment potential, 2) to apply consortium credits that imply minimizing lending risks and guarantees for repaying large loans and 3) to arrange cooperation between agricultural producers that have different legal statuses to enable joint investments and to minimize the risks.

Thus, a step-by-step implementation of the innovation-investment system into the development of land amelioration practices opens up new opportunities for a larger volume and higher efficiency of food production on ameliorated lands together with maintaining a high soil quality and further improvements in the food security of Ukraine.

## 4.4. Information, regulations and methodologies for supporting the conservation and use of salt-affected soils

**S.A. Balyuk, M.A. Zakharova and M.E. Lazebnaya (Ukraine)**

The main sources of information on the current condition of irrigated soils in Ukraine include the following: 1) large-scale soil assessment data, 2) land registry ('land cadastre'), 3) data from the agrochemical records ('passporting') of agricultural lands, 4) agro-ecological monitoring data, 5) research data of scientific and educational institutions and 6) data of the national environmental monitoring system. All these information sources on the soil cover within the irrigated areas in Ukraine are described below in more detail.

1) ***Large-scale soil assessment data*** (1957-1961) and subsequent data up the mid-1970s are not completely applicable to the current situation, as they fail to reflect human-induced changes in soil cover (such as those resulting from irrigation practices) and only characterize a limited number of soil properties. However, these data are used as a basis for soil grouping, identification of soil regions ('regionalization') and soil assessment as well as the implementation of agricultural technologies. Clearly, these materials need to be updated to a higher level and supplemented by the use of new methodologies to create a new integrated database.

2) ***The land registry*** is based mainly on the large-scale soil assessment data and a generalized evaluation system. Hence, it has the same shortcomings as the above-described information source and fails to record rapid changes in soil quality.

3) Information from ***the agrochemical records of agricultural lands*** (10 agrochemical records of soils since 1964) are compiled and published in the National report on the state of soil fertility. However, methods of such agrochemical soil assessments differ from those used in irrigated soil assessments, for instance, mixed soil samples are taken without a spatial reference to a geographic coordinate system and the particle-size composition of soils is not taken into account. The resulting data characterize a whole field, but not soils *per se* and, therefore, don’t reflect any irrigation-induced changes in soil cover.

4) ***Agro-ecological monitoring*** (AEM) is the main source of information on the ameliorative state of irrigated soils. The AEM is performed in compliance with the Land Amelioration Law of Ukraine (№ 1389-XIV of 14.01.2000), the Water Code of Ukraine (№ 213/95-BP of 06.06.1995) and several decisions of the Cabinet of Ministers of Ukraine. A systematic monitoring is applied to 2170 thousand hectares of irrigated lands. However, the AEM system also has its shortcomings, as it monitors only a limited number of parameters: irrigation water quality, groundwater table, groundwater salinity (mineralization), water loss with drainage, soil salinity and alkalinity. The data obtained are summarized in departmental reports together with conclusions on the ecological-ameliorative state of irrigated lands. The authors believe that the AEM data together with the data of agrochemical soil assessments and the agrochemical records of agricultural lands should be included into a unified national environmental monitoring system.

5) ***Research data of scientific and educational institutions*** are obtained via observations within a network of long-term field experiments. Many properties of soils are monitored in the course of such experiments. However, the data do not characterize the entire soil cover of an irrigated area.

6) ***The national environmental monitoring system*** is controlled by the Ministry of Agrarian Policy of Ukraine (State Institution 'Soil Protection Institute of Ukraine' - the agrochemical records (passporting) of agricultural lands) and the State Water Resources Agency of Ukraine (hydrogeology-amelioration expeditions and parties – the data on the ameliorative state of irrigated and drained lands). The procedures for data collection are controlled by different governmental departments, therefore, there are disagreements on observation methods and programmes and a lack of a common structure and comparability of databases, most of which are still paper-based outputs that cannot be used in modern data analysis systems, i.e., they are incompatible with modern technologies. All these factors make it impossible to gain the maximum use out of such data for conducting assessments and drawing forecasts of the state of irrigated lands with the aim of sustainable management.

The authors suggest several measures that can help to gain sufficient, accurate, precise and useful information on the state of irrigated soils and to solve the problem of soil protection and improvement of its fertility. Soil assessments should be unified with the agrochemical records of agricultural lands and the agro-ecological monitoring, i.e., a new agrochemical soil monitoring methodology should be developed and implemented. The data collected by different methods should complement each other and form a comprehensive database, which can serve for quality assessment and forecasts, management, use and conservation of irrigated soils. Such joint monitoring system should rely on the latest achievements of soil science and unified work programmes and methodologies and conform to European standards.

The Regional Implementation Plan for the realization of the Eurasian Soil Partnership programme 'Approaches to the sustainable management of soil resources in 2015-2019' implies the development of international regulations and methodologies as a basis for the rational use and amelioration of salt-affected soils. An adaptation of old standards to the latest scientific achievements is one of the main principles of the rational use and amelioration of salt- affected soils. In this respect, legislative documents require timely updates and the development of new standards according to the subject matter. Standardization in the area of environment and soil protection is aimed at a) re-defining and classifying the existing regulations, rules and requirements on the conservation and rational use of soils and b) providing legislative support to sustainable and ecologically harmless land use in the agricultural industry.

In Ukraine, legislative documentation of various sorts is developed and produced by the Technical Committees on Standardization (TC). In particular, national regulatory documents are supplied by the TC 142 'Soil Science' and the TC 145 'Amelioration and Water Use'. Currently, the governmental committees have developed and implemented more than 300 regulatory documents, which include around 30 standards for assessing the state and rational use of salt-affected and irrigated soils. The standards are developed with the use of international experience, principles of integrity and conformity to existing laws. There are also a series of handbooks with instructions and methodological recommendations.

# 4.5. Technical support for the conservation and use of salt-affected soils

## 4.5.1. The system of hydrotechnical, agricultural and chemical amelioration of saline and alkaline soils

**S.A. Balyuk, A.A. Nosonenko and E.N. Drozd (Ukraine)**

Amelioration measures applied to soils include the following groups: 1) hydrotechnical – drainage systems and soil leaching to remove salts, 2) agricultural – crop rotation systems, fertilization systems and soil tillage systems including ameliorative deep ploughing and 3) chemical – chemical amelioration treatments of irrigation waters and soils.

***Drainage systems.*** A drainage network consists of interconnected hydrotechnical constructions (drains, collectors, pumping stations, etc.) that serves to remove an excess of groundwater beyond the irrigated area into a storage place [8, 21] and provides maintenance of soil water and salt regimes that are favourable for growth and development of crops.

Soil drains within an irrigated area can be horizontal, vertical or combined and joined (horizontal and vertical). Horizontal drains gather and direct the groundwater away from the ameliorated area, while collectors transport it to the storage place. In cases of a thick upper layer of water-resistant soil or sediment and a confined aquifer, it is advisable to install vertical drains, i.e., holes with filters at the entry and joints to direct the collected water into pipes. Depending on the geological situation, one drainage hole can service an area from 100 to 500 ha. Vertical drainage systems are used, as a rule, for performing three main tasks: 1) the use of freshwater from confined aquifers for irrigation and simultaneous desalinization of soils, 2) the prevention of saline groundwater from rising towards the surface and triggering secondary salinization of soils within irrigated areas and 3) the replacement of saline groundwaters by fresh ones.

There are several techniques of purification and desalinization treatments of drainage waters that have been developed with the aim of improving the ameliorative state of irrigated lands. These techniques include local water treatment facilities, which use sorbents and ion exchange resins, and biological water treatment systems using natural energy (evaporation, displacement by ice in winter, etc.).

Combined systems of vertical and horizontal drainage improve the efficiency of water removal. A combination of horizontal drains and rows of wells that allow gravitational water flow into a horizontal pipe allows the removal of excessive water from the upper soil layer with a poor permeability.

***Soil leaching to remove salts.*** Soil leaching to remove salts is a treatment designed for reducing an excessively high concentration of salts down to a level that permits the growth of agricultural crops. The treatment involves supplying freshwater to the soil surface and collecting the drained saline solution [21]. Leaching treatments are applied to soils containing toxic salts of alkali metals, alkaline earth metals and/or heavy metals with the aim of detoxifying such soils.

Under agricultural crops the thickness of a treated layer is usually around 1 m. This can be decreased to 0.5 m under highly and moderately salt-resistant crops with shallow root systems (fodder beet, *Sorghum sudanense* and other sorghum varieties, cereal crops and some vegetable crops), if the soil layer below that depth is only weakly saline.

Flooding is the main and most widespread technique of soil leaching. An optimal time period for flooding is September-October, when the groundwater table is deep and evaporation is low. At that time, leaching treatment also serves as soil irrigation. Preparation for leaching includes soil ploughing, levelling, repeat ploughing, application of calcium-containing ameliorators, harrowing and the creation of ridges to prevent run-off.

The method of saline soil leaching using sprinkler irrigation was developed and implemented by specialists from the Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky (Kharkiv). Soil pre-treatment before sprinkling includes leaching by flood irrigation without the construction of dividing ridges on the field surface. Sprinkling devices of any type can be used if they provide uniform moistening of soils together with water supply rates of up to 3-4 thousand $m^3$ / ha for a period of several days [14].

On weakly saline soils and also in cases, where residual salinity is retained after leaching treatments, sprinkler irrigation rates are lower. These are undertaken either in spring (at the beginning of the growing season) or in autumn (as a moisture-recharge treatment to support winter crops).

Leaching of saline soils by sprinkler irrigation in combination with vertical drainage systems and chemical amelioration treatments are 10 times cheaper and require 4-5 times less water, than traditional leaching by flooding. The rates of soil desalinization and yield increases are the same in both cases.

***Fertilization system.*** The system of fertilization is based on techniques of applying mineral and organic fertilizers in a crop rotation, at specified rates and times

According to [7], optimal rates of fertilizer application should be determined from data on nutrient concentrations of the soil within each field. On fields where the actual concentrations of nutrients in the soil are equal to optimal levels, there is no need to apply fertilizers. If concentrations of nutrients within a specific field are lower than optimal, then the fertilizer rate is determined by the method of elementary balance. Phosphate application rates are determined from its uptake by desired crops and potassium application rates – by assessing the content of this nutrient in the soil.

Bacterial fertilizers can replace up to 30 kg/ha of active ingredient of nitrogen or phosphate fertilizers.

Farm-yard manure applications to soil can be replaced by applications of cereal straw, maize stems or green manure. They can support the same yields as farm-yard manure, but with 30.3% lower rate of mineral fertilizers and up to 60% lower input of energy per 1 ha of the field area [7].

An improvement of irrigated soils can be achieved through the injection of fertilizers into the irrigation system, i.e., fertigation. According to [15], fertigation can be carried out with the use of soluble fertilizers (single and combined), which do not produce too much waste and do not cause corrosion. They can be mixed with irrigation water in almost any proportions. The application process is totally automatic, labour-saving and inexpensive. In situations where there are shortages of organic and mineral fertilizers such resource-efficient methods of application are very important.

For example, the use of a complex mineral fertilizer (so-called 'tuk') saves 30-50% of application rates of, primarily, phosphates.

The application of fertilizers directly under plant roots has the following advantages:

- wasteful fertilizer losses are reduced by adding nutrients closer to the most active parts of root systems and by mixing nutrients with a smaller volume of soil;
- processes of phosphorus and potassium immobilization (transformation of available forms into unavailable forms) are less developed;
- coefficients of nitrogen and phosphorus uptake by plants are increased by 5-20% due to the high nutrient availability.

The use of local raw materials and industrial wastes such as sapropels (rich organic sediments), pond silt and lignin is a very important practice in the improvement of irrigated soils [7].

The use of green manure – a fertilizer consisting of growing plants that are ploughed back into soil – is another important method of soil improvement. Plants that can be used as green manure include the following: lupins, peas, white sweet clover, common vetch, oilseed radish, winter and summer oilseed rape, rye, oats, trigonella, serradella, white mustard, etc. Leguminous plants are more suitable for increasing the content of nitrogen in soil, while cereal crops are suitable for improving soil structure and plant health.

In cases, when there is a deficiency in one or another nutrient in the soil, the application of microfertilizers is practiced. Microfertilization can be achieved through small additions of mineral fertilizers, application of dissolved fertilizers and pre-sowing treatment of seeds. The injection of micronutrients (salts of copper, zinc, cobalt, molybdenum, etc.) into irrigation system results in their uniform distribution over a field and generally improved crop growth [20].

Taking into account the shortage of mineral and organic fertilizers and the current state of agriculture in Ukraine, it is suggested that the fertilization of irrigated soils should be conducted as follows [7]:

- mineral fertilizers should be used only under priority crops to ensure their maximal agronomic and economic efficiency;
- fertilizer rates should be determined depending on the agrochemical properties of soils (nutrient availability levels for different crops during different stages of the growing season);
- fertilization systems should be economically efficient and use primarily local sources of fertilizers, which ensure a high return of investment in crop yields;
- fertilizer application techniques, rates and time schedules should be determined on the basis of previous fertilization practices (primarily the timing and rates of organic fertilizer application in a crop rotation scheme);
- mineral fertilizers should be prioritized firstly for use on irrigated and chemically ameliorated areas and secondly on formerly irrigated areas;
- potassium and chlorine-containing mineral fertilizers should not be used on soils affected by irrigation salinity and alkalinity and residual salinity and alkalinity.

***Soil tillage systems.*** Science-based systems of soil tillage should sustain the fertility of irrigated soils and prevent their degradation, yet use the full potential of bioclimatic conditions (via collection, saving and rational use of water [10]) and protect natural resources. Such systems improve cost-effectiveness and can increase crop yields by 15- 20%.

The highest yields and productivity in crop rotation were achieved by the use of a differentiated tillage system, which includes deep ploughing (for row crops) alternated with shallow and surface tillage using a chisel plough (for intercrops, cereals and post-harvest sowing of maize and sunflower) as well as zero tillage (for maize as green fodders).

The practice of soil slitting can be effective in preventing run-off from fields under winter crops and perennial grasses. Slits of 2x140 cm at a distance of 4 m to a depth of 40-45 cm are made. The optimal times for performing soil slitting under perennial grasses is autumn before soil freezing, and for winter crops slitting should be performed before the appearance of seedlings. After ploughing in the late summer-autumn, which achieves an optimal soil density, the soil can be used for sowing early crops after cultivation with a heavy harrow. A spring-tooth harrow (drag harrow) can be used on stony soils in spring time.

Fields retaining a cleared surface after late harvests can be used for winter wheat and summer crops with zero tillage, if the following conditions are present: good soil structure, low mechanical resistance, high infiltration capacity, high biological activity and the absence of surface crust. Shallow tillage using a disc harrow and retaining mulch on the soil surface is also applicable [19].

***Ameliorative deep ploughing.*** Ameliorative deep ploughing (ADP) is one of the tillage methods applied to Solonetz and solonetzized soils including those with irrigation-induced alkalinity. The ADP level should be 10-15 cm deeper than the effervescence boundary (determined by testing with 10% HCl), which allows the ameliorative mixing of calcium compounds naturally present within a 35-60 cm layer of soil. The ADP results in the mixing of the solonetzic eluvial (E) and illuvial (B) horizons and a part of the transient horizon (between the B and C horizons).

A correctly performed ADP is a one-off procedure that profoundly changes the soil profile structure, which does not restore to its original state for a period of 40-50 years following ADP. This period is characterized by significantly better hydrophysical, chemical, physicochemical and biological soil properties. Soils that underwent ADP treatment 50 years ago still support a higher productivity of agricultural crops than similar soils that were not subjected to ADP or that underwent chemical amelioration.

ADP is performed in summer and autumn, when soil conditions are optimal and allow for high-quality tillage. ADP is carried out on fields that are subsequently used as true fallow, occupied fallow or for row crops in the next year. In spring, these fields should be cultivated by a chisel plough to a depth of 20-25 cm for 2 or 3 times to ensure the best soil mixing and surface levelling.

ADP requires an obligatory application of organic fertilizers. Farm-yard manure should be applied at rates of 40-60 t/ha within non-irrigated fields and 80-100 t/ha within irrigated fields. If the availability of farm-yard manure is scarce, then it can be replaced by local peat, sapropels, sludge and/or food production waste [7].

***Chemical amelioration treatments of irrigation waters and soils.*** Chemical treatments of irrigation waters and irrigated soils are aimed to improve their quality and increase yields of agricultural crops. This type of amelioration is usually performed by applying chemical substances to water or soil.

The chemical amelioration treatments include the following:

- Physicochemical methods for the improvement of medium-quality irrigation waters (Class 2, according to the state standard, DSTU 2730: 2015). Firstly, this involves water treatment with calcium ameliorators (gypsum, chalk, lime, calcium nitrate, calcium chloride and calcium-containing waste products such as phosphogypsum);
- The application of the above-listed substances as well as sediments (loesses, red-brown clays, etc.) to soils in a dry state is economical (as there is no need for water or water-amelioration equipment).

The mechanism of action of ameliorators involves the displacement (or prevention of adsorption) of salinity-forming cations (primarily sodium) within the soil exchange complex. It is accompanied by favourable changes in hydrophysical, agrochemical, physicochemical, biological and other soil properties due to a decrease in the mobility of soil colloids, lowering of soil alkalinity, improvement of micro- and macrostructure, increase in the water resistance of soil aggregates and also an increase in soil permeability, which prevents compaction, surface crust formation, loss of structure and swelling phenomena. This is also accompanied by an increase in levels of availability of nitrogen, phosphorus, potassium and calcium, a decrease in solubility and mobility of humus, activation of microbiological processes and a general increase in agricultural crop productivity [7].

The chemical amelioration of irrigated soils in Ukraine should be conducted under the following conditions:

- the use of medium-quality irrigation waters (Class 2, according to the state standard, DSTU 2730: 2015) with moderate risks of occurrence of irrigation-induced salinity or alkalinity in soils;
- the application of soil leaching to remove salts with irrigation waters of different qualities and the use of formerly irrigated soils with primary and secondary salinity or alkalinity and decalcination;
- giving amelioration priority to soils that have high and moderate alkalinity;
- the application of ameliorators to soils in the form of solution or suspension and along the contours of Solonetz areas during the periods of maximal manifestation of agrophysical alkalinity;
- the use of local ameliorators containing calcium, iron-calcium and sulphuric acid components of industrial waste under a condition of their compliance with sanitary and ecological regulations (toxic substances originated from waste application should not accumulate in soil and groundwater in quantities above maximal permissible levels);
- the use of ameliorated lands for growing water-demanding, highly productive and valuable crops in preference to salt-resistant and alkali-resistant crops species, varieties and hybrids.

To save resources, the chemical amelioration of irrigation water should be conducted only when the agrophysical alkalinity of soils and the toxic impact of soil solution on plants reach critical levels, i.e., with early spring irrigation prior to sowing and during the germination of agricultural crops and in autumn during recharge irrigation.

Irrigation-induced alkalinization of soils can be mitigated by applying dry chemical ameliorators directly to soil. The ameliorators should be applied during post-harvest ploughing and harrowing of soils in autumn to prepare the soil for sawing in spring. If a soil has not undergone autumn tillage, then ameliorators can be applied to the soil just before or just after spring ploughing. Under winter crops and perennial grasses, the optimal time for ameliorator application is during the late winter or early spring (February-March), when the soil surface is partly frozen.

It is also possible to use local limestone and wastes of stone mining and sugar industries. Such ameliorators contain calcium in the form of carbonate, $CaCO_3$, which has a gentle, but long-lasting ameliorative effect (compared to that of phosphogypsum) and, therefore, should be applied to soil with some surplus so that it lasts for several years.

In some industrial areas, it can be economically feasible to use iron-calcium wastes of the steel industry as soil ameliorators. Calcium carbonate wastes with permissible levels of toxic substances can be applied to soils with irrigation waters in the form of suspensions or after their chemical treatment with sulphuric acid [7].

## 4.5.2. Phytobiological and agroforestry amelioration systems

**P.S. Truskavetsky and V.P. Tkach (Ukraine)**

A soil phytomelioration system is a combination of measures for rapidly improving salt-affected soils by including certain ameliorative crops into crop rotations. Phytomelioration is the most profitable biological measure for sustaining and increasing soil fertility in both agroecological and economic senses. The costs of phytomelioration are 5-10 times lower than those of chemical amelioration.

The efficiency of phytomeliorative measures is determined by the natural influence of plants that is one of the key factors of soil formation (biological factor). The efficiency of phytomeliorators increases in the following order: annual leguminous crops – perennial cereal crops – perennial leguminous crops – grass mixtures in crop rotations – long-term perennial grass mixtures.

A lesser, but still significant positive effect on soils is achieved by growing winter cereals, because of their dense and uniformly spread root systems. The phytomeliorative effectiveness of winter cereals is quite close to that of perennial grasses due to their their ability to suppress weed growth and the large volume of root residues. The soil-protective efficiency of agricultural crops increases in the following order: summer cereals – pulses – winter crops – annual grasses – biannual leguminous crops – perennial grasses.

Planting and sowing salt-resistant plants on saline and alkaline soils encourages their gradual desalinization and a gradual improvement of their properties. It is advisable to use phytomelioration in combination with agrotechnical and engineering measures for improving the ameliorative state of salt-affected soils.

As a result of the selection of plant species through breeding and crossing, some promising species and ecotypes of plants have been obtained, which can be used as bio-ameliorators on soils that have undergone secondary salinization and soils irrigated by saline water. Promising plant species include the following: *Suaeda arcuata, Suaeda acuminata, Atriplex cana, Atriplex canescens, Climacoptera crassa, Bassia hyssopifolia, Salicornia herbacea, Kochia scoparia, Glycyrrhiza glabra, Artemisia halodendron,* etc.

Some sun-tolerant crops (e.g., *Melilotus albus*) have deep root systems that can loosen a dense saline B horizon. The decomposition of plant litter on the surface supplies the organic matter and nutrients (nitrogen, potassium, calcium, etc.) to soil. Moreover, carbon dioxide produced by the process of decomposition reacts with soda and converts it into less toxic sodium bicarbonate.

Biological methods of soil desalinization are recommended for use on moderately and strongly saline loamy sands and loams with a chloride salinity of less than 0.6. The effect of planting salt-tolerant and sun-tolerant crops is most pronounced on improved pastures on poor soils in the south-east of Russia, Kazakhstan, India and Argentina, in particular, on salt-affected floodplain soils. Phytomelioration is an ecologically harmless primary or secondary measure for the improvement of alkaline soils [11].

Almost all tree species of temperate regions are unable to grow on salt-affected soils that contain toxic soluble salts. Such tree species are unable to naturally colonize such soils and fail to survive if artificially planted. This is explained by the fact that tree species need large root zone that is free from salts. Planted trees die even if soluble salts occur at a depth of 1.5-2 m. Therefore, sustainable forestry is a particularly difficult challenge of salt-affected soils.

A distinct relationship between the type and degree of soil salinization and the growth and survival rates of different tree and shrub species has been demonstrated by studies conducted in the G. M. Vysotsky Ukrainian Research Institute of Forestry and Forest Amelioration.

Analysis and synthesis of data on the growth of tree and shrub species on soils containing different salt concentrations allow species to be grouped according to their tolerance to excessive salt concentrations as follows:

- Salt-tolerant species: *Tamarix ramosissima, T. tetrandra and T. pallasii*;
- Strongly salt-resistant species: tree - *Elaeagnus angustifolia*, shrubs - *Lonicera tatarica, Ribes aureum* and *Cornus sanguinea*;
- Salt-resistant species: in forest-steppe and true steppe, trees – *Quercus robur, Pyrus pyraster, Acer campestre, A. tataricum and Ulmus laevis;* shrubs – *Crataegus* spp. and *Rhamnus cathartica*; in dry steppe - *Robinia pseudoacacia, Gleditsia sp., Ailanthus* sp., *Styphnolobium japonicum, Fraxinus angustifolia* and *Thuja* sp.; under favourable soil moisture conditions - *Populus alba* and *P. bolleana*; to a lesser degree fruit trees such as *Prunus armeniaca, Morus alba, Cydonia oblonga* and *Prunus cerasifera;* shrubs - *Amorpha fruticosa, Ligustrum* sp. and *Caragana arborescens*.
- Weakly salt-resistant species: *Fraxinus excelsior*, Pinus spp. (including *P. nigra* subsp. pallasiana, P. pinaster and to lesser degree *P. sylvestris*), *Juniperus* spp. (*J. virginiana* and *J. sabina*), *Populus* spp. (*P. nigra* and *P. deltoides*) and *Acer negundo*.
- Salt-intolerant species: all other species.

The presence of carbonates ($MgCO_3$) and chlorides in soil solution presents the most serious threat to tree health. It has been statistically proven that the growth of different tree and shrub species is only significantly correlated with the depth of occurrence of toxic salts, while the influences of all other properties of saline soils are insignificant.

Earlier studies have shown that the water of soil solutions containing toxic concentrations of soluble salts is unavailable for trees. The water availability for trees also decreases with an increase in soil alkalinity and total mineralization (salinity) of the groundwater. Therefore, soils that are well-moistened by salt-containing waters remain physiologically dry.

Soils are subdivided by their respective salt concentrations and moisture contents into the following categories of suitability for agroforestry (agro-sylviculture): fully suitable, partially suitable, conditionally suitable, suitable for salt-resistant shrub species and totally unsuitable.

The main agrotechnical and ameliorative measures practiced in agroforestry on salt-affected soils include the following: deep ploughing, wide spacing, using salt-tolerant species and careful management of soils and plantations. The sylvicultural quality of soils within dry regions cannot be significantly improved by applications of gypsum, mulch, organic and mineral fertilizers [12, 18].

# 4.6. Synergetic amelioration complexes

**M.I. Romaschenko and A.A. Nosonenko (Ukraine)**

Synergetic amelioration complexes (SACs) involve the combined implementation of a number of highly efficient science-based ameliorative measures to achieve ecosystem amelioration targets. In this sense, SACs are aimed to encourage the maintenance and improvement of self-regulatory ecosystem mechanisms to renew natural resources.

An SAC can be considered as a coherent system of integrated development (co-evolution) of ameliorative measures and the noosphere (the sphere of human thought) that provides for the maximal possible reduction of ecological risks, effective increases of potential productivity of soil resources, integration and the adaptation of human and nature interactions for the accomplishment of sustainable (balanced) social development. Successive solutions to the problems of ameliorative land management and green economy are based on a synergistic methodological approach [11].

At the present time, one of priority goals of amelioration science is to attain the maximal possible savings of labour, energy and natural (including water) resources together with an increase in the efficiency of their use.

Non-irrigated saline and alkaline soils should be analysed and subdivided according to their resistance to the further development of salinization and alkalinization processes under the impact of both natural and man-made factors within certain soil areas. The development of the above-specified processes in non-irrigated soils is usually connected with a shallow occurrence of groundwater with an increased mineralization (salt content), the presence of salt-affected parent materials and sediments and poor drainage [16].

On the basis of existing data, non-irrigated saline and alkaline soils are subdivided into four types of land areas:

- areas, where the causes and the effects of salinization and alkalinization processes are absent, i.e., 'stable' land areas that do not require any ameliorative treatments;
- areas, where occasional manifestations of salinization and alkalinization processes are possible, i.e., potentially unstable areas, for which preventive agrotechnical measures (the use of salt- and sun-tolerant crops, green manure and rational fertilization and tillage of soil) are recommended;
- areas characterized by low and medium degrees of development of salinization and alkalinization processes, where complexes of agrotechnical measures are designed for the restriction and a partial eradication of such processes (application of calcium-containing chemical ameliorators, soil leaching to remove salts and ameliorative deep ploughing); such measures are described in respective parts of this Handbook.
- areas characterized by a high degree of development of salinization and alkalinization processes and generally unsatisfactory ecological and ameliorative conditions. As a rule, these areas are found in coastal lowlands by the sea and wet estuaries, where highly saline groundwater occurs at a shallow depth. Such areas are not recommended for amelioration, because of their low fertility and the high cost of their reclamation. In some cases these areas are protected as nature reserves or used as recreational zones.

Irrigated saline and alkaline soils should be managed with the use of innovative water-saving techniques of irrigation. Soil-protective water-saving techniques are highly recommended for implementation under conditions of limited water resources and soil degradation tendencies. These techniques are economical and maintain a balanced development of agricultural ecosystems [13].

The development of irrigation salinity and alkalinity of soils is mitigated by a combination of ameliorative measures that are described in respective parts of this Handbook.

The currently growing deficit of water and energy resources and the deterioration of the ecological-ameliorative condition of irrigated lands within significant areas creates an imperative need for identifying and implementing water-saving soil-ameliorative measures based on water-saving irrigation techniques. Such measures can help to provide for the sustainable management of irrigated lands, maintenance and growth of their productivity, rational use of labour, water, soil and energy resources and a higher level of food security. In conclusion, an analysis of the current state of irrigated lands in Ukraine suggests that drip irrigation is the most promising water-saving technique to date.

Drip irrigation is currently the most widespread water-saving irrigation technique used in Ukraine. This technique allows water to drip slowly to the roots of plants and, at the same time, supply macro- and micronutrients, chemical ameliorators, plant medications and growth regulators. As a result, there have been significant increases in crop productivity and savings on irrigation water, energy resources, mineral fertilizers and a highly significant decrease in the negative impacts of irrigation on the environment.

In Ukraine, drip irrigation is used for perennial crops as well as row fodder and vegetable crops within a total area of about 70000 ha and there are demands for the construction of new drip irrigation systems to provide for an annual increase in their total area by 15000 ha.

The use of drip irrigation in a rotation of vegetable crops allows for the following:

- optimal soil water, air, temperature and nutrient regimes;
- the possibility of prompt and efficient application of all agrotechnical measures;
- saving 1.5-5.0 times more irrigation water than traditional irrigation systems;
- lowering the costs of energy expenditure on irrigation by 1.5-25 times;
- saving of 30-50% in fertilizers due to their direct placement into the root zone in irrigation water solutions.

Thus, the further development of soil irrigation systems in Ukraine should involve the implementation of soil-water regulations and water-saving amelioration measures based on new and appropriate irrigation techniques and regimes.

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# Chapter 5.
# Innovative methods and technologies for amelioration of salt-affected soils and agroforestry practices in marginal landscapes

## 5.1. The use of a proximal technique of electromelioration on localized areas of Soda Solonetz-Solonchak in Armenia

**S.V. Saakyan (Armenia)**

Electromelioration is an effective method for the chemical amelioration of saline and alkaline soils that allows for the reclamation of Solonetz without the need for transporting large amounts of ameliorators [1, 2, 14]. However, this method has not been widely adopted in practice due to some methodological problems. Research on this matter has concluded that the main disadvantages of this method include the long distances between the electrodes and the need for high-voltage direct current and freshwater for soil leaching.

The long distance between the electrodes is dictated by the necessity to spread the electric field over a large area; otherwise there would be a need for a far larger quantity of electrodes. At the same time, wide positioning of electrodes implies a need for high voltage direct current to produce the electrolysis effect. This results in the use of large amounts of electric power and is, hence, an energy inefficient method. The use of freshwater for leaching contributes to a decrease in the strength of electric current, which causes further inefficiency due to a reduction in desalinization rate and an increase in the duration of soil amelioration.

An analysis of experimental studies has shown that the best method of amelioration of alkaline soils is a proximal technique of electromelioration, in which soil is treated not directly, but indirectly - through electrically treated irrigation water with additions of salts. For this purpose, there is a need for a specialized device for the treatment of salt-containing water. Such device has already been developed and applied in practice after a series of laboratory experiments, which established optimal parameters of saline water treatment [9-10].

The experiments were conducted at a 0.1 ha site, where soils were affected by secondary salinity and alkalinity.

All shrubs at the site were uprooted and the soil was levelled. Between the remaining rows of trees, 1.5-m-wide strips of soil were ploughed to a depth of 25-30 cm and experimental plots 1.5x1.5 m2 with earth ridges 20-25 cm high along their boundaries were set up. The soils of experimental plots were acidified using a device for saline water treatment and then washed with freshwater. Those soils were characterized by the soda-sulphate-chloride type of salinity. They had a total alkalinity of 0.17-7.37 mmol(eq.)/100 g and the exchangeable sodium and potassium concentrations of 5.4-12.7 mmol(eq.)/100g. The pH of soil solution was from 8.3 to 9.8. The content of soluble salts within a soil layer of 0-50 cm varied from 0.4 to 2.0%.

The experiment was carried out in three replications with three different treatments:

- Soil leaching without chemical ameliorators (control).
- Chemical amelioration of soil by sulphuric acid solution with subsequent leaching of soil by freshwater.
- Chemical amelioration of soil by acidified (using a specialized device) saline groundwater with subsequent leaching of soil by freshwater.

The calculated rates of sulphuric acid application to achieve soil desalinization were 100 t/ ha on average and 43.6 kg/2.25 $m^2$ for an experimental plot. The ameliorator with an acid concentration of 50 mmol(eq.)/l was applied in a quantity of 436 $m^3$. Soil acidification and leaching treatments within experimental plots were followed by tree planting.

The experimental results yielded the following conclusions:

- The leaching of Soda Solonetz-Solonchak without the use of chemical ameliorators decreased the content of soluble salts by 16.1% and that of exchangeable sodium by 6.5%, but the soil remained saline, alkaline and generally unsuitable for the growth of agricultural crops.
- The HCl treatment of Soda-Solonetz-Solonchak caused desalinization and dealkalinization of soil, which resulted in leaching of soluble salts and toxic ions from the 0-1 m layer of soil so that their remaining concentrations reached desirable levels.
- The use of electrically treated acidic water produced the same result as the HCl treatment, i.e., an improvement of soil quality.
- The local soil amelioration technique reduced the rates of chemical ameliorator and water use by 10-15 times as compared to traditional methods, which creates good prospects for the practical application of this new method on farms.

## 5.2. Innovative technologies for the amelioration and use of salt-affected soils in Kazakhstan

**A.S. Saparov and V.M. Kan (Kazakhstan)**

### 5.2.1. Differentiated system of amelioration of salt-affected paddy soils

The amelioration of salt-affected soils of paddy rice farms in the south and southeast of Kazakhstan is supported by a new differentiated technology system designed by scientists from the U.U. Uspanov Kazakh Research Institute of Soil Science and Agrochemistry. This system allows optimal crop productivity within the first year without any soil leaching pre-treatment.

The '**NTO3 – 1,2,3,4**' amelioration technology for salt-affected soils of rice fields has several modifications that are adapted for different degrees and chemical types of salinity and different crop varieties. The 'NTO3-1,2' technologies were first implemented on a total area of more than 100 thousand hectares in Kazakhstan and Uzbekistan in 1980 and later tested in Ukraine, Russian Federation, North Korea and China. Recently, the 'NTO3-3,4' technologies have been developed and implemented on rice fields in the Karatal District in the Almaty Region and the Kazaly District of the Kyzylorda Region.

The presented technologies are principally different from the existing soil amelioration technologies of the world and permit to the growth of rice on salt-affected soils and obtain optimal yields in the first year of cultivation [3]. These technologies are cost effective and ecologically safe.

**Technology "NTO3-1"** is designed for amelioration of strongly saline loamy soils. At the core of this technology lies the use of recently developed small-volume ameliorators that produce synergistic effects in combination with certain organic additives (rice straw), water supply, soil tillage and fertilization. Such ameliorators are applied to soil once in every 7-10 years. The 'NTO3-1' is intended for two types of rice fields: 1) on previously cultivated strongly saline and alkalize soils and 2) on virgin soils and soils with secondary salinity.

**Technology "NTO3-2"** is designed for improving the fertility levels of moderately and weakly saline soils and the productivity of rice on non-saline soils. The use of 'NTO3-2' provides an increase of up to 15-20% in rice yields in response to ploughing in chopped straw applied at a rate of up to 3 t/ha and the pre-sowing treatment of seeds (PTS) with a 40% solution of polyfunctional chemical ameliorator (PFCA) for 1 hour, with subsequent sowing performed at any time. The PTS is performed with the use of specialized equipment, which has been fully tested on irrigated lands in the districts of Karatal, Akdaly and Kazaly in Kazakhstan as well as the region of Fergana and 24 farms within the autonomous republic of Karakalpakstan in Uzbekistan.

T**echnology "NTO3-3"** is designed for reclamation of saline clayey soils for rice cultivation. It is commonly known that non-saline clayey soils are the best for rice cultivation, as they have a high potential fertility and low infiltration capacity that saves on irrigation water and favours the maximal accumulation of nutrients and organic compounds. The 'NTO3-3' reclamation of salt-affected clayey soils is performed with the use of combined chemical agents (SACA, AS and PFCA, see Box 1) and the following technical measures. Firstly, the soil undergoes an early spring ploughing to a depth of 20-22 cm accompanied by soil tillage with a disc harrow. After that, the soil is levelled and mineral fertilizers are applied: N - 500 kg/ha, P2O5 - 240 kg / ha and also SACA - 5 t/ha. Then, rice seeds are sown after their pre-treatment with 2.7% AS solution at a rate of 20-25 l/t for a period of 30-120 minutes. The process is completed by PFCA application at a rate of 200 kg/ha to the soil surface after rice seeds are sown. Subsequently, paddy fields are flooded to saturation level and irrigated accordingly.

**Technology "NTO3-4"** is designed for reclamation of saline sandy soils for rice cultivation. Sandy soils have a high infiltration capacity and, therefore, major flooding is a challenge. Such soils are widespread in the Republic of Kazakhstan and occupy large areas within the river basins of Syr Darya (30%), Ili (35%) and Karatal (40%). At the present time, most of these soils are affected by secondary salinization. The 'NTO3-4' involves the regular spring preparation of paddy fields (soil tillage with a plough, disc harrow and leveller followed by fertilization). Then, before sowing, crumbled white clay is applied to the soil surface at a rate 10 t/ha. The AS treatment of rice seeds prior to sowing, the PFCA application to soil, flooding and irrigation techniques are similar to those in the 'NTO3-3' technology [3, 5].

**Box 1. Brief descriptions of chemical ameliorators – SACA, AS and PFCA**

**SACA – supra-atomic chemical agent.** This is a readily hydrolysable agent applied to flooded soil, where it forms iron hydroxide and sulphuric acid. The latter neutralizes the carbonate alkalinity caused by the presence of sodium carbonate and bicarbonate. As a result, sodium sulphate ($Na_2SO_4$) is produced, which is easily leached from soil together with other soluble salts.

**AS – adaptogenic substance** is an agent synthesized by A.G. Mamonov (2008) from lignite (brown coal) of the B3 brand from the mines of Oi-Karagai and Kiyakty, extracts from wild plants of Kazakhstan and other special substances. The mechanism of its action, which was experimentally demonstrated by the inventor, resulted in two- to three-fold increases in the bioenergy of seeds and plants during the early stages of their development, as compared to that of the control.

**PFCA – polyfunctional chemical ameliorator** is the core agent of newly developed methods of the reclamation of clayey and sandy saline soils of rice fields, which helps to combat boron toxicity, alkalinity of soil solution and alkali production by microorganisms that are present in irrigation water and the upper horizons of paddy soils.

The reclamation technologies for clayey and sandy saline soils ('NTO3-3' and 'NTO3-4', respectively) mean that leaching or water disposal from paddy fields are forbidden during the entire period of rice growth. After rice plants have reached the tillering stage, drainage waters can be used for irrigation. With a correct implementation of these technologies, rice can ripen 8-12 days earlier than usual.

The use of the above-described technologies for amelioration of saline soils has significant agronomic and economic benefits and advantages.

### 5.2.2. Agricultural nanotechnologies for increasing yields of maize on poor and salt- affected soils

***Characteristics of newly developed agents***: Adaptogenic substances or agents are synthesized from lignite (brown coal) from the mines of Oi-Karagai and Kiyakty in Kazakhstan. These are small-volume agents applied in very low doses, as compared to their alternatives. For instance, a 0.8% solution of the C-1-1 agent for seed treatment is applied at a rate of 8 g/ha and a 0.04% solution of the PA-2-1 agent for plant spraying – 120 g/ha.

***Effects***: Adaptogenic substances help to increase the germination and viability of seeds, the resistance of plants to diseases and adverse environmental conditions and the speed of development of root systems and above-ground mass. As a result, grain crops ripen 7-16 days earlier than normally.

The use of new chemical agents in agriculture results in a 30-70% increase in plant production. Adaptogenic substances containing humic acids are not a source or replacement of nutrients for plants, but only serve to boost the nutrient uptake by plants, both from the natural nutrient pool of soil and fertilizers applied. Therefore, adaptogenic substances should be used in a mixture or in combination with mineral fertilizers.

Agricultural nanotechnologies can find application in maize growing regions of Almaty, Jambyl and Southern Kazakhstan.

### 5.2.3. Innovative technologies for the use of saline-alkaline soils under green forest plantations

The innovative method of reclamation and use of Soda-Solonchak-Solonetz was developed at the U.U. Uspanov Kazakh Research Institute of Soil Science and Agrochemistry. This method is based on the practical utilization of industrial wastes coming from the Stepnogorsk Chemical Plant (phosphogypsum) and thermoelectric plants in Astana and Karaganda cities (ash – the product of coal combustion). The prospective use of these wastes is favoured by their low costs (transportation, crushing and fractionation) and the presence of nutrients (phosphorus, calcium, potassium, nitrogen compounds and micronutrients) in their composition. Kazakhstan has almost inexhaustible reserves of such wastes to be used in soil amelioration.

***Amelioration of Soda-Solonetz-Solonchak***. Experimental tests were conduced at the EPU-2012 site with the aim of studying the improvement of alkaline soils by applying soil treatments with chemical ameliorators in combination with measures for storing water in soil from winter, spring and summer precipitation [3, 5]. The experimental site was located on Soda-Solonchak-Solonetz and had an area of 0.15 ha. The experimental treatments were applied in 3 replications on experimental plots 150 m2 each and included the following:

1. Control.
2. Phosphogypsum, 30 t/ha + ash, 15 t/ha (50% - i.e., half dose)
3. Phosphogysum, 60 t/ha + ash, 30 t/ha (100% - i.e., full dose).

The full dose of phosphogypsum application rate was calculated with corrections for moisture content, particle size and wind speed (more than 6 m/s) – up to 30% loss of ameliorators. The experimental treatments also included variations in soil tillage.

***Physicochemical description and efficiency of technology.*** This technology was developed as a part of a general tendency for the chemization of agriculture in irrigated areas, in particular, on Soda-Solonchak-Solonetz in arid regions. Some ameliorative systems on Soda Solonetz already exist, e.g., acidification with the use of sulphuric acid followed by soil leaching. However, the acidification treatment is chemically very harsh on soil and has disadvantages connected with the following: high rates of mineral acid application, large volumes of leaching water, handling toxic substances, metal corrosion problems and the loss of soil organic matter through mineralization and inhibition of microbiological activity. Another method widely used for Soda Solonetz improvement involves soil levelling, application of gypsum or phosphogypsum, deep tillage with a chisel plough that does not invert the soil profile, profound leaching and subsequent crop cultivation with the presence of drainage system.

***Treatment of tree seeds and saplings with a 'Humi-K' modified bio-organic fertilizer***
Different bio-organic fertilizers that help to increase the quality of tree saplings and obtain ecologically clean products were tested at the aforementioned EPU-2012 site and a forest nursery.

The aim of experiments was to initiate the mechanism of soil fertility renewal and to increase the viability of tree saplings (up to 90% in Kazakhstan). Young trees and shrubs were treated with bio-organic fertilizers, plant hormones (phytohormones) and growth stimulants of the new 'Humi-K' generation developed at the U.U. Uspanov Kazakh Research Institute of Soil Science and Agrochemistry, phytohormones synthesized by M.K. Gilmanov and a Japanese product branded 'Alinsandes' [4]. Shrubs of golden currant (Ribes aureum) were treated with the 'Humi-K + Vermicompost', 'Gilmanov nanobiostimulant' and 'Alinsandes' growth biostimulants at the Ak Kaiyn forest nursery in 2012.

## Recommendations

1. Phosphogypsum and ash are required in high doses for the improvement of Solonetz at the EPU-2012 site due to a high content of alkali salts and an exchangeable sodium percentage (ESP) of 40-70%.

2. A full dose of ameliorators should be applied to soil to decrease the ESP from 40-70% to 2-8%. The use of a half dose of ameliorators produces an unstable neutralization effect and the ESP reduction to 10-45%, with widely varying exchangeable calcium content.

3. The reclamation of Solonetz is associated with the optimization of sylvicultural plant nutrition. The use of 'Humi-K' modified liquid bio-organic fertilizer is recommended as an effective treatment, because it stimulates the reproduction of ammonification bacteria, increases the contents of nitrogen and humus and the numbers of oligotrophic organisms in soil, i.e., optimizes the nitrogen balance by supporting free-living aerobic nitrogen fixing bacteria.

4. The application of 'Humi-K' fertilizer solution to soil improves the nutrition of many forest plant species due to the activity of dominant aerobic members of soil microbial community.

## 5.3. Precision agriculture systems on saline and alkaline soils

**V.V. Medvedev and A.A. Nosonenko (Ukraine)**

Precision agriculture is a site-specific crop management system that takes into account spatial heterogeneity, i.e., variability within a field.

Soil heterogeneity is an important management challenge. The heterogeneity predetermines differences in soil properties, plant nutrition and water and temperature regimes within a field. As a consequence of heterogeneity, soils within a field will have different fertility levels. Because of differences in the moisture content of soils at higher and lower parts of the field, it is practically impossible to achieve high-quality soil preparation over an entire field to enable seed to be sown at the same depth. Consequently, seeds germinate at different times leading to differential phenological stages of plant development up to the time of harvest.

Among causal factors of intra-field heterogeneity, the first and foremost is the heterogeneity of parent materials, i.e., their variability in particle-size composition, chemical and mineralogical composition and physical properties on both vertical and horizontal planes. The vertical differentiation is represented by layers of different ages. Soils inherit the salinity characteristics of parent materials (e.g., a specific mosaic pattern of soil salinity distribution is known over salt domes in the area of the Dnieper River). Soil gley features (excluding pseudo-gley) behave similarly, usually being predetermined by the degree of waterlogging in parent materials.

The use of hydrotechnical irrigation systems results in a significant increase in the heterogeneity of soil cover because of temporal and spatial factors. The soil cover is modified due to secondary salinization and alkalinization, compaction and loss of structure as well as rising groundwater. Patches of soils with excessive salt accumulations or waterlogging due to perched water or shallow groundwater table are very common within river floodplains in steppe regions. In some places, soil ares affected by karst and suffosion phenomena. Territories at higher hypsometric levels, especially those which are affected by saline groundwater, are characterized by localized deterioration of the ecological and ameliorative state of soils and the development of slope processes. Closed-drainage lowlands are characterized by subsidence phenomena and the appearance of mesodepressions known as ‘pods’ or ‘steppe saucers’.

According to F.I. Kozlovsky [6], irrigation for 20-25 years results in a complex spatial change in microtopography and soil properties. The initial microtopography becomes totally transformed, the moisture level is significantly increased and processes of infiltration-induced leaching and subsidence-induced soil compaction develop.

The spatially differentiated transformation of saline and alkaline soils is highly evident and must be taken into account in land use and management (with preference to precision agriculture) as well as soil protection and improvement. It is also necessary to further investigate the impacts of some negative processes causing heterogeneity such as irrigation-induced erosion, subsidence as a result of salt leaching, halogenation, consolidation (development of vertic features and cementation) and waterlogging near irrigation channels. It is also necessary to verify the role of surface levelling, which according to some studies [7] does not decrease, but increases the degree of soil heterogeneity and favours soil striation (change in the soil surface structure with change in moisture level within a short distance from irrigation channels).

In general, irrigation has a significant impact on soil-forming factors and, therefore, results in the development of new types of man-made spatial structures of the soil cover.

An increase in the structural complexity of soil cover over the course of long-term irrigation is associated with numerous and diverse manifestations of heterogeneity that require the precise application of both agrotechnical and ameliorative measures. According to [8], the practice of precisision agriculture on irrigated Common Chernozems of the Donetzk Region (Ukraine) should focus on tasks of reducing the high alkalinity of soils and optimizing plant nutrition via nitrogen fertilizer application. That experimental research [8] aimed to identify which parameters of soil fertility have significant effects on the productivity of barley and cabbage. The coefficients of correlation between the yields of barley and cabbage (centner, i.e. 100 kg per hectare) and soil properties were tested at 40 points within the field.

The soil properties tested reflected the diagnostic criteria of Chernozem degradation and included the following:

- the content of toxic soluble salts, in chlorine equivalents (0-50 cm);
- the ration of Ca: Na in water extract (0-50 cm);
- pH in water (0-25 cm);
- exchangeable sodium and potassium percentages (%) of the sum of cations (0-25 cm);
- the total content of humus,% (0-25 cm);
- the total content of nitrate and ammonium nitrogen, mg / 100 g of soil (0-25 cm);
- the content of labile $P_2O_5$ by Chirikov method, mg / 100 g of soil (0-25 cm);
- the content of labile $K_2O$ by Chirikov method, mg / 100 g of soil (0-25 cm);

A strong correlation was detected between the following parameters:

a) barley yield (2001) – total of N-NH4 and N-NO3, mg / 100 g of soil, with correlation coefficiant r = 0.71;

b) cabbage yield (2002) – pH in water; r = -0,59;

c) barley yield (2003) – total of N-NH4 and N-NO3, mg / 100 g of soil, r = 0.71

A medium degree of correlation was found between the barley yield (2001) and pH in water (r = -0.36). The influence of other testes parameters of soil on crop yields were insignificant.

Therefore, crop productivity on Common Chernozems with different degrees of irrigation salinity depends on the spatial variability in the content of mineral nitrogen and the pH (water) of the plough layer. In a precision agriculture system (PAS) the attention should be focused on the optimization of nitrogen supply to plants and the control of alkalinity of soil solution. The most satisfactory results can be obtained by a differentiated application of nitrogen fertilizers and acidifying agents – physiologically and chemically acid mineral and organic substances. It should be taken into account that temporal variability in soil properties (especially the nitrogen content) is quite strong and, therefore, soil properties need to be monitored during the growing season as a part of practical implementation of PASs [8].

The PAS technology can be implemented following the assessment of heterogeneity of physical, physicochemical and agrochemical parameters of soil within the field. A geostatistical computer processing of data is conducted with the aim to differentiate field parts by three levels of fertility: (i) optimal or near optimal – no need for soil treatment; (ii) intermediate – standard ameliorative treatments are needed and (iii) low – more complex treatments are needed.

Field studies conducted in the Sukhaya Steppe by the Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky (2012–2015) revealed that a standard chemical amelioration (application of gypsum and ammonium nitrate) of an abandoned

Dark Chestnut soil with a residual weak alkalinity can produce a positive effect on the productivity of winter wheat and sorghum. The results obtained present the prospect of saving about 60% of calcium-containing ameliorators and 30% of nitrogen fertilizers by implementing PAS on alkaline soils in the Sukhaya Steppe [8].

Practical implementation of precision agriculture requires purchase of special equipment for differentiated soil tillage and application of fertilizers and ameliorators, as indicated by the analyses of field maps. Successful application of precision agriculture also implies that agricultural practice should acquire new resource-saving, soil-protective, innovative and competitive technologies that can help with technological renovation and increase the economic potential of farming businesses. Experiences of Western European countries and the 'Druzhba-Nova' Agro Company in Chernihiv (Ukraine) demonstrate that the implementation of precision agriculture requires a single payment of 100-150 thousand USD to farmers for purchasing equipment and materials, which can be paid back in 1-3 years (depending on the size of land area). The experimental site at the 'Druzhba-Nova' Agro Company can be used as a PAS demonstration project in Ukraine. Precision agriculture is a growing trend in leading agricultural producing countries, where it is gradually replacing traditional agricultural systems.

## 5.4. Biosaline technologies and approaches to the management of salt-affected agricultural lands under arid climate conditions (by examples in Central Asia and Transcaucasia)

**K.N. Toderich (UAE), I. Shoaib (UAE), T.M. Khunshazarov (Japan) and G.M. Khasankhanova (Uzbekistan)**

The Aral-Caspian Depression with its sharply continental arid climate faces a serous problem in producing enough food for a rapidly growing local population. The situation is exacerbated by an increase in degraded land area due to soil salinization and loss of fertility combined with unsuitable land management practices of growing wheat and cotton. The intensive use of water and land resources, excessive irrigation, overgrazing and felling trees and shrubs for fuel (firewood) has resulted in the degradation of fertile soils into unproductive lands unsuitable for irrigation farming, animal fodder production or cattle grazing [11-13, 16, 17]. Annual financial losses due to soil salinization are estimated at 31 million USD, while the cost of land abandonment due to soil salinization is more than $12 million a year. Shortages of irrigation water lead to the necessity to use low-quality saline water for irrigation. This, in its turn, has a negative effect on the agricultural industry in the sense that the fragile balance of existing crop cultures can be lost, because most traditionally grown crop cultures are sensitive to soil salinization.

Therefore, the development of alternative systems of agricultural production is especially important for mobilizing existing marginal resources within the region to bring profitability to local farmers without any damage to the environment.

The system of biological amelioration is aimed at the improvement of land quality, primarily, soil fertility and the support of highly nutritious and high-calorie fodder production on salt-affected soils, virtually wastelands, which can be reclaimed for agriculture, while at the same time restoring their condition as functioning agricultural ecosystems.

Biosaline technologies for the reclamation of salt-affected soils and restoration of productivity of degraded agricultural ecosystems were developed by the International Centre for Biosaline Agriculture in Central Asia and Transcaucasia (ICBA CAT) and have been successfully implemented in practice in agricultural crop production, fodder production and animal husbandry.

### Technology 1. Diversification of salt-resistant agricultural crops and methods for increasing the productivity of plant and animal husbandry to enhance the living standards of farmers.

Practical application and integration of different farming practices on salt-affected and degraded lands results in the diversification of agricultural crop production, which helps to produce more food and increase farmers' income. It has been demonstrated by many national and regional projects within the framework of the ICBA-CAT Programme that cultivation of high-yield, salt-, drought- and frost-tolerant varieties of cereals, pulses, fodders and other crops is a very effective measure for the improvement of properties of salt-affected soils and respective increases in crop yields. Farmers are also interested in diversification and the introduction of new crop varieties, which are resistant to pests, droughts and water/soil salinity and can be grown on marginal lands.

The following crop species have shown the best growth results on marginal lands: sorghum, African millet, triticale, sesame, quinoa, amaranth, Jerusalem artichoke, globe artichoke, peas, mung beans, saltbush and *Kochia* spp. These species are grown as pure or mixed cultures, main crops or secondary crops after wheat harvest or in rotations with rice or cotton. Experiments in growing these crop species on arable and livestock farms in Uzbekistan, Kazakhstan, Kyrgyzstan, Tajikistan and Azerbaijan have shown that they are highly nutritious foods with high production of green biomass and high yields of seed, which can successfully be grown on salt-affected clayey and sandy soils, which are otherwise unsuitable for the profitable cultivation of wheat or cotton.

Moreover, many non-traditional crop varieties are adaptable to saline irrigation water. The most acceptable salt composition of irrigated water includes those types that are dominated by sulphate and bicarbonate anions and magenesium and calcium cations. The presence of calcium carbonate and gypsum in soil can partly mitigate problems arising from the use of saline irrigation water, including drainage water (EC = 2.2 dS/m, SAR = 4.8; pH = 7.7-8.3).

**The best soils for drainage water utilization are sands and sandy soils with a high infiltration capacity and a low cation exchange capacity**

- the use of undiluted saline water for irrigation of sandy soils: the water salinity should not exceed 5 g/l and salt-tolerant non-traditional crops should be used. Each batch of irrigation water should completely percolate the soil, with 50-80% of irrigation water going into the drainage system. The soil should be leached with fresh water every 2-3 years;
- the use of saline water diluted with fresh water: on loamy and clayey soils;
- leaching of Solonchaks and other salt-affected soils: water with a salinity level up to 6 g/l can be used. Leaching combined with irrigation of rice can be performed with the use of water that has a salinity level up to 4 g/l.

Leaching of Solonchaks can be successful on soils of predominantly sandy composition.

Correct introduction of selected varieties of non-traditional salt-tolerant crops such as African millet (*Pennisetum glaucum*) and sorghum (*Sorghum bicolor*) can become a reliable resource for animal grazing and supplementary feed used for livestock farming, especially, on highly saline soils and groundwater. In the Central Kyzylkum (central part of the Kyzylkum Desert) and the Surkhandarya Region of Uzbekistan and the Khatlon Region of Tajikistan, the early sowing of many of the aforementioned crop species (sown in the late February, when the soil temperature is +5 to +10°C) allows 2-3 harvests of green fodders and viable seeds to be obtained before the onset of hot weather.

The most promising high-calorie grain fodders of multipurpose use include species and genetically modified strains of sorhgum that produce from 70.3 to 97.8 t/ha of green biomass for fodder within one growing season, with a fodder moisture content of 71.1- 78.0% and sugar content of 5.7-13%, which implies the production of sugar at a rate of 1.7-5.7 t/ha.

African millet is a cost-effective alternative of sorghum and often used as a succession crop in the reclamation of marginal salt-affected lands. The use of African millet helps to reduce the extent of summer fallow practices by replacing them with crop cultivation practices, which also contribute to increases in biodiversity and soil fertility.

A highly promising new variety of millet called 'Khashaki 1' was created in 2012 as a result of experiments conducted at the Uzbek Agricultural Research and Production Centre (UARPC) and supported by the International Centre for Biosaline Agriculture (ICBA). The 'Khashaki 1' millet has been recognized as a salt-tolerant, drought-tolerant and heat- tolerant variety of dual purpose (biomass fodder and grain production) with high potential for successful growth under a wide range of soil and climatic conditions. Farmers have expressed interest in this new variety of millet for its prospective use in fodder production (green biomass and silage) in combination with maize and legumes (Fig. 5.4.1).

*Fig. 5.4.1. Members of the Regional Network on sorghum and millet seed propagation (Bajavut, Uzbekistan, 2014).*

Research conducted by the authors on weakly saline soils of the Syr Darya Region has demonstrated that these soils, in comparison with non-saline soils of the Tashkent Region, can support a better growth of hybrid varieties of sorghum and African millet, i.e., plants have an increased height, shortened growth period and a higher yield of green biomass and dry matter (Table 5.4.1). Under harsher climatic conditions, with different type of soil salinity and the use of saline irrigation water in the Republic of Karakalpakstan, the yields on maize were considerably reduced, yet the growth rates and yields of green biomass of African millet were only insignificantly affected.

*Table 5.4.1. Plant height, the growing season duration and yields of sorghum varieties and African millet on soils of different degrees of salinity.*

| Crop | Names of local varieties | Height if plants, (cm) | Growing season (days) | Yeild, t/ha | |
|---|---|---|---|---|---|
| | | | | Biomass | Dry matter |
| Non-saline soil (Tashkent) | | | | | |
| Sorghum | Korabosh | 259.7 | 103 | 51.09 | 13.10 |
| | Karlik Uzbekistana | 162.8 | 127 | 71.33 | 17.43 |
| African millet | Khashaki 1 | 209.1 | 86 | 72.53 | 21.97 |
| Weakly saline soils (Syr Darya) | | | | | |
| Sorghum | Korabosh | 239.7 | 94 | 78.63 | 20.30 |
| | Karlik Uzbekistana | 161.4 | 117 | 65.19 | 19.46 |
| African millet | Khashaki 1 | 201.4 | 80 | 70.71 | 18.30 |
| Weakly saline soils (Karakalpakstan) | | | | | |
| Sorghum | Korabosh | 181.0 | 92 | 32.53 | 9.28 |
| | Karlik Uzbekistana | 112.5 | 118 | 32.25 | 10.15 |
| African millet | Khashaki 1 | 182.5 | 81 | 44.86 | 14.78 |
| Moderately saline soils (Karakalpakstan) | | | | | |
| Sorghum | Korabosh | 177.0 | 96 | 23.51 | 6.47 |
| | Karlik Uzbekistana | 88.5 | 122 | 18.42 | 6.21 |
| African millet | Khashaki 1 | 178.5 | 82 | 36.08 | 8.08 |

*Source: K. Toderich et al., Tashkent, 2015 [ 11]*

The yields of green biomass of maize were reduced by 2.0-2.1 times on weakly saline soils and by 4.7-5.1 times on moderately saline soils in the Republic of Karakalpakstan, as compared to those on similar soils of the Syr Darya Region. African millet had a threshold of salt- resistance and the potential for stable yield production 2.5-3.0 times higher than maize and annual pulse crops. The 'Khashaki 1' locally bred variety of African millet was characterized by an increase in the growth rate and biomass (fresh and dry) by 2.0- 2.5 times in comparison to local varieties of millet (*Pannicum* sp.). Sorghum and African millet grown on degraded soils were producing 30% more dry matter and 25% more seed than the local crop varieties.

African millet and sorghum are recommended for the use either as main crops sown in the early spring or as follow-up crops (in crop rotation) after harvesting wheat or rice.

Arable and livestock farmers are interested in the introduction and use of sorghum and African millet for grain production on marginal lands. More detailed information can be found here:

*https://www.youtube.com/watch?v=2e6avQVTrVw&feature=youtu.be*

## Quinoa (Chenopodium quinoa Willd.) as a multi-purpose salt- and drought-tolerant agricultural crop

Experimental trials on seed samples and the creation of regional and national nurseries for the propagation, selection, agrotechnological research and seed production of quinoa (*Chenopodium quinoa*) were undertaken within the framework of the ICBA Project on Regional partnership for increasing the food security of produce grown under unfavourable conditions in Central Asia.

As quinoa is a salt- and drought-tolerant plant, it has very promising agricultural use as an alternative food and fodder crop and it can grow on poor soils under arid and semiarid conditions in Kyrgyzstan, Uzbekistan, Tajikistan and Azerbaijan.

Quinoa seed is gluten-free, very nutritious, protein rich (11-18%) and generally rich in saturated amino acids, fats, micro- and macronutrients. Quinoa seed yields vary depending on the agroecological zone: from 3.8 t/ha (in Karakalpakstan) to 5.1 t/ha (in the south of Tajikistan and in the piedmont regions in the area of Issyk-Kul Lake). The seeds can be used as health food, e.g., to diversify the diet of children. Chemical by-products including saponins originating from quinoa seed are also used in cosmetics and pharmaceutical industry.

Quinoa leaves are nutrient rich, with a protein content of 8.75-10.85% and a cellulose content of 7.68-8.90%. Quinoa inflorescences have a high sugar content of 95.84-92.73%. The above-ground biomass and seed processing residues are used as cattle fodder.

Great interest in the growth and distribution of quinoa seeds has been expressed by local farmers, householders and private businesses including restaurant chains (Fig. 5.4.2).

*https://www.youtube.com/watch?v=Dwr7XxzBLjI*

*Fig. 5.4.2. The successful promotion of quinoa varieties in Uzbekistan (June, 2015)*

## Technology 2. The use of halophytes to increase the productivity of marginal lands under conditions of arid climate and shortages of freshwater supply for irrigation

Halophytes or salt-loving plants grow well on salt-affected soils irrigated with saline water. Such plants uptake salts and, consequently, prevent soil damage. There are more than 760 halophyte species in the flora of Central Asia. These under-used phytoresources are little known and scarcely applied in agricultural systems, medicine and other industries in this country. However, some of halophytes represent a good source of food for humans, while others are desirable for industrial use as a source of renewable bioenergy. The use of halophytes in the reclamation of salt-affected lands around artificial lakes within the basin of Aral Sea would contribute to the economic growth of surrounding regions.

Halophytes can be used in soil reclamation as desalinization agents and phytoameliorators, because many of them are capable of uptaking salts from soils and irrigation water and concentrating such salts in the above-ground biomass. The process of soil desalinization usually requires a period of 3-5 years and occasionally 6-7 years in cases of very high salinity levels. Lands reclaimed under halophytes can be used for growing traditional agricultural crops.

Experimental research into the potential significance of halophyte species as economic resources, i.e., food products for local people, animal fodders, biofuel and a remedy for restoration of highly saline soils to a condition suitable for growing traditional agricultural crops has been conducted.

The ability of halophytes to promote soil desalinization is due to a combination of three factors. The upper one meter layer of highly saline loamy soils in semidesert areas has a salt content of 48 t/ ha. Halophytes with an above-ground biomass of 18-20 t/ha can uptake salts from soil at rates of 8-10 t/ha per year. Halophytes shade the soil surface and thus hinder evaporation and associated upward migration of salts into the upper layer of soil. This green mulch effect is equal to 2.5 t/ha of salts per year. Consequently, an area planted with halophytes is characterized by salt removal from soil at rates of 10-12.5 tonn per year (http://www.cac-program.org/video/play/9)

Liquorice (*Glycyrrhiza glabra*) known for its medicinal properties and nutritional value is considered to be a promising ameliorator for the successful reclamation of irrigated saline soils. Liquorice gives yields of 6-8 t/ha in hay and 8-10 t/ha in root (valuable raw material for pharmaceutical and food industries) on irrigated saline soils with a shallow groundwater table in the Syr Darya Region and Central Kyzylkum. After liquorice plants have been uprooted (every 5 years) the irrigated soils can be used for less salt-tolerant crops such as sunflower, barley, triticale, etc.

A soil desalinization effect similar to that produced by liquorice was achieved by planting perennial *Atriplex* species in the Karnabchul Desert. *Atriplex* is known as a high-quality fodder plant that forms thick growth on salt-affected soils and favours the restoration of natural vegetation cover and the improvement of soil properties. *Atriplex* species were successfully used in the reclamation of gypsum-containing and alkaline soils in the south- west of Kazakhstan. Many *Atriplex* species can also be used as a fuel by local people.

The biomass of halophytes (*Suaeda*, *Salicornia*, *Karellnia caspia*, *Climacoptera*, *Atriplex*, annual *Salsola* spp., etc.) that grow on salt-affected lands unsuitable for traditional agricultural crops can be used in the production of biogas. It is possible to obtain up to 300-400 m3 of biogas from one tonne of the dry matter of such plants *(http://www.cac-program.org/video/play/8)*

## Technology 3. The creation of winter fodder reserve stocks and the improvement of animal feed systems by the use of halophytes

A large-scale intraspecies and interspecies selection of halophytes has been conducted by the authors in cooperation with colleagues from the Institute of Karakul Sheep Breeding and Desert Ecology Research (Uzbekistan). As a result, there are 15 selected halophyte species and ecotypes that can be grown on soils affected by secondary salinization due to irrigation water salinity and can prospectively be used in bioamelioration, production of calorie-rich fodders and the pharmaceutical industry. These species include *Suaeda arcuata, S. acuminata, S. paradoxa, Atriplex hortensis, Climacoptera lanata, Chenopodium album, Salsola orientalis, Salicornia* sp., *Kochia scoparia, Glycyrrhiza glabra, Artemisia halodendron,* etc. The selected halophyte species can produce 10-12 tonnes of dry matter of fodder, 1-1.5 tonnes of seed and generally up to 1.5 tonnes of protein per hectare of sandy soil irrigated with saline water (Fig. 5.4.3).

The main technological operations applied to Artemisia-ephemeroid communities on Typical Brown Semidesert, Chestnut and Dark Chestnut soils of piedmont deserts of the Nurat Mountains are timed as follows: Early Spring – tillage of soil strips 12-50 m wide to a depth of 16-18 cm with direction of furrows being perpendicular to the direction of prevailing winds; May-June – soil tillage to a depth from 6 to 8 cm depending in the degrees of weed growth and soil compaction; Autumn (November) and winter (December-February) – sowing of various fodder crops including small shrubs, annual and perennial grasses, often with snow cover still present, which helps the seeds to undergo natural stratification and produce viable seedlings for when freshwater is present in abundance (autumn rain and later snow melt water cause a natural leaching of salts from the upper soil layers).

*http://drylandsystems.cgiar.org/news-opinion/2015-review-combating-land-degradation-and-climate-change-central-asia*

*Fig. 5.4.3. Halophytes (Kochia scoparia, Atriplex nitens and Suaeda) as fodder crops at the Kyzylkesek site .*

Various sheep diets based on locally grown fodder crops including halophytes have been developed within the framework of regional projects. The fodder assessment and recommendations of feed rates are based on analyses of a wide range of nutrition factors and aimed to increase the fodder efficiency.

Data on the biological, chemical and nutritional characteristics of some salt-resistant fodder crops and halophytes that are grown on soil irrigated with artesian water and that can potentially be used as animal feed are given below (Table 5.4.2).

*Table 5.4.2. The nutritional composition and energy value of some traditional salt-tolerant fodder crops and halophytes (in the flowering state)*

| Varieties studied/ Fodder crops | Chemical composition, % | | | | | Bulk value | |
|---|---|---|---|---|---|---|---|
| | Crude protein | Crude fat | Cellulose | Nitrogen-free extracts | Ash | Kcal | Mcal/kg |
| Alfalfa | 16,1 | 1,6 | 11,6 | 60,8 | 9,1 | 4162 | 17,4 |
| Licorice | 20,7 | 4,2 | 33,4 | 33,3 | 7,51 | 4417 | 18,4 |
| Pearl millet (Hashaki 1) | 13,3 | 1,1 | 22,4 | 47,2 | 7,9 | 3834 | 16,0 |
| Sorghum | 13,0 | 1,2 | 17,7 | 50,1 | 4,0 | 3761 | 15,7 |
| Maize | 10,6 | 1,5 | 23,0 | 40,8 | 8,3 | 3476 | 14,5 |
| Suaeda paradoxa | 23,6 | 2,8 | 20,9 | 27,5 | 21,9 | 3662 | 15,3 |
| Climacoptera lanata | 22,6 | 2,4 | 18,6 | 27,6 | 27,5 | 3474 | 14,5 |
| Atriplex nitens | 9,0 | 1,47 | 31,6 | 45,7 | 10,5 | 3964 | 16,5 |
| Halostachys belangeriana | 14,7 | 3,2 | 27,9 | 14,3 | 38,5 | 2934 | 12,2 |
| Karelinia caspia | 5,6 | 1,2 | 21,5 | 52,7 | 16,5 | 3614 | 15,1 |

*Source: K. Toredich et al., Tashkent, 2015 [ 11].*

Experience has shown that improved technologies for growing fodder crops and their mixtures can help to achieve higher quality and digestibility of animal feed. An analysis of the calorific values of hay has demonstrated that mixed crop cultures provide better quality fodders, i.e., allowing manufacturers to fully realize the bioenergetic potential of plants and to produce balanced foods complying with animal husbandry regulations.

*Atriplex nitens* and annual weeds are particularly tolerant to irrigation by saline water. The maximal production of green biomass occurs when the plants are actively growing and flowering. At the time of seed production, their growth rate significantly declines, which has been confirmed by correlation analysis. Therefore, annual halophytes can be harvested during their growth and flowering stages and included into animal diets. Later harvesting is not recommended because plant structures undergo sclerification and loose their nutritional value.

## Technology 4. The use of saline artesian water for the improvement of pasture quality and fodder production for livestock farming in arid deserts (desert oasis agriculture)

Saline waters can be used for the irrigation of sandy desert soils so long as halophytes are included within the crop rotation, as they can uptake up to 40% of the salts from soil solution. This is an obligatory condition of ecologically safe use of saline irrigation water. The artesian water has a neutral reaction (pH 7.4) and moderate salinity (EC= 5.6- 8.3 dS/m).

This technolohy has been successfully tested in the Kyzylkum Desert (Kanimekh District, Navoiy Region, Uzbekistan), where local people traditionally practice livestock farming, which both supports their livelihoods and their cultural values.

In seeking to improve their income, the people of Kyzylkum increase the numbers of cattle they keep without due consideration of the area and condition of pastures. Such improper use of pastures and excessive grazing pressures present serious threats to biodiversity. Therefore, there is an urgent need to establish a better system of fodder production with a decrease in grazing pressure.

The suggested technology is very cost-effective and can produce the following yields per hectare:

- 3-5 tonnes of winter wheat straw and 1.5-2.0 tonnes of winter wheat grain;
- 48-78 tonnes of silage made of maize, sorghum or millet;
- 14.4-15.0 tonnes of hay of alfalfa (lucerne);
- 23 tonnes of above-ground biomass of liquorice;
- 5-10 tonnes of hay of halophyte species.

Non-traditional fodder crops as either pure or mixed cultures produce hay yields of 15- 30 t/ha and have a high nutritional quality.

The benefits of implementing this technology include a) an improvement of the soil quality, b) the protection of the upper layer of soil via the restoration of vegetation cover and c) the prevention of overgrazing of pastures by more efficient management of fodder production on irrigated lands.

*http://www.cac-program.org/video/play/10*

Irrigated agriculture systems using saline artesian water in Kyzylkum produce a net income of 12.5 million UZS per year.

## Technology 5. The surface improvement of degraded *Artemisia*-ephemeroid pastures

Increases in grazing pressure on *Artemisia*-ephemeroid pasture communities on grey-brown soils results in the accumulation of chlorides and mixed chloride and sulphate salts and the loss of humus, total nitrogen, available phosphorus and potassium from the soil. Such consequences of human impact on pastures are very undesirable, yet the cost of the rehabilitation of such pastures is extremely high.

Joint research by the ICBA-CAT and the Institute of Karakul Sheep Breeding and Desert Ecology Research (Uzbekistan) has demonstrated that the productivity of degraded pastures can be increased by 20-40% through the improvement of the surface layer of soil (half of the rooting depth) under *Artemisia*-ephemeroid communities on brown sandy soils. Surface improvement technology implies the creation of alternating strips of ploughed and naturally vegetated soil within an area of pasture. It has been applied on pastures in the areas of Karnabchul and Malikchul and piedmont semidesert communities of the Nurat Mountains.

Areas of cultivated pasture with limited irrigation can be profitable in the piedmont and steppe regions and on lower mountain slopes in the south of Kazakhstan, the Chuy Valley in Kyrgyzstan, the valleys of Zaravshan and Fergana in Uzbekistan and the Ashtsky Region in Tajikistan.

Experimental research sites were located on the most severely trampled semidesert and desert pastures around human settlements, within small livestock farms, around artificial water reservoirs, waterholes and shelters for sheep and cattle in piedmont and semideset regions.

The direction of ploughed strips is perpendicular to that of prevailing winds. Seed is usually sown in December-January, to a depth of 1-2 cm in a dense bed. The use of fodder crop species with different ecological and phytocenological characteristics is preferable for creating pasture agrocenoses to be used all year round. Such species include trees (*Haloxylon aphyllum*), large shrubs (*Salsola Richteri and Salsola Paletzkiana*), medium shrubs (*Halothamnus subaphyllus*), small shrub-like herbs (*Salsola orientalis, Kochia prostrata, Camphorosma* sp. and *Artemisia* sp.) and grasses (*Poa bulbosa* and short-lived ephemeroids).

The creation of perennial pastures using desert and semidesert species of fodder crops is achieved by sowing seed within ploughed soil strips 12-60 m wide, with undisturbed natural pasture vegetation strips 24-120 m wide left in-between. Seed is sourced from fodder plant nurseries (seed isles) created on elevated open slopes with respect to prevailing wind direction and plant flowering times. Ripe seeds are carried by the wind and are self-sown over distances of 50 to 100 m within a pasture, thus, allowing for the self regeneration of pasture communities.

The net income from 100 ha of improved pasture is 4-6 times higher than that from an equal- sized area of natural Artemisia-ephemeroid pasture. Capital investment into creation of artificial pastures is paid back in 4-5 years. Such artificial pastures maintain a high productivity for 20-35 years if used rationally.

## Technology 6. Creation of cultivated sown pastures under conditions of limited supplementary irrigation

In semidesert regions soil moisture reserves are quickly depleted, where snow is removed from mown areas by wind action. This is often the main reason for decreased yields of green biomass and hay. Therefore, to create *Kochia* prostrata grasslands for harvesting hay and seeds, it is recommended to subdivide a field into 3-4 parts that can be used in turn year by year, i.e., to create a rotation of *Kochia prostrata* within an irrigated field *(http://cac-program.org/news/ detail/450)*

The complete germination of sown seeds on the experimental *Artemisia*-ephemeroid pastures was due to natural irrigation in spring by water from melted snow and mud-flows descending from mountains down to piedmont plains.

In the mountain foot-hills there are many sources of water that can be potentially used for irrigation: melt-water, water of permanent and temporary mountain streams, small rivers and, if required, water from artesian wells. In practice, good results were obtained by the construction of water-collecting pools, where the collected water can be held for a day to allow it to warm up and purify as sediment particles sink to the bottom prior to being used for the irrigation of fields.

Irrigated plant nurseries (seed isles) were created near the Tutli village in the area of Nurat city in the Navoiy Region (Uzbekistan). The plants grown with the help of local female farmers included *Kochia prostrata, Agropyron* sp., *Halothamnus subaphyllus* and leguminous herbs (*Onobrychis* sp., *Medicago sativa, Melilotus* sp., *Trifolium* sp., etc.). Perennial species produced seed during the second year of growth, with irrigation applied once or twice over a whole growing season.

Fresh biomass and hay yields in the first year of plant growth within the irrigated area were 10-20% higher than those on non-irrigated fields on same soils and under the same climatic conditions.

Plants can be sown in wide or narrow rows as pure or mixed cultures. Sometimes, check-row planting, transplanting (fodder species of desert shrubs and small shrubs) or rootstock propagation (perennial grasses) can be practiced.

## Conclusion

Soil degradation under the impact of salts is the most important negative factor that limits the efficient use of land resources. As a result of progressive soil salinization, some agricultural lands have become unsuitable for normal use.

The first and foremost objectives of biosaline agriculture in arid regions include restoration of salt-affected lands, creation of highly productive agricultural biocenoses in place of formerly degraded ones, their inclusion into agricultural use, the improvement of the ameliorative state and fertility of soils.

Soil rehabilitation by the use of halophyte species is an effective way to both productively utilize and desalinize salt-affected soils that are unsuitable for traditional agricultural crops.

Results of experimental tests have identified the most successful halophyte species that can be grown on salt-affected soils and used as winter fodders for farm animals. These species include *Atriplex nitens, Climacoptera lanata*, species of *Kochia, Salsola, Aellenia, Haloxylon, Artemisia, Ceratoides, Suaeda, Glycyrrhiza,* etc. The dry matter yields of fodder crops harvested from newly created halophyte plantations can vary from 1.2 to 1.5 t/ ha depending on the local environmental conditions and plant species composition. Moreover, halophyte pastures can be used in different seasons with stable yields from year to year and provide a diverse diet for farm animals.

The creation of cultivated and sown halophyte pastures under conditions of limited supplemental irrigation by saline artesian water requires sufficient quantities of high-quality viable seeds.

There is a need for further development of appropriate technologies for domestication (cultivation) of halophytes as well as other under-utilized traditional and non-traditional crop species such as quinoa, African millet, amaranth, soybean, etc. This would help to increase food security and food production. An expansion of such technologies over Central Asia and Transcaucasia via a multifaceted approach could demonstrate the benefits of growing salt-resistant plants together with the promotion of best agricultural practices on salt-affected soils among rural communities, farmers and politicians.

The creation of an interactive and readily available web-site in the local language together with multimedia tools (CDs, apps, etc.) as well as increasing the potential of arable and livestock farmers and small-holders are the priority tasks for the near future.

## 5.5. Agroforestry on salt-affected soils in degraded agricultural landscapes in Uzbekistan

**T.I. Khamzina (Uzbekistan)**
(based on the publication by Khamzina A., Lamers J., Vlek P., ZEF Bonn, Germany)

This article presents results from research on the rehabilitation of degraded arable lands by means of their afforestation conducted in the region of Khorezm (Khwarezm) within the framework of the ZEF/UNESCO interdisciplinary programme (2002-2009). Studies on the ecosystem services and profitability of agroforestry practices on marginal lands allowed for an assessment of the efficiency of this alternative land use technology, with an emphasis on its multipurpose benefits.

The aims of experimental studies included an assessment of the role of small forest plantations in the restoration of degraded soils of formerly arable fields, the improvement of soil productivity and ecosystem health and the development of alternative sources of income for rural populations. The studies included the following stages: (i) spatial-temporal assessment of the degradation of irrigated arable lands in the Khorezm Region, (ii) screening of local tree species and selection of most suitable species for growing on degraded lands with a shallow groundwater table, (iii) creation of small forestry areas on degraded areas of arable lands with sufficient water supply for trees and (iv) assessment of ecosystem services of forest vegetation.

The study sites were located on irrigated arable lands that were either marginally suitable or totally unsuitable for agriculture, mostly due to soil salinization. Many such lands were used only as low-productive pastures that were virtually unprofitable for land owners.

**Approach and methodology**. Prior to carrying out the experiments on the afforestation of marginal lands, a detailed research and inventory of local tree species and forest resources on by the use of MODIS satellite imagery and aerial photography was conducted within the framework of the ZEF/UNESCO Project 'Economic and Ecological Restructuring of Land- and Water Use in the Region Khorezm, Uzbekistan' [23].

In total, 15 tree species were assessed for their suitability for agroforestry. A high tolerance to salts was among the most important assessment criteria, because soil salinization is the main factor that limits biomass production. Priority was given to multi-purpose species of local origin that were well-adapted to the agro-climatic conditions of the Khorezm Region and generally familiar to local land owners.

The three most prospective tree species were selected for testing on low-productive soils with a shallow groundwater table over two growing seasons [18]. Preparation of the experimental site for tree planting included soil ploughing and leaching to remove salts. Tree saplings were planted with a spacing of 1.0x1.7 m, with alternating groups of species planted in 5-7 rows each. A plantation density of 5714 trees per hectare with a spacing of 1.75 m between the rows was sufficient to allow biomass harvesting (for firewood and leaf fodder) by the end of the first year of growth.

The suitability of studied species for use in agroforestry was assessed on the basis of their potential benefits for soil fertility and moisture content (via biodrainage, i.e., soil drying due to the transpiration capacity of plants), the needs of local people (food supply and quality, animal fodders and firewood) and carbon sequestration (CO2 storage in biomass and soil) within the Khorezm Region [18, 19, 21, 22].

## Research site and results

The Khorezm Region with a total area of 681.6 thousand hectares is located in the north-west of Uzbekistan, in the lower reaches of the Amu-Darya River. The landscape is a vast alluvial plain within the Amu Darya River delta gently sloping towards the Aral Sea (with a slope inclination of i = 0.00012-0.0002). The mean annual precipitation of only 100 mm predetermines an irrigation-dependent agriculture.

Khorezm is a large oasis region with a dense network of irrigation channels and collectors to supply water to the land. A very level ground surface presents difficulties in maintaining the water flow within irrigation and drainage systems, with a high risk of groundwater rising caused by impediments to water circulation.

A spatial-temporal land assessment has revealed that 36% of irrigated arable lands within the Khorezm Region tend to loose their productivity, with 14% of them being moderately and strongly degraded. Only 4% of the area is occupied by woodlands including just 0.4% of saxaul forests and scattered poplar and willow thickets.

Living windbreaks of planted trees and shrubs around agricultural fields represent 0.8% of the area of willow and poplar thickets [23].

From the aforementioned criteria for identifying suitable tree species for agroforestry use, three promising species have been selected: Russian olive (*Elaeagnus angustifolia*), Euphrates poplar (*Populus euphratica*) and Siberian elm (*Ulmus pumila*) (Table 5.5.1).

*Table 5.5.1. Tree species selected for the experiment [20]*

| Botanical names of trees | | Characteristics and harvesting criteria |
|---|---|---|
| English | Latin | |
| Russian olive | *Elaeagnus angustifolia* | Fast-growing, salt-resistant, N-fixing, Fruting, |
| Euphrates poplar (Turanga) | *Populus euphratica* | Fast-growing, dominant species of riparian forests, salt-resistant |
| Siberian elm | *Ulmus pumila* | Slow-growing, valuable wood for construction, frequent component of windbreak plantations, salt-resistant |

These tree species were successfully planted on highly saline soils at the experimental site (Yangibazar, Khorezm), where a soil salinity level of more than 20 dSm/m was recorded during the growing season and where saline groundwater with the salt concentration of 1-5 dSm/ m occurred at the depth of 0.9-2.0 m. Two years after irrigation was stopped, the trees were able to use the groundwater and produced yields of above-ground biomass of 10-60 t/ha (Fig. 5.5.1).


*Fig. 5.5.1. The experimental site for agroforestry, Khorezm, Uzbekistan [18]*

***Ecosystem services: biodrainage and salinization control.*** The ability of these tree species to efficiently uptake saline groundwater is the most important argument for the development of agroforestry on marginal lands. The research results presented below are for 5-year-old trees. The plantations were characterized by a total transpiration of 13 mm/day during the growing season. Russian olive (*E. angustifolia*) had the highest transpiration capacity of 1300 mm within the growing season in the absence of irrigation, which is comparable with the annual transpiration of Australian eucalyptus, which is one of the best known tree species used for biodrainage purposes.

The salt concentration within the root zone of trees increased from 4 dSm/m (after soil leaching before planting) to 12 dSm/m. Therefore, the long-term use of tree plantations will require soil leaching once in every ten years. The studied species showed a high productivity despite the increased salt concentration in soil due to their high tolerance to salts.

***Nitrogen reserves***. Over the period of 5 years the total nitrogen content at the experimental site within the 0-20 cm layer of soil increased by 6-30% depending on the tree species. An increase in the content of available nitrogen in soil was most significant under Russian olive (*E. angustifolia*) being a nitrogen-fixing plant. Despite the presence of excessive salt concentrations within the root zone, the efficiency of biological fixation of nitrogen increased from 40 to almost 100% over the period of 5 years since the trees were planted. A nitrogen fixation rate of 20 kg/ha was recorded in the first year, increased up to 0.5 t/ha two years later and then stabilized at 0.3 t/ha per year. Tree species that are capable of nitrogen fixation at rates of 0.1-0.3 t/ha/year are generally considered as very efficient and Russian olive can be included in this category. When the plantation was 4 years old, about 100 kg of nitrogen was released as a result of decomposition of nitrogen-rich leaf litter and incorporated into the soil [19].

***Carbon sequestration.*** The creation of forest plantations on marginal lands serves to both combat land degradation and aid carbon sequestration in soil. Research results obtained in Khorezm showed that soil organic carbon reserves grew on average by 20% over the period of 5 years following afforestation, with carbon sequestration rates of 2-7 t/ha within the upper 20 cm thick soil layer. The wood biomass of the studied species was characterized by carbon sequestration of 10-20 t/ha in the fifth year following afforestation, excluding some wood harvested for fuel. Russian olive demonstrated the most efficient carbon sequestration within wood biomass. If such sequestration rates could be certified within the framework of the Clean Development Mechanism (CDM) under an agricultural amelioration project, then respective subsidies could support the alternative use of degraded lands for agroforestry.

Benefits of growing trees: firewood. Firewood was harvested as a result of thinning the 5-year-old tree plantation to half its density down to 2300 trees/ha. Firewood of the studied tree species had a calorific value of 18-19 kJ/kg or the energy oil equivalent of 8-19 t/ha. Such an amount of energy can cover the annual needs of 55-90 people

Cotton plant stems that are widely used by the rural populations have 4 times lower energy value [15, 18, 22]. Artificial forest plantations on degraded lands as a firewood source can also help to reduce the illegal cutting of native willow and poplar thickets and saxaul forests.

Research into the restoration of ecosystem services and the economic value of degraded lands suggests that their use in agroforestry is ecologically beneficial and financially profitable. However, this innovation cannot yet be widely implemented because of a lack of administrative and legislative support. Financial obstacles could be overcome by the use of subsidies and loans. Potential annual profits from non-wood products of agroforestry can support rural households, but would need to be commercialized. The agricultural education service, which deals with the popularization of environmental sciences and management techniques, could provide help in encouraging farmers to plant recommended tree species.

The diversity and scale of positive outcomes from afforestation demonstrated within the framework of the ZEF/UNESCO Project can help to increase the awareness of financial and ecological advantages of agroforestry practices on degraded arable lands.

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# Chapter 6. Assessment of the cost effectiveness of combined measures for the amelioration of salt-affected soils

## 6.1. Methods for assessing the cost effectiveness of measures for the amelioration of salt-affected soils

**A.V. Kucher (Ukraine)**

In the economic sense, cost effectiveness (or economic efficiency) is understood to reflect the balance between the effect (income) and its cost (expenditure). An optimal balance can be achieved by maximizing the effect without increasing costs or through producing the same effect with reduced costs.

The cost effectiveness of the amelioration of salt-affected soils should be considered as a complex economic phenomenon that reflects the ratio between the results obtained in terms of income (gross output, value added, net output and profit) and the cost of the land as a commodity and/or production costs.

On the basis of the analysis of recent scientific publications, existing approaches to assessing the cost effectiveness of salt-affected soil amelioration can be subdivided into the four following groups: i) Resource Cost-Income Approach, where the economic effect is compared to the cost of the land resources, which are subjected to amelioration treatment; ii) Expenditure Approach, where the economic effect is compared to the expenditure on the implementation of ameliorative measures aimed at producing the effect; iii) Resource- Expenditure Approach, where both previous approaches are used in combination, i.e., assessments are performed for both the resources and the expenditure; iv) Targeted Approach, when the cost effectiveness is determined by the degree of attaining target parameters of salt-affected soils subjected to amelioration treatment. The use of a single approach usually does not exclude the possibility of the use of another and such combined use of these approaches is expected to continue in practice, with each combination specifically tailored for specific aims.

A cost effectiveness assessment as a substantiation of the economic purpose of salt-affected land amelioration should be based on the following principles [6]:

- The cost effectiveness of land amelioration projects is usually determined by the increase in net income, which is calculated as the difference between income with amelioration and income without amelioration. Therefore, there is a need for raw data on both incomes to perform the calculation;
- Soil amelioration is usually undertaken on long-term projects that include several stages with separate results;
- Soil amelioration projects are aimed, as a rule, to solve problems of maintaining and

improving soil fertility, therefore, project results should be taken into account in the cost effectiveness assessment;

- Amelioration projects are often targeted at the holistic management of water and soil resources, therefore, cost effectiveness assessments should also include financial, social and ecological aspects;
- Amelioration projects often can and should involve the combined application of different methods of land amelioration. Hence, greater cost effectiveness is provided by the best combination of such methods tailored to the specific site conditions;
- As a rule, amelioration projects have not only economical (increases in the land value and income from its rational use), but also socio-ecological results that should also be taken into account when assessing the cost effectiveness of such projects.

The analysis and assessment of the cost effectiveness of implementing measures for amelioration of salt-affected lands involves the use of the following parameters: i) crop yield increase; ii) the cost of the crop yield increase (net income from the measure); iii) increase in the labour efficiency and decrease in the production costs on ameliorated land; iv) increase in profit from amelioration of salt-affected lands; v) profitability of the investment into amelioration; vi) payback period of an investment into amelioration and vii) coefficient of the economic efficiency of an investment into amelioration of salt-affected lands.

Additional parameters may include the following: levels and dynamics of the price of land as a natural resource; the value of avoiding ecological damage; rational spending of funds; gross output, added value, net output and profit per 100 ha of agricultural land; land value; payback coefficients of all production costs (gross, net, etc.); profitability and income levels.

The assessment of the cost effectiveness of costly long-term amelioration projects also requires the use of parameters, which characterize changes in monetary value over time and allow for corrections to statistical outputs, and the adjusted present value (APV) approach that involves determinations of well known parameters such as net present value (NPV), discounted payback period (DPP), profitability index (PI), internal rate of return (IRR), modified internal rate of return (MIRR), etc. Calculations of these parameters are based on the APV theory and the assumption that the present value of one Ukrainian hryvnia is higher than its future value [5].

The aforementioned parameters should not be considered as a complete system, as they can be supplemented by other parameters and data according to the purpose and methodology of each specific amelioration project.

Parameters and criteria for assessing ecological benefits and cost effectiveness can be selected and/or calculated during the course of an amelioration project, with the following aspects taken into consideration [8]:

- The aim of the project. Clearly, the aim predetermines the methods, therefore, parameters and criteria of ecological benefits and cost effectiveness of an amelioration project should reflect the aim of the project and the interests of its participants;
- Project assessment timing. According to modern principles of project and investment analysis, the cost effectiveness assessment should be a step-by-step procedure, as projects are usually

designed in several stages. Appropriate assessment parameters and criteria should be selected for each stage;

- Project assessment scale. Land amelioration projects can be assessed at different levels: governmental, departmental, regional and local, which depends on the particular agricultural producers, investors or creditors. Cost effectiveness assessment methods can differ at different levels;
- Available data. The data availability, degree of detail, type of format, comparability and possible limitations are vital considerations for performing valid calculations.

## 6.2. Approaches and methods for assessing the ecological benefits and cost effectiveness of the amelioration of salt- affected soils

**I.P. Aidarov (Russia)**

The main principle of environmental protection law stipulates that no use of natural resources can be justified, if profits from it do not exceed the damage caused by it [2].

Assessments of ecological benefits and cost effectiveness of the amelioration of salt-affected soils and all other environmental management projects involve the use of net present value (NPV):

$$NPV = \sum_{1}^{T} (P - З - И)(1 + E_{н})^{-t} - K \quad (6.1)$$

where: $P$ – results obtained at a certain time t of the calculation period T, rub. З – expenses at the time t, including the current expenses, rub.; $И$ – damages to the environment including plants and animals, water and soils and local people, rub.; $E_H$ – adjusted present value coefficient that characterizes permissible risk of environmental damage in the future. $E_H$ = 2-3 %.

At the current time, the adjusted present value (APV) coefficient is often considered as profit rate (6-8%), which does not comply with environmental protection laws; T – assessed period, years; K – financial investments, rub./ha. The values of P, З and И are determined as difference between non-ameliorated and ameliorated land parameters. An obligatory requirement of investment project efficiency is that NPV > 0.

Ecological damage in its first approximation can be estimated from changes in the biodiversity level and the value of ecosystem services:

$$\mathbf{И}_{экол} = \mathbf{\Delta\delta Ц} \ (6.2) \quad (6.2)$$

where: Δδ – biodiversity change of non-ameliorated and ameliorated lands; Δδ = δ1 – δ2. Biodiversity levels of different agricultural lands are specified in Table 6.2.1.

### *Table 6.2.1. Relative levels of biodiversity of different agricultural lands, %*

| Forests, meadows, marshes | Forest belts | Orchards | Hay meadows and pastures | Cropland |
|---|---|---|---|---|
| 100 | 49 | 23 | 60 | 10 |

*Note: The biodiversity values are corrected with reference to the land productivity [2]*

Financial investments into land amelioration are predetermined by the possibilities for the use of advanced and ecologically safe technologies and equipment. The NPV value is suitable for various assessments, but does not give information on the ecological stability of agricultural landscapes.

An objective assessment of the ecological benefits and cost effectiveness of land amelioration measures should involve an additional parameter that characterizes the ecological stability of irrigated agricultural landscapes [2, 3]. The ecological stability can be evaluated by the use of the following equation:

$$K_c = \frac{\sum_1^n f_i K_1 K_2}{\omega} \qquad (6.3)$$

the coefficient of ecological stability of a natural floodplain ecosystem, unit fractions; fi – relative areas of biotic and abiotic elements of the ecosystem , %; K1 – coefficient characterizing the relative ecological significance of ecosystem elements, unit fractions; K2 – coefficient of ge o morphologi cal stabil ity of f loo d plain relief K2 = 0.7; ω – the total area of floodplain, ω = 100 %.

Relative ecological significance coefficients are presented in Table 6.2.2.

### *Table 6.2.2. Relative ecological significance coefficients*

| Biotic and abiotic components of a landscape | Bioclimatic zones | | | | | |
|---|---|---|---|---|---|---|
| | Northern taiga | Southern taiga | Forest steppe | Steppe | Dry steppe | Semidesert |
| Forests | 0,48 | 0,80 | 0,84 | 1,00 | - | - |
| Meadows | 0,40 | 0,60 | 0,80 | 0,95 | 0,70 | 0,20 |
| Hay meadows | 0,38 | 0,58 | 0,78 | 0,93 | 0,66 | 0,18 |
| Pastures | 0,39 | 0,59 | 0,79 | 0,94 | 0,67 | 0,19 |
| Cropland | 0,08 | 0,11 | 0,13 | 0,15 | 0,11 | 0,06 |
| Human settlements and industrial zones | -1,00 | -1,00 | -1,00 | -1,00 | -1,00 | -1,00 |

*Note: The values of coefficients are corrected according to biodiversity and productivity levels.*

The degree of natural ecosystem stability (Kc) is assessed using the following grades: ≤ 0.33 – unstable, 0.34-0.50 – weakly stable , 0.51-0.66 – moderately stable, > 0.66 – very stable.

## 6.3. Assessing the effectiveness of laser land levelling and agroforestry in Uzbekistan

(results of the projects by the CACILM and the GEF SGP in Uzbekistan)

**T. Khamzina, R. Ibragimov and U. Abdulaev (Uzbekistan)**

Every aspect of land use and management makes a contribution to the achievement of maximal yields and profits. According to conclusions from recent projects by the Asian Development Bank (ADB, 2005) and the Central Asian Countries Initiative for Land Management (CACILM, 2009), the most effective improvements of land management practices include levelling, deep ploughing, fertilizer application, crop diversification, agroforestry and efficient water use [4, 10].

This article focuses on some of the results and experiences obtained from the projects of the ADB, the United Nations Development Programme (UNDP) and the Global Environment Facility Small Grants Programme (GEF SGP) in Uzbekistan, which have demonstrated potential benefits of the wider implementation of innovative soil tillage techniques for increasing agricultural land productivity and supporting livelihoods of local people [1, 4, 7, 9] .

### Cost effectiveness of laser land levelling

A level ground surface is the most important factor of effective water and soil use under irrigation. An uneven field surface hinders soil tillage and causes waterlogging within hollows during irrigation followed by rapid soil salinization. It is believed that a patchy distribution of salt-affected and bare soils within fields results from imperfect levelling of the surface.

Laser-guided land levelling creates a surface with a level range of just ±3 cm, which provides for the even moistening of soil within fields and prevents the development of salinization patches. An analysis of the costs of laser land levelling in the experiment conducted at the 'A.Temur' Farm in the Urgench District of the Khorezm Region in 2010 demonstrated that this innovative technology was cost effective and profitable (Table 6.3.1).

### *Table 6.3.1. Cost effectiveness of laser land levelling (per 1 ha) [10].*

| | Wheat | | | | Cotton | | | |
|---|---|---|---|---|---|---|---|---|
| | Traditional technique | Laser levelling. | Difference | | Traditional technique | Laser levelling. | Difference | |
| | | | amount | % | | | amount | % |
| **Expenditures, thousands UZS (so'm)** | | | | | | | | |
| Machinery | 453,1 | 508,9 | 55,8 | 12,3 | 595,2 | 649,7 | 54,5 | 9,2 |
| Work force | 63,9 | 49,1 | -14,8 | -23,2 | 113,2 | 100,4 | -12,8 | -11,3 |
| Irrigation | 72,8 | 53,1 | -19,7 | -27,1 | 90,8 | 71,9 | -18,9 | -20,8 |
| Other | 500,5 | 520,2 | 19,7 | 3,9 | 572,1 | 621,1 | 49 | 8,6 |
| **Total:** | **1090,3** | **1131,3** | **41** | **37** | **1371,3** | **1443,1** | **71,8** | **5,2** |
| Water discharge, m³/ha | 5,725 | 4,011 | -1714 | -30 | 10000 | 8000 | -2000 | -20 |
| Yield, centner/ha | 40,0 | 44,0 | 4 | 10 | 25 | 27,5 | 2,5 | 10 |
| Income, thousands UZS | 1260 | 1,386 | 126 | 10 | 1508,5 | 1659,3 | 150,8 | 10 |
| **Profit, thousands UZS** | **169,7** | **254,7** | **85** | **50,1** | **137,2** | **216,2** | **79** | **57,6** |
| Rate of return, % | 15,5 | 22,5 | 7 | | 10 | 15 | 5 | |

In wheat and cotton fields, the laser land levelling required 9.2-12.3% more expenditure on equipment, but allowed for 11-23% cheaper labour, 20-30% less water for irrigation and 10% higher yields. In total, laser land levelling brought additional profits of 85 and 79 thousand UZS/ha under winter wheat and cotton, respectively. This was explained in part by yield increases and also by lowering the total cost of soil management [11].

Financial returns from laser levelling equipment. The laser levelling equipment purchased in Tashkent (from a local representative of Leica Geosystems) had a total cost of 11501 USD or 18634 UZS (according to the 2010 exchange rate) plus 0.2% customs fee. The return of investment with additional profits can depend on the sources of financial loans and individual farm sizes (Table 6.3.2).

### *Table 6.3.2. Financial returns from laser levelling equipment*

| Form of finance | Cost, UZS | Extra profit, thousands UZS/ha (per 1 year) | Required area, ha (per 1 year) | Extra profit thousands UZS/ha (per 3 years) | Required area, ha (per 3 years) |
|---|---|---|---|---|---|
| **Winter wheat** | | | | | |
| Net present value | 18633,9 | 85,0 | 219 | 490,3 | 38 |
| Loan (14%) | 26460,1 | 85,0 | 250 | 490,3 | 54 |
| Credit (16%) | 27578,2 | 85,0 | 254 | 490,3 | 56 |
| **Cotton** | | | | | |
| Net present value | 18633,9 | 79,0 | 236 | 472,3 | 39 |
| Loan (14%) | 26460,1 | 79,0 | 335 | 472,3 | 56 |
| Credit (16%) | 27578,2 | 79,0 | 349 | 472,3 | 58 |

The calculations have demonstrated that the financial investment of purchasing laser levelling equipment can be returned within 3 years, if farmers are able to use it on field areas of 38-56 ha under wheat or 39-58 ha under cotton, with the field size requirement dependent on the source of finance. The specified field areas generally match with average farm sizes in Uzbekistan.

## Cost effectiveness of agroforestry

Half of the irrigated soils in Uzbekistan are affected by varying degrees of salinization due to natural factors and inappropriate land management. About 80 thousand hectares of land are completely or partially abandoned. The completely abandoned lands undergo further salinization, waterlogging and fertility loss. The partially abandoned lands (with a fertility grade below 20) are still used for animal grazing, but no longer for arable crops due to their reduced cost effectiveness for farmers. However, such lands can return to profitability after they have been ameliorated as a result of agroforestry (agro-sylviculture) practices involving the creation of small plantations of multipurpose tree species that are tolerant to salinization, waterlogging and drought.

Experimental mixed plantations of Russian olive (*Elaeagnus angustifolia*), Euphrates poplar (*Populus euphratica*) and Siberian elm (*Ulmus pumila*) were created on highly saline soils within the regions of Khorezm and Karakalpakstan within the framework of the ZEF/UNESCO Project [9].

Calculations of the forestry business income and expenses for a period of 7 years were based on assessing the net present value (NPV) after subtracting the 14% discount and adding possible income from selling forest produce (e.g., firewood, leaf fodder and fruit) and potential carbon sequestration subsidies within the framework of the Clean Development Mechanism. For comparison, the NPV was also calculated using the data on wheat and cotton productivity on poor soils in the Khorezm Region (Table 6.3.3.).

The cultivation of the annual crops (winter wheat and cotton) on marginal lands resulted in financial losses of 52 to 231 Euro/ha even with sufficient irrigation. The NPV of different tree plantations on marginal lands ranged from 415 to 3934 Euro/ha. Carbon sequestration subsidies (97-271 Euro/ha) constituted 5-20% of the total profit from agroforestry. Such subsidies can help with the further practical implementation of agroforestry of degraded lands.

***Table 6.3.3. Net present value (NPV) of crops on marginal lands [11].***

| Parameters | Profits from crops on degraded lands | | | | |
|---|---|---|---|---|---|
| | Cotton | Winter wheat | Russian olive | Euphrates poplar | Siberian elm |
| Total NPV, Euro/ha | -231 | -52 | 3934 | 1185 | 415 |
| Payments for $CO_2$ sequestration Euro/ha | 0 | 0 | 198 | 271 | 97 |
| Irrigation norm (Netto), mm/year | 600 | 540 | 80 | 80 | 80 |

It was calculated that agroforestry as a land reclamation practice resulted in irrigation water savings of up to 35000-40000 $m^3$/ha within the 7 year period. However, these figures can be doubled with the inclusion of water used on soil leaching under annual crops. Therefore, the total cost of water savings in agroforestry can be estimated at around 500-600 Euro/ha.

Generally, agroforestry is preferable to annual crop cultivation on degraded lands because of its cost effectiveness and water saving benefits. The income and expenses of agroforestry on marginal lands are illustrated in detail in Figure 6.3.1.

The analysis shows that maximal investment is needed at the initial stage of the implementation of agroforestry practices, which includes tree planting costs and the development agreement cost within the framework of the Clean Development Mechanism (on average about 700 Euro/ha). Subsequent expenses are relatively smaller and include the costs of irrigation, weeding, pruning, thinning, fruit harvesting and tree cutting at the end of the 7-year-long rotation period. The income to expense ratio had the following values: 3.5, 1.8 and 1.4 for *E.angustifolia*, *P. euphratica* and *U. pumila*, respectively.

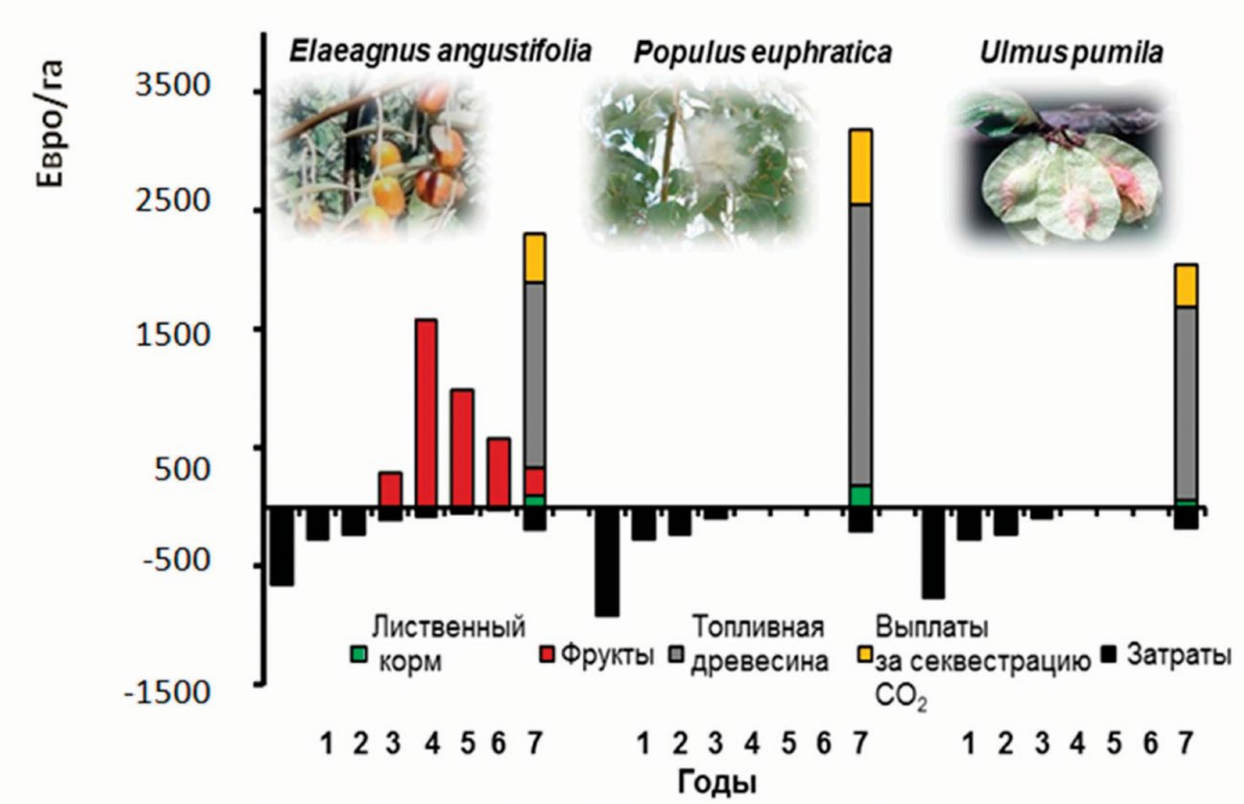


*Fig. 6.3.1. Income and expenses of agroforestry on marginal lands [1].*

Key: green = Leaf fodder, red = Fruit, grey = Firewood, yellow = Payments for CO2 sequestration, black = Expenditures; 1…7 = Years; vertical axis = Euro/ha

The maximal profit of 3500 Euro/ha came from Russian olive (*E. angustifolia*) due to the annual income from fruit selling. The fruit yields decreased over the 7-year-long period as plantations became too thick with growth and needed thinning. The firewood harvested from Euphrates poplar (*P. euphratica*) gave a profit of 2300 Euro/ha, which was also a significant contribution to the total profit of agroforestry. The profit of leaf fodder production was insignificant.

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# Part II.
# Tutorial examples, guidelines and exercises

## Annex A.
## Classifications, assessment criteria and distribution of salt-affected soils

### A1. Assessing the chemical properties of soil salinity

#### *Table A.1. Soil salinity chemistry: the balance of anions (cmol(eq.)/kg)*

<table>
<tr><td colspan="2">Saline soils with neutral salts (Total alkalinity < $Ca^{2+}+Mg^{2+}$, pH<8,5)</td><td colspan="4">Alkaline soils (Total alkalinity>$CA^{2+}+Mg^{2+}$, pH>8,5)</td></tr>
<tr><td colspan="2">Total alkalinity < 20% of the ∑ of anions</td><td colspan="2">Total alkalinity > 20% of the ∑ of anions</td><td colspan="2">Total alkalinity < 20% of the ∑ of anions</td></tr>
<tr><td colspan="6">The chemical types of salinity by the balance of anions (mmol eq/100 g of soil)</td></tr>
<tr><td>Chloride</td><td>$Cl^-/SO_4^{2-} > 2$</td><td>Soda</td><td>Total alkalinity > $Cl^-$ and > $SO_4^{2-}$</td><td rowspan="2">Chloride and sulphate-chloride with the participation of soda</td><td rowspan="2">Total alkalinity < $Cl^-$ and < $SO_4^{2-}$, $Cl^- > SO_4^{2-}$</td></tr>
<tr><td>Sulphate-chloride</td><td>$Cl^-/SO_4^{2-}$ =1-2</td><td>Chloride-soda</td><td>Total alkalinity > $Cl^-$, $SO_4^{2-}$ < 20% of the ∑ of anions</td></tr>
<tr><td>Sulphate-chloride</td><td>$Cl^-/SO_4^{2-}$ =0,5-1</td><td>Sulphate-soda</td><td>Total alkalinity > $SO_4^{2-}$ , $Cl^-$ < 20% of the ∑ of anions</td><td rowspan="2">Sulphate and chloride-sulphate with the participation of soda</td><td rowspan="2">Total alkalinity < $Cl^-$ and < $SO_4^{2-}$, $SO_4^{2-} > Cl^-$</td></tr>
<tr><td>Sulphate</td><td>$Cl^-/SO_4^{2-} < 0,5$</td><td>Soda- chloride</td><td>Total alkalinity < $Cl^-$, $SO_4^{2-}$ < 20% of the ∑ of anions</td></tr>
<tr><td>Sulphate (gypsum)</td><td>$Cl^-/SO_4^{2-} < 0,5$<br>$SO_4^{2-3}$ $Ca^{2+}$<br>$Ca^{2+}$>8-12</td><td>Soda- sulphate</td><td>Total alkalinity < $SO_4^{2-}$, $Cl^-$< 200% of the ∑ of anions</td><td></td><td></td></tr>
</table>

#### *Table A.2. Soil salinity chemistry: the balance of cations (cmol(eq.)/kg)*

| The chemical type of salinity | The balance of cations |
|---|---|
| Sodium | $Na^+>Ca^{2+}$, $Na^+>Mg^{2+}$, $Ca^{2+}<20\%S\kappa$*, $Mg^{++}<20\%\Sigma\kappa$ |
| Magnesium | $Mg^{2+}>Ca^{2+}$, $Mg^{2+}>Na^+$, $Na^+<20\%S\kappa$, $Ca^{2+}<20\%\Sigma\kappa$ |
| Calcium | $Ca^{2+}>Na^+$, $Ca^{2+}>Mg^{2+}$, $Na^+<20\%S\kappa$, $Mg^{2+}<20\%\Sigma\kappa$ |
| Magnesium-sodium | $Na^+>Mg^{2+}$, $Ca^{2+}<20\%\Sigma\kappa$ |
| Calcium-sodium | $Na^+>Ca^{2+}$, $Mg^{2+}<20\%\Sigma\kappa$ |
| Calcium-magnesium | $Mg^{2+}>Ca^{2+}$, $Na^+< 20\%\Sigma\kappa$ |
| Sodium-magnesium | $Mg^{2+}>Na^+$, $Ca^{2+}<20\%\Sigma\kappa$ |
| Sodium-calcium | $Ca^{2+}>Na^+$, $Mg^{2+}<20\%\Sigma\kappa$ |
| Magnesium-calcium | $Ca^{2+}>Mg^{2+}$, $Na^+< 20\%\Sigma\kappa$ |

*Note: Σк – the sum of cations, mmol(eq.)/100 g of soil*

### *Table A.3. Relationships between soil alkalinity and fertility [12]*

| Parameters | Values of parameters | | | |
|---|---|---|---|---|
| Exchangeable sodium, % of the cation exchange capacity | <5 | 10-15 | 25-30 | >50 |
| Total alkalinity (%), in water extract | 0,02 -0,04 | 0,05 -0,06 | 0,07-0,08 | 0,1- 0,2 |
| pH of soil paste and water suspension | 7,5-8,4 | 8,5-9,0 | 9,0-9,5 | 9,5-10 |
| Relative fertility, % | 100 | 75-60 | 30-20 | 0 |

### *Table A.4. The characteristics of saline and alkaline soils [20]*

| Parameter | Saline soils | Alkaline soils |
|---|---|---|
| pH | < 8,3 | >8,5 within the profile and (or) ESP*>15 in the B horizon |
| Chemical type of salinity | Dominant ions are $SO_4^{2-}$ and $Cl^-$ | Dominant ions are $HCO_3^-$ or $CO_3^{2-}$ or both |
| Influence of electrolytes on soil | Coagulation of colloids | Peptization, dispergation |
| Toxic impact on plants | High osmotic pressure of soil solution | Alkalinity of soil solution |
| Main purpose of amelioration | Removal of electrolyte excess by washing (leaching) | Lowering the high pH, neutralizing the alkalinity via chemical amelioration |

*Note:* **ESP*** *- exchangeable sodium percentage expressed as a % of the total cation exchange capacity (CEC).*

## A2. Diagnostics of solonetz and solonetzized soils

Solonetz (alkaline or sodic) and solonetzized soils (undergoing alkalization) are characterized by a profile with differentiated clay distribution, consisting of the Natric (eluvial) and Solonetzic (clay-illuvial) horizons with specific properties and saline C horizons [6, 10, 13].

### *Table A.5. Soil grouping by the degree of solonetzization (alkalization) - by sodium percentage (%) of the sum of exchangeable bases*

| Degree of solonetzization | According to the Classification …(1977) [11] | | Egorov and Minashina (1976) | According to Kovda, (1968) [12] | |
|---|---|---|---|---|---|
| | highly humic soils (chernozems) | soils poorer in humus (brown, chestnut, etc.) | | Chernozem zone | Zone of chestnut and brown soils |
| Non-solonetzized | <5 | <3 | <5 | - | - |
| Weakly solonetzized | 5-10 | 3-5 | 5-10 | <10 | <5 |
| Medium solonetzized | 10-15 | 5-10 | 10-25 | 10-15 | 5-10 |
| Strongly solonetzised | 15-20 | 10-15 | >25 | 15-30 | 10-15 |

### *Table A.6. An approximate composition of exchangeable bases in zonal (non-saline) soils*

| Soils | Exchangeable bases composition, % of their sum | | | The sum of exchangeable bases, mmol (eq.)/100 g of soil |
|---|---|---|---|---|
| | $Ca^{2+}$ | $Mg^{2+}$ | $Na^+$ | |
| Greyzem on loess-like loam | 60-80 | 10-35 | 4-10 | 7-11 |
| Chestnut soil on loam | 68-75 | 20,-30 | 3-5 | 20-22 |
| Chernozem on loam | 75-80 | 15-20 | 2-3 | 35-45 |

In Ukraine, the degree of solonetzization, including secondary solonetzization, is determined on the basis of the following criteria: the sum of exchangeable sodium and potassium expressed as the % of the cation exchange capacity and thermodynamic parameters (aNa / √aCa, pNa-0,5pCa) in the soil solution. Four grades of secondary soil solonetzization are distinguished: non- solonetzized, weakly solonetzized, medium solonetzised and strongly solonetzized (Table A.7).

### *Table A.7. Soil grouping by the degree of secondary solonetzization [7]*

| Degree of secondary solonetzization of soils | The buffer capacity of soils | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | weakly buffered | | | medium buffered | | | highly buffered | | |
| | Na+K, % | $\frac{aNa}{\sqrt{aCa}}$ | PNa-0,5pCa | Extractable Na+K, % | $\frac{aNa}{\sqrt{aCa}}$ | pNa-0,5pCa | Extractable Na+K, % | $\frac{aNa}{\sqrt{aCa}}$ | pNa-0,5pCa |
| **Clayey soils** | | | | | | | | | |
| Non-solonetzized | less than 1 | less than 0,5 | more than 1,65 | less than 3 | less than 1 | less than 1,35 | less than 5 | less than e 2 | more than 1,05 |
| Weakly solonetzized | 1-3 | 0,5-1,0 | 1,65-1,35 | 3-6 | 1-3 | 1,35-0,87 | 5-10 | 2-7 | 1,05-0,50 |
| Medium solonetzized | 3-6 | 1,0-3,0 | 1,35-0,87 | 6-10 | 3-7 | 0,87-0,50 | 10-15 | 7-10 | 0,50-0,35 |
| Strongly solonetzized | more than 6 | more than 3,0 | less than 0,87 | more than 10 | more than 7 | less than 0,50 | more than 15 | more than 10 | less than 0,35 |
| **Sandy soils** | | | | | | | | | |
| Non-solonetzized | less than 3 | less than 1 | more than 1,35 | less than 5 | less than 2 | more than 1,05 | less than 6 | less than 3 | more than 0,87 |
| Weakly solonetzized | 3-6 | 1-3 | 1,35-0,87 | 5-10 | 2-7 | 1,05-0,50 | 6-12 | 3-8 | 0,87-0,44 |
| Medium solonetzized | 6-10 | 3-7 | 0,87-0,50 | 10-15 | 7-10 | 0,50-0,35 | 12-16 | 8-12 | 0,44-0,27 |
| Strongly solonetzized | more than 10 | more than 7 | less than 0,50 | more than 15 | more than 10 | less than 0,35 | more than 16 | more than 12 | less than 0,27 |

*Note: 1. The soils are grouped according to the Classification of soils by the degree of secondary solonetzization (DSTU 3866-99). 2. The Clayey soils include clay loams and sandy loams, the Sandy soils include loamy sands and loams*

## A3. Criteria for estimating gypsum content in soils

Gypsum-containing soils have been well studied, with many publications available on the diagnostics, genesis and amelioration of gypsum-containing soils. Judging from the properties of the diagnostic gypsum horizon, N.G. Minashina and L.L. Shishov (2002) suggested the following types of this horizon can be distinguished: crust, gazha, granular, segregation, arzyk and columnar [8].

On the basis of the Classification and Diagnostics of Soils of the USSR (1977), it is suggested to differentiate soils by the presence of gypsum-rich horizons (with more than 10% $CaSO_4*2H_2O$ in the bulk composition) occurring at a depth of more than 20 cm from the surface. The soils are differentiated by the depth of the upper boundary of the gypsum-rich horizon, the thickness of this horizon and the structure of gypsum pedofeatures [11]. The parameters and criteria of gypsum-rich soil horizons according to [16] are given in Table A.8.

### *Table A.8. Parameters and criteria of gypsum-rich soil horizons [16]*

| № | Parameters | Criteria |
|---|---|---|
| 1 | The depth of the upper boundary of gypsum-rich horizon, cm | Gypsum accumulation at/near the surface (the upper boundary within 0-20 cm)<br>Gypsum accumulation in the upper part of soil profile (20-50 cm)<br>Gypsum accumulation in the middle of soil profile (50-100 cm)<br>Gypsum accumulation in the lower part of soil profile (100-200 cm)<br>Gypsum-containing bedrock (deeper than 200 cm) |
| 2 | The content of gypsum ($CaSO_4x2H_2O$),% | Low (2-10%)<br>Medium (10-20%)<br>High (20-40%)<br>Very high (more than 40%) |
| 3 | The thickness of gypsum-rich horizon, cm | Thin <30<br>Medium 30-100<br>Thick >100 |
| 4 | Prevailing sizes of gypsum pedofeatures, mm | Flour- or powder-sized (very fine crystalline) <0,1<br>Fine crystalline 0,1-1,0<br>Medium crystalline 1-5<br>Coarse crystalline >5 |
| 5 | The morphology of gypsum pedofeatures | Flour-like or powdery gypsum (forming a continuous gypsum-rich horizon that also contains calcium carbonate and soluble salts)<br>Small gypsum concretions (so-called 'millet-like' or 'rice-like' concretions crushed between fingers and thumb)<br>Accumulations of fine-crystalline gypsum ('worm-like' features along pores and root channels that cause a significant increase in the soil horizon density)<br>'Pseudosand' of sand-like medium-sized gypsum crystals<br>Columnar (spongy) fine-crystalline gypsum<br>Gypsum roses and plates of transparent yellowish glass-like gypsum |

## A4. Criteria for estimating the content of carbonates in soils

Description of a saline soil necessarily requires an estimation of the content of carbonates, particularly, the upper boundary of effervescence with 10% HCl , the properties of the horizon of maximal carbonate accumulation, etc. Judging from the upper boundary of effervescence, soils can be subdivided into the following grades: calcareous at the top (with the upper boundary of effervescence at 0-20 cm), calcareous in the upper part of profile (20-40 cm), calcareous in the middle part of profile (40-100 cm) and calcareous in the lower part of profile (100-200 cm). An estimation of the content of carbonates in soils according to the Classification and Diagnostics of Soils of the USSR ( 1977) is based on the presence of highly calcareous (more than 30% $CaCO_3$) horizons within the soil profile and bedrock [11]. Soil grouping by the content of $CaCO_3$ within a calcareous layer as well as by the depth, thickness and consistency of highly calcareous ( more than 30% $CaCO_3$) layers is presented in the Tables A.9 - A.10.

### *Table A.9. Soil grouping according to the content of carbonates*

| Soil grouping by the content of carbonates | The content of carbonates of earth metals, % |
|---|---|
| Weakly calcareous | $\leq 2$ |
| Calcareous | 2-15 |
| Medium calcareous | 15-25 |
| Strongly calcareous | 25-50 |
| Very strongly calcareous | >50 |

*Table A.10. Soil grouping according to the presence of highly calcareous layers (more than 30% $CaCO_3$) within the soil profile and bedrock [11].*

| № | Parameters | Criteria | |
|---|---|---|---|
| 1 | The upper boundary of a highly calcareous layer, cm | -at the top<br>-within the upper part of profile<br>-within the middle part of profile<br>-within the lower part of profile<br>-at the bottom | <30<br>30-60<br>60-100<br>100-200<br>>200 |
| 2 | The thickness of a highly calcareous layer, cm | -thin <40<br>-medium 40-100<br>-thick >100 | |
| 3 | The consistency of a highly calcareous layer | -loose<br>-sporadically compacted<br>-continuiously compacted | |

## A5. Distribution of salt-affected soils in some countries of the Eurasian Region (a b rief overview).

**Azerbaijan (A.G. Aliev and S.A. Safarli)**. There is a wide diversity of environmental conditions and soil-forming factors within the Republic of Azerbaijan, which includes nine out of eleven climatic zones known in the world. The environments vary from plains that are lower than sea level to high mountains of the Greater and Lesser Caucasus.

The salt-affected lands of Azerbaijan have a total area of about 600 thousand hectares. The processes of soil salinization create serious problems and hinder the development of agriculture. Soil salinization is most severely manifested within the Kura-Aras Lowland. Although some parts of this territory have been artificially drained, the removal of salts from soils by leaching and the restoration of soil health require greater amounts of fresh water.

About 633.8 thousand ha (43.8%) of irrigated lands are currently affected by salinization. Soil salinization processes have negative impacts on agricultural crop productivity on arable lands. The crop yields have decreased on average by 23%, 47% and 85% on weakly, moderately and strongly saline soils, respectively.

As a result of the wide-scale implementation of amelioration measures, many parts of the Kura-Aras Lowland have been drained. The ameliorated land with a total area of 593 thousand hectares includes 310.4 thousand ha of open horizontal drainage systems, more than 264.4 thousand ha of closed drainage systems and 13.2 thousand ha of vertical drainage systems. The collector-drainage networks of closed, open and other types have total lengths of 10, 9.7 and and 11.6 thousand km, respectively [1-5].

**Georgia (E. Sanadze).** Salt-affected soils in Georgia occupy an area of 112600 ha, which represents 1.6% of the total area of the country. Such soils are found on plains, mostly within the Alazani Valley and Eldari Lowland and to a lesser extent within the Kvemo Kartli Province (Gardabani, Marneuli, Samgori and Krtsanisi and very few in Shua Kharaba).

Salt-affected foils of Georgia are found within the dry subtropical climatic zone with hot summers and snow-free winters, mean annual temperatures of 12.1-12.5°C, sum of active temperatures of 4000-4500 °C, a growing season of 7 months and a mean annual precipitation of 380-600 mm with the largest peak in winter followed by peaks in May and June and precipitation to evaporation ratio within a range of 0.33-0.50.

Salt-affected soils occur mostly within intermontane basins, alluvial plains and dry lake beds at different altitudes. Their parent materials are salt-containing alluvial and proluvial-diluvial sediments including clays. The natural vegetation is represented by steppe communities.

Salt-affected soils of Georgia can be subdivided into two large groups: Solonchak and Solonetz, which have very different properties, although connected in terms of their genesis. Their salt composition is dominated by sodium sulphate (mirabilite or Glauber's salt) and chlorides. They have a high pH and poor air circulation and infiltration capacities due to their clayey composition, poor structure and a high content of montmorillonite. Soils affected by different degrees of salinity/alkalinity require different ameliorative treatments that may include hydrotechnical (e.g., drainage), agricultural (e.g., salt-resistant crop cultivation) and agrotechnical (e.g., tillage) measures.

**Moldova (V.F. Filipchuk and Yu.G. Rozloga).** The main areas of distribution of salt-affected soils in Moldova are found within floodplains of internal and trans-boundary rivers of the Republic. Agricultural lands now occupy an area of 180 thousand hectares out of the total of 250 thousand hectares of floodplains. As a result of flood prevention via the control of river flow by dams, floodplain ecosystems are turning into steppe, which is accompanied initially by the development of evaporation-induced halogenesis (salinization) processes in soils and ground waters followed by solonetzization (alkalization) processes.

The rates of soil degradation (salinization and alkalinization) within floodplains are predetermined primarily by hydrogeological processes (migration and accumulation of salts) within the soil-groundwater system [17]. Therefore, the main characteristics of salt-affected soils include the following: infiltration capacity (degree of natural drainage), upward and downward fluxes of saline solutions between the soil (zone of hypergenesis) and underlying sediments, the prevalent type of salt accumulations and the content and composition of salts (degrees of salinization and alkalinization) in soils. On the basis of these characteristics, the salt-affected soils of Moldova are differentiated into ameliorative provinces, regions and groups.

The soil-ameliorative regionalization, which is used as the basis for planning the amelioration of salt-affected soils in Moldova, is shown on the map below (Fig. A.1.). An analysis of large- scale ameliorative maps and hydrogeological data on salt accumulation in soils has shown that about a half of arable alluvial soils within the Republic are now found in an unsatisfactory condition due to salinization, alkalinization, waterlogging and loss of structure (slitization).

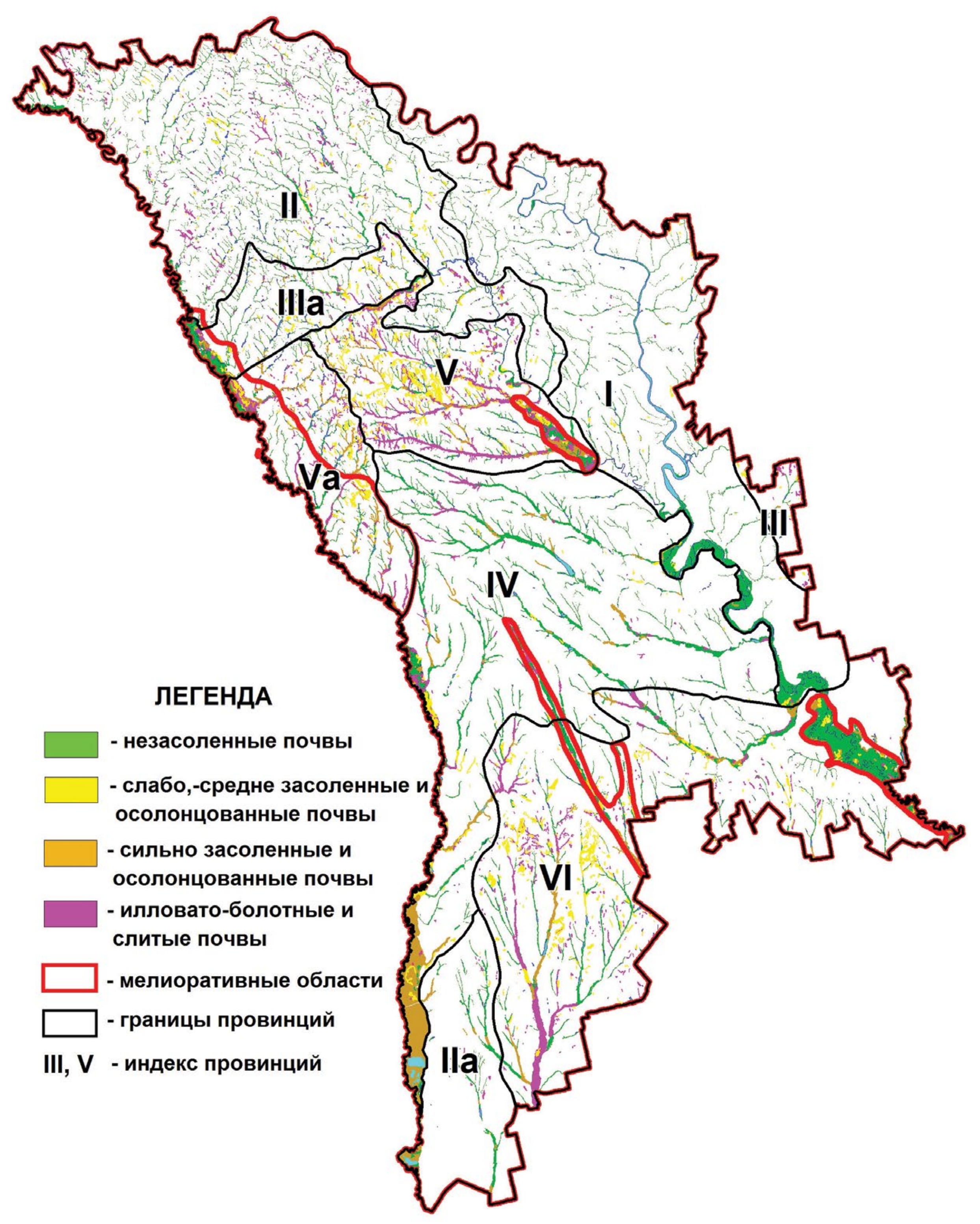


***Fig. A.1. The soil-ameliorative regionalization of floodplain soils in the Republic of Moldova.***

*Ameliorative provinces characterized by the following: I – free migration of salts; II, IIa – migration of soluble salts; III, IIIa, IV – migration and local accumulation of salts at geological barriers; V, Va – active accumulation of salts; VI – hindered migration of salts.*

*Key to the legend: green = Non-saline soils, yellow = Weakly and medium saline and alkaline soils, orange =Strongly saline and alkaline soils, purple = Marsh and vertic soils, red line = Ameliorated areas, black line = Province boundaries, Roman numerals - Province indices.*

**Russia (E.I. Pankova)**. Salt-affected soils are found in 42 out of 89 constituent entities of the Russian Federation. According to the state land registry (cadaster), saline and saline- alkaline soils occupy total areas of 16.3 and over 23 million hectares, i.e., 9% and 12.5% of agricultural lands in Russia, respectively. Therefore, altogether salt-affected soils constitute about 21% of agricultural lands in Russia [8].

Salt-affected soils are particularly widespread in the south of Russia – in semidesert, dry steppe, steppe and forest-steppe zones. In some regions salt-affected soils occupy up to 30% of the arable land area, e.g., in the Astrakhan Region, Republic of Kalmykia, Republic of Dagestan, Novosibirsk Region, etc. Hence, the use and management of salt-affected soils are serious challenges within the southern parts of Russia.

In the south of the European part of Russia, salt-affected soils are represented mostly by Solonetz and associated varieties with chloride and sulphate types of salinity and often with a high alkalinity in the solonetzic B and saline C horizons. The south of West Siberia is characterized by the prevalence of sodic soils and south-eastern Siberia has local areas of saline soils, usually, within depressions and river valleys. Salt-affected soils are particularly typical in irrigated areas, which have a high risk of secondary salinization. In consequence, the use and management of salt-affected soils are highly significant challenges in the south of the European and West Siberian parts of Russia.

**The Region of Central Asia (the Aral Sea Region formerly called Middle Asia)** includes five countries – Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. Salt-affected soils are primary features of dry landscapes of this region, which create high risks and threats to agricultural industry, ecosystem health and biodiversity. Currently, the Aral Sea Region is considered to be an area in ecological crisis, particularly, due to secondary salinization, degradation and desertification of the lands.

An analysis of environmental conditions within the Aral Sea Region has concluded that the wide-scale salinization within this region has been caused by the arid climate coupled with certain topographic and hydrogeological conditions. The Turan Valley is a closed depression surrounded by mountains, where saline waters flow down from the slopes and deposit salts within the depression following water evaporation under the arid conditions. The arid climate favours both active accumulation and preservation of salt deposits. Relic (ancient) salt deposits prevail within this region and cover large areas, particularly, in the middle and lower reaches of the rivers within the Aral Sea basin [16].

Highly saline soils occupy relatively small areas of the upper reaches of the rivers in Tajikistan and Kyrgyzstan, while much stronger and more extensive salinization causes many problems in the lower reaches of the same rivers in Kazakhstan, Turkmenistan and Uzbekistan [9, 14, 19].

**Ukraine (S.A. Balyuk and E.N. Drozd).** According to the State Land Registry (Cadaster) of Ukraine, land resources of the country have a total area of 60.3 million ha, of which 41.6 million ha (69% of the total area of Ukraine) are under agricultural use, of which 32.5 million ha (53.9%) are arable lands. Ukraine has a great agricultural potential due to the existence of large areas of naturally fertile Chernozem-type soils (about 27 million ha or 65% of the total area of agricultural lands). However, 75% of the total area of Ukraine is characterized by totally or partially unfavourable moisture conditions, which hinders the efficiency of the agricultural industry.

Salt-affected soils of Ukraine are found in sub-boreal, forest-steppe and steppe zones. These soils can be conventionally subdivided into two kinds, one with natural (primary) salinity and the other with secondary salinity. According to the Ukrainian soil classification, salt-affected soils belong to the following taxa: Saline and Alkaline Chernozems (mostly on loesses), Meadow Chernozems, Meadow Chestnut soils, Meadow soils, Alluvial soils, Dark and Alkaline Chestnut soils, Solonchakous Solonetz (saline-sodic soils) and Solonchaks.

Data on the total areas of the above-listed salt-affected soils can be found in the State Land Registry. Solonetz (alkaline) soils are included within the area of salt-affected soils in the Land Registry, but require separate consideration in land management and amelioration planning. Most salt-affected soils in Ukraine are ploughed, with the exception of highly saline varieties and Solonchaks [15, 18].

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| | |
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# Annex B.
# Assessing water suitability for irrigation

**S.A. Balyuk, M.I. Romashchenko, A.A. Nosonenko and M.A. Zakharova (Ukraine)**

Systems for assessing the quality of irrigation water were initially based on determining water salinity levels for evaluating the risks of secondary salinization of soils. Later, several attempts have been made at classifying the irrigation water quality in terms of risks of secondary alkalinization of soils. In particular, in the USA [1], the sodium adsorption ratio (SAR, calculated as the amount of sodium divided by the square root of half the sum of the amounts of calcium and magnesium) has been introduced as an irrigation water quality parameter. In more recent systems of irrigation water quality assessment developed by scientists from different countries [1-3, 8-10] various combinations of parameters have been used depending on the regional specifics of soil properties, pollution by heavy metals, pesticides, silt, bacteria, etc.

A team from the Laboratory of Fertility of Irrigated and Solonetzized soils of the Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky (Kharkiv) directed by Prof. S.A. Balyuk developed a methodology for the experimental assessment of soil and water quality on the basis of their own long-term research data and existing publications by Ukrainian and international colleagues. This methodology involved the use of parameters for the assessment of the risks of soil salinization and solonetzization/alkalinization and salt toxicity to plants under the impact of high salt concentrations in irrigation water in connection with the soil buffering capacity and thermodynamic parameters.

The methodology for the experimental assessment of soil and water quality was based on the analysis of the composition of salt ions in soils and water. Three classes of irrigation water quality (i.e., suitable, provisionally suitable and unsuitable) were assigned to different soils depending on the soil buffering capacity and calculated values of total salt concentration in water. This system for irrigation water assessment has become mandatory for use in Ukraine, since it serves as a basis for development and ratification of the State Standard of Ukraine (DSTU 2730-94) "The irrigation quality of natural water: agronomics criteria"[5]. This State Standard has been amended as a result of its practical application and use by the State Water Agency and hydrology-amelioration expedition of Ukraine for a period of 20 years [6].

This State Standard regulates the irrigation water quality on the basis of chemical criteria and parameters of the salt composition of soil and irrigation water, which predetermine the risk of irrigation salinity, solonetzization/alkalinization of soil and salt toxicity to agricultural crops.

The irrigation water quality in regard to alkalinization hazard should be assessed using the parameters of pH, toxic alkalinity and carbonate hardness. Water quality class should be determined from the two most extreme values of these three parameters.

Irrigation water quality in relation to the risks of soil solonetzization should be assessed by the ratio (percentage) of the sum of alkali cations (sodium and potassium, meq/dm3) divided by the sum of all cations (meq/$dm^3$), together with soil type, buffering capacity and particle-size composition, the balance of magnesium and calcium cations in irrigation water and the water quality class in relation to the risk of alkalinization [56].

The system for water quality assessment in regard to the risk of salt toxicity to agricultural crops is presented in Table 1. Toxic effects of natural water can be caused by high alkalinity or acidity that can affect plants, especially, at early stages of their development as well as ions of $Cl^-$, $NO_2^-$, $NO_3^-$, $NH_4^+$ and $CO_3^{2-}$ and hydrogen sulphide.

### *Table B.1. Irrigation water quality classes to evaluate the risk of its toxic impact on plants in sprinkler irrigation systems*

| Water quality parameters | | | Toxic ions, in equivalents of Cl | Water quality classes |
|---|---|---|---|---|
| pH | $CO_3^{2-}$ meg/$dm^3$ | $Cl^-$, meq/$dm^3$ | | |
| from 6,5 to 7,5 | 0 | more than 3,0 | less than 15 | I |
| from 5,5 to 6,4<br>from 7,6 to 8,8 | from 0,1 to 0,6 | from 3,0 to 15,0 | from 15 to 40 | II |
| more than 8,8<br>more than 5,5 | more than 0,6 | more than 15 | more than 40 | III |

There is also a system for irrigation water quality assessment related to solonetzization risks, which is based on the thermodynamic parameters of water and the buffering capacity of soils. If water quality classes, which are determined from concentrations of alkali metal cations and thermodynamic parameters, do not coincide, then preference is given to the class determined form alkali metal cations as a final estimate, because this takes into account more soil properties including particle-size composition. The phytotoxicity of irrigation waters that are not polluted by toxic compounds can be assessed on the basis of soil pH, carbonate hardness and the content of chloride ions.

The other State Standard [7] (developed in cooperation with colleagues from the Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences) regulates the ecological safety of all types of irrigation water used in agricultural practices (apart from rice cultivation) in Ukraine. Regulations set in this Standard are applied to all surface and subterranean natural waters.

Ecological safety criteria are applied to the assessment of the quality of natural waters used in irrigation according to sanitation and hygiene as well as environmental pollution regulations. The results of such assessment serve as a basis for the determination and control of permissible levels of man- made impacts resulting from irrigation.

Surface and subterranean waters used in irrigation are assessed with the use of parameters that characterize the following: (i) chemical composition, (ii) environmental safety and phytotoxicity, (iii) sanitary-toxicological properties of chemical elements and compounds and their abilities to migrate in water solutions, (iv) bacteriological pollution and (v) concentrations of radioactive substances (controlled by separate regulations).

There are three classes of natural water quality for irrigation purposes: Class I – suitable, Class II – provisionally suitable and Class III – unsuitable. Class II water can be used along with ecological impact assessment and the mandatory application of agro-ameliorative measures. Class III water requires amelioration up to a higher class before it can be used on the land. If the water can be attributed to different quality classes on the basis of different parameters, then its final grade is determined by the least favourable parameter value.

The quality control of irrigation water in terms of ecological safety [7, 8] is based on two groups of parameters:

a) First group – water properties and element concentrations that are essential for soil health. These parameters are regulated in respect to their influence on the environment;

b) Second group – water properties and element concentrations that have adverse affects on the state and functioning of agricultural ecosystems and the environment. These parameters are regulated on the basis of irrigation water quality class.

The first group includes ecological and ecologo-hygienic parameters such as:

- the content of nitrogen;
- the content of micro-nutrients (manganese, iron, copper, boron, cobalt, zinc and molybdenum) and fluorine;
- the biochemical oxygen demand (BOD5).

The second group includes the following parameters:

a) ecotoxicological: (1) concentrations of heavy metals (lead, mercury, cadmium, selenium, arsenic, total chromium, bismuth, nickel and vanadium) and (2) concentrations of pesticides, phenols, cyanides, detergents, oil and oil products;

b) sanitary-bacteriological: the presence of (1) Escherichia coli (coli index), (2) Escherichia coli phages (coli-phage index), (3) pathogenic microflora and (4) viable helminth eggs;

c) radioactive substances.

The classes of natural water quality assessed by concentrations of microelements and heavy metals are presented in Table B.2.

## *Table B.2. The quality assessment of natural waters based on the content of micro-elements and heavy metals, mg/l*

| Chemical elements | Water quality classes | | | |
|---|---|---|---|---|
| | Class I | Class II | | Class III |
| Aluminum | less than 2,0 | from 2,0 | up to 5,0 | more than 5,0 |
| Litium | less than 1,0 | from 1,0 | up to 2,5 | more than 2,5 |
| Iron*) | less than2,0 | from 2,0 | up to 5,0 | more than 5,0 |
| Zincum*) | less than 0,5 | from 0,5 | up to 1,0 | more than 1,0 |
| Manganese*) | less than0,5 | from 0,5 | up to 1,0 | more than 1,0 |
| Chromium ($Cr^{3+}$)*) | less than 0,2 | from 0,2 | up to 0,5 | more than 0,5 |
| Molibdenum | less than 0,005 | from 0,005 | up to 0,01 | more than 0,01 |
| Vanadium | less than 0,05 | from 0,05 | up to 0,1 | more than 0,1 |
| Tungsten | less than 0,03 | from 0,03 | up to 0,05 | more than 0,05 |
| Bismuth | less than 0,05 | from 0,05 | up to 0,1 | more than 0,1 |
| Fluorine | less than 0,8 | from 0,8 | up to 1,5 | more than 1,5 |
| Boron*) | less than 0,2 | from 0,2 | up to 0,5 | more than 0,5 |
| Selenium | less than 0,01 | from 0,01 | up to 0,02 | more than 0,02 |
| Nickel*) | less than 0,08 | from 0,08 | up to 0,2 | more than 0,2 |
| Copper*) | less than 0,08 | from 0,08 | up to 0,2 | more than 0,2 |
| Chromium ($Cr^{6+}$)*) | less than 0,05 | from 0,05 | up to 0,1 | more than 0,1 |
| Cobalt*) | less than 0,02 | from 0,02 | up to 0,05 | more than 0,05 |
| Lead*) | less than 0,02 | from 0,02 | up to 0,05 | more than 0,05 |
| Cadmium*) | less than 0,005 | from 0,005 | up to 0,01 | more than 0,01 |
| Mercury*) | less than 0,002 | from 0,002 | up to 0,005 | more than 0,005 |
| Beryllium | less than 0,05 | from 0,05 | up to 0,1 | more than 0,1 |
| Arsenic | less than 0,02 | from 0,02 | up to 0,05 | more than 0,05 |

**) The priority group of elements according to [3]*

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# Annex C.
# Assessment methods, criteria and indicators for monitoring saline and alkaline soils

## C.1. Methodological aspects of aerial photography using an unmanned aerial vehicle (UAV)

**S.A. Balyuk, V.B. Solovei, M.A. Solokha and S.P. Truskavetskiy (Ukraine)**

### Aerial photography using an unmanned aerial vehicle (UAV).

An UAV with a video camera that operates within the visible spectrum can be used for a detailed and quick investigation of soil cover.

The preliminary interpretation of images of alkaline and saline soils involves the following:

- Soil areas are delineated judging primarily from colour differences in the image. The sizes and shapes of soil areas can be reliably determined from the image analysis, as has been shown by field verifications (ground truth) over 5 years of studies.
- Alkaline and saline soil areas are visible within images due to either the stressed appearance of vegetation (including all leguminous, cereal and fodder crops), i.e., a lighter colour in comparison with the surrounding vegetation, or by the absence of vegetation (Fig. C.1). It is possible to identify local depressions within fields under cereal crops due to a darker green colour of vegetation (in April-May).

*Fig. C1.1. An irrigated field under crops. A patch of Solonetz is bare (on the left). The lower ground is vegetated (on the right, with more saturated green colour in the centre of the field).*

The colour of the soil surface depends on the humus content, which can be indirectly assessed from higher moisture levels (within depressions) and corresponding changes in the colour of cereal crops within a period from the mid-May to mid-July.

**The creation of soil maps on the basis of satellite imagery.**

The high mobility of soluble salts in saline and alkaline soils predetermines the image interpretation criteria. The analysis of multi-temporal multi-spectral satellite images that illustrate the seasonal dynamics of land surfaces is very reliable. For example, dry steppe Solonchak and Solonetz in well-moistened condition (in spring and late autumn) have very low brightness and appear as dark-grey or even black areas within images, but the same soils in a desiccated state (in summer) acquire salt crust on their surface and appear as almost white within images.

It is generally known that the brightness of vegetation colour within images of salt-affected soils as compared to that of non-saline and non-alkaline soils is decreased within the green and near-infrared ranges (0.53-0.61 and 0.76-0.90 μm, respectively), but increased within the red range (0.62-0.68 μm) [3, 4].

Image synthesis with the infrared channel can show normally developed vegetation in purple and vegetation suppressed by salts – in pink, yellow and greenish tones depending on the degree of suppression [4]. The use of near infrared region of the electromagnetic spectrum (0.8-2.5 μm) allows the identification of suppressed plant growth even at the early stages of soil salinization, when visible signs of suppression are still absent. For example, the optical density of mesophilic grasses within the near-infrared range begins to decrease at soil salinity levels above 0.2-0.4% [3].

In particular, satellite imagery allows for the reliable identification of soils with different moisture and salt concentrations, depending on the state and character of vegetation within lowlands in the middle reaches of the Dnieper River in Ukraine, where saline groundwater appears at a shallow depth and soils of Solonetz type are widespread. Subsequently, soil genesis can be verified by ground surveys.

## C.2. Methods for assessing the trends of modern salt accumulation processes in soils using salt concentration measurements

**S.A. Balyuk (Ukraine) and I.P. Aidarov (Russia)**

Salt accumulation trends under conditions of unstable water regime and other natural factors can be assessed from a large volume of data on simultaneously determined salt concentrations in soils. The assessment procedure includes the statistical analysis of data and identifying the distribution patterns of random values of toxic salt (or ion) concentrations within the soil layer 2 m thick, which excludes the influence of seasonal fluctuations in salt concentrations [6].

Practical calculations can be performed using a simple method for processing large data sets, which is widely used in hydrology and amelioration. This method is based on the comparison of the arithmetic mean of salt concentrations within the assessment layer $x_0$) with salt concentrations corresponding to 50% of salt reserves (x). The difference $\pm(x - x_0)$ can indicate the direction and rate of the salt accumulation process. The value of $(x_0)$ is calculated as follows:

$$x_0 = \frac{\sum_c}{N} \ .$$

To calculate value of (x), the data on salt concentrations within the assessment layer are arranged in descending order and then the test point number (k) is determined, where salt concentrations correspond to 50% of salt reserves. $K = p/100(N + 0.3) + 0.4$; where: $p = 50\%$; N – size of data set (number of test points). The K value is rounded. In cases, when $(x - x_0) = 0$, this corresponds to a normal distribution of random values of salt concentrations and indicates a stable salt regime. Such cases rarely occur in nature. In cases, when $(x - x_0)$ is above or below zero, this corresponds to asymmetric lognormal distribution and indicates unstable soil regimes. Where $(x - x_0) > 0$, then a current salinization trend is identified. If $(x - x_0) < 0$, then there is a desalinization of soils.

### An example of statistical analysis

An experimental site that has an area of 500 ha is located at Farm No. 5 near a large artificial channel in the Golodnaya Steppe (Uzbekistan). The assessment soil layer – 2 m thick, the number of test points – 60, the groundwater table ≥3-5 m and salinity level 5-15 g/l. Calculations are based on chloride ion concentrations, according to [2]. The results are presented in Table C.1.

*Table C.1. Statistical data*

| X, % | $X_0$, % | Salt accumulation trend |
|---|---|---|
| 0,032 | 0,023 | Progressive salinization of soils |

## C.3. Organizational issues and criteria for irrigated soil quality assessments in Ukraine

**S.A. Balyuk (Urkaine)**

The organization of agro-ameliorative soil surveys and monitoring (selection of key sites) should be based on the following information:

d) monitoring irrigated soils at a local scale (within one or several farms) requires the analysis of existing soil-ameliorative maps of suitable scales, cartograms of nutrient contents, land use plans, field history books, data from previous surveys including soil salinity tests and other information on land use and crop rotations (statistical outputs and personal observations of farmers on crop yields);

e) regional-scale monitoring also requires water and soil quality data from previous ecological surveys and short-term and long-term monitoring projects.

Thereafter, typical soil taxa and key sites should be delineated on a map with respect to irrigation network, crop fields and soil pollution sources (air- and waterborne).

The number of key sites should be planned with consideration of the number of currently or formerly irrigated typical soil taxa and adjacent drylands. The dryland key sites should be comparable to irrigated ones in terms of initial soil and water conditions as well as current land use. The key sites should be marked in the field and recorded with geographical coordinates. The costs of field, laboratory and desk research should be estimated and recorded. Ecological and ameliorative assessments and monitoring should be performed in compliance with the following criteria and parameters (Table C.2).

### *Table C.2. Criteria and parameters for the assessment of the ecological-agricultural state of irrigated lands in Ukraine [5]*

| Criteria | Parameters |
|---|---|
| Hydrogeology | The mean depth of groundwater table (GWT) during the growing and irrigation season, m, in relation to the critical GWT depth ($H_{cr.}$) |
| | The depth of GWT during the pre-sawing period, m |
| | The mean GWT in paddy fields between growing seasons, m |
| | The GW salinity, g/dm$^3$ when the GWT is below $H_{cr.}$ , from $H_{cr.}$ to 5,0 m |
| | The hydrochemical composition of GW when the GWT s below $H_{cr.}$ , from $H_{cr.}$ to 5,0 m |
| Geological engineering | The coefficient of porosity (of the plough layer and subsoil, the thickness of profile) |
| | The degree of manifestation of exogenous geological processes:<br>– swamping and flooding;<br>– water erosion and deflation;<br>– landslides and mechanical disturbance of deposits;<br>– subsidence and suffosion karst<br>– secondary hyromorphic processes in soil and deposits |
| Soil amelioration | The degree of salinization within the upper 1 m of soil and aeration zone |
| | The degree of soil alkalinization |
| | The degree of soil solonetzization |
| | The depth of occurrence of the salt layer first from the surface , m |
| | The depth of occurrence of the solonetzic horizon, m |
| | Particle-size distribution, % |
| | Soil density, g/cm$^3$ |
| | Soil aggregate composition (within the plough layer) |
| | Field water capacity, % |
| | The maximum hygroscopicity, % |
| | The wilting point, % |
| | The organic matter content, % |
| | The content of mineral nitrogen, mg/kg:<br>– nitrate<br>– ammonia<br>– phosphorus in soils, mg/kg<br>– potassium in soils, mg/kg |
| | Irrigation water quality |
| Ecology and toxicology | A general pollution of ground and surface waters |
| | Soil pollution, mg/kg:<br>– zinc, manganese, copper, cobalt, boron, molibdenum, cadmium, lead and mercury<br>– traces of pesticides (DDT and its metabolites, hexachlorane (the total of isomers), 2, 4 D – amine salt) |
| Agronomy | The productivity of crops, t/ha |
| | The quality of plants produced |

# C.4. Main criteria and indicators for monitoring soil as a natural resource

**I.P. Aidarov (Russia)**

Natural resource monitoring should involve the analysis of the following parameters:

**Changes in atmospheric conditions** that occur mainly as a result of man-made disturbance of the natural land surface, water circulation, etc. Monitoring such changes includes assessments of the following parameters:

- the energy budget of the irrigated land surface;
- atmospheric precipitation;
- exchange between surface and subsurface soil moisture, which predetermines the trends and rates of hydrological and soil processes;
- river discharge rate.

**Changes in the surface water quality** including the following assessments:

- river discharge rate;
- the degree of river flow control via dams and the total volume of water resources;
- the volume of water discharged from drainage and sewage networks
- the mineralization (salinity) and chemical composition of river water;
- water quality in terminal elements of river network (lakes and seas).

**Changes in the groundwater quality** including the assessment of fluctuations in the groundwater table and salinity.

**Changes in soil quality** including the following assessments:

- physical properties (soil porosity, field moisture capacity, maximal molecular moisture capacity and infiltration rate) and physicochemical properties (composition of exchange bases, etc.) ;
- the composition and content of humus and the content of available plant nutrients;
- the type and degree of soil salinization and the distribution pattern of salts within soil profile;
- the surface-subsurface water exchange: $\Delta W = Oc + Op - C \pm g$, where: Oc and Op – precipitation and irrigation water, mm; C – runoff, mm; g – water exchange between soil solutions and groundwater, mm. The '+' and '-' signify upward and downward water fluxes, mm, respectively;
- the soil quality class and productivity depending on water infiltration rate and salinity;
- ion exchange (Na – Ca and Na – Mg) adsorption coefficient.

**Irrigation network quality and irrigation techniques** including the following assessments:

- the coefficient of efficiency of an irrigation system within a farm or a cluster of farms, water losses from the irrigation system and their influence on the groundwater table in surrounding areas including the risk of damage to human settlements as a result of raised groundwater table;

- irrigation rates (net and gross) and timing;
- irrigation technique and the uniformity of moisture distribution over soil surface;
- irrigation water salinity and chemical composition.

**Drainage network quality** including assessments of the following:

- hydrogeological conditions, validity of calculations, types and parameters of drainage systems;
- the volume, salinity and chemical composition of drainage water and its disposal techniques (repeated use in irrigation, discharge into natural reservoirs, etc.);
- salinity of irrigated drained lands. It would be incorrect to assess the soil desalinization effect by the total sum of salts removed with drainage water. Instead, the amount of salts removed from the assessment layer of soil should be used: $\Delta G = Go - \alpha Д$, where: $\Delta G$ – change in salt content within the assessment layer, t/ha; Go – amount of salts brought with irrigation water, t/ha; Д -the total amount of salts removed with drainage water, t/ha; α – the share of salts removed from the assessment layer, which is calculated from drainage system parameters. The deeper the drains and the greater the distance between drains, the lower the α value (that varies within a range from 0.4 to 0.8). A horizontal drainage system can remove 20-60% of salts from the assessment layer [1].

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# Annex D.
# Innovative methods of mapping and monitoring saline and alkaline soils

## D.1. Innovative methods of electromagnetic induction and remote sensing for mapping and monitoring saline and alkaline soils (brief overview)

**M.V. Konyushkova (Russia)**

There are two approaches used in the mapping and monitoring of saline and alkaline soils. The first approach is based on measuring soil properties with the use of proximal soil sensing technologies including electromagnetic induction (EMI). The second approach involves the identification of soil-landscape relationships in different environmental-agricultural situations followed by the mapping of such relationships with the use of traditional and digital mapping and remote sensing techniques.

### Soil mapping with the use of electromagnetic induction

The EMI method is based on field measurements of the apparent electrical conductivity (ECa) with the use of a portable device that can be carried by hand or attached to a tractor (Fig. D.1). The data are transferred from the device to a portable computer along with GPS coordinates that are recorded in real time. The Geonics EM-38 ground conductivity meter (Canada) is the most common device for measuring electrical conductivity through EMI, which allows the assessment of soil salinity within a layer 1-1.5 m thick. A more detailed description of this method can be found in published papers [9, 11]. Similar devices include the DUALEM-421 sensor that has been recently introduced in practice. This sensor is capable of measuring the ECa at six different depths, which allows creation of multidimensional (3D and even 4D) models of salt distribution in soils [21] (Fig. D.2).


*Fig. D.1. A tractor equipped with an EM-38 ground conductivity meter and a satellite navigation system, with direct data transfer to a portable computer (USDA Salinity Lab, Riverside, USA).*

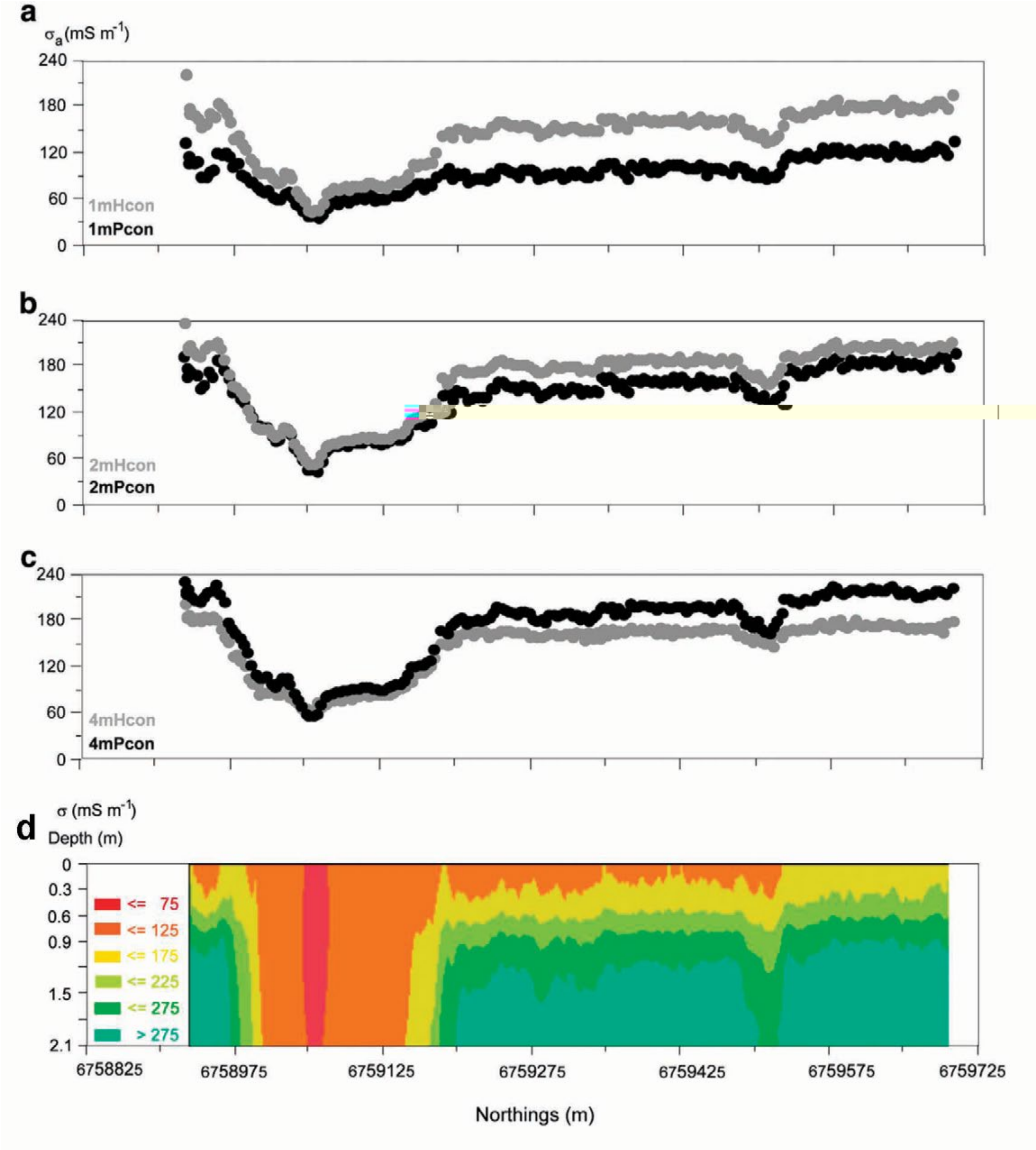



*Fig. D.2. The vertical distribution pattern of the apparent electrical conductivity ( σa, mSm/m) measured using a DUALEM-421 sensor in its horizontal ( Hcon) and perpendicular ( Pcon) positions, with different distances between its transmitter and receiver: a – 1 m, b – 2 m, c – 4 m.*

*The assessment of distribution of electrical conductivity values ( σ, mSm/m) (d) [21].*

Measured values of soil electrical conductivity depend on the salinity of soil solution, the soil porosity and the type and quantity of clay particles in the soil [16]. The EMI method also has significant limitations that prevent the possibility of taking accurate measurements in dry conditions (i.e., on drylands or when moisture content of irrigated soils is low) or in soils and parent materials with irregular particle-size composition. In the absence of such limitations, the EMI method allows for a quick and reliable assessment of soil salinity over a large area. The comparison of EMI data with laboratory measurements of electrical conductivity of saturated soil-paste extracts shows correlation coefficients of 0.74–0.78 and very similar distribution patterns of data obtained by the two methods [10]. More precise measurements can be obtained by simultaneous testing of ECa and soil moisture, which enebles the possibility to separate the effects of salinity and moisture on the electrical conductivity of soil.

The EMI is a basic method applied in the soil salinity assessment system that was developed in the USA and now used worldwide [19].

## Soil mapping by the use of remote sensing

### Soil salinity

Soil salinity assessments on the basis of remote sensing data involve the use of a series of spectral indices such as colour saturation and brightness indices, soil salinity index and vegetation index (for more detail see [5], pp. 26-28). Such indices illustrate relationships between different aspects of the study materials and their spectral characteristics.

Relationships between soil salinity and spectral indices differ for bare and vegetated soil surfaces. In cases of bare surfaces, soil salinity correlates with indices calculated by the addition or multiplication of brightness values of visible and near-infrared light, but has no connection with vegetation index. An increase in soil salinity is reflected by an increase in brightness within the visible (especially, blue) and near-infrared spectra [12, 18]. However, the degree of association between these parameters depends on the state of the soil surface (e.g., whether it is moistened, cracked or trampled) as well as the mineralogical composition of salt crusts [16, 17] (Fig. D.3).

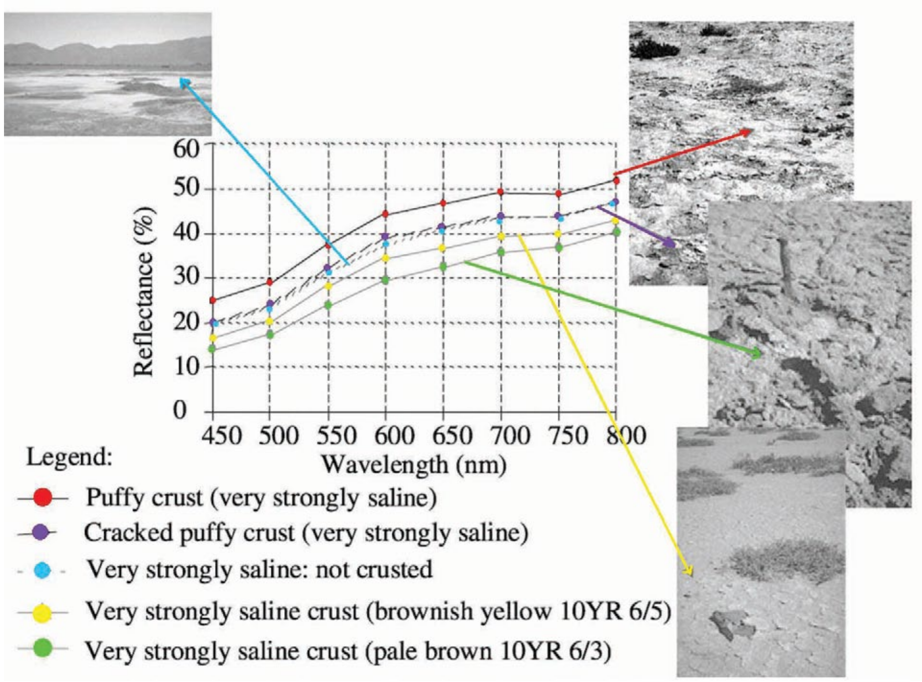



*Fig. D.3. The influence of the salt crust surface on the reflectance capacity (ground survey using a Crop Scan radiometer) [16].*

In cases of vegetated surfaces, soil salinity closely correlates with the vegetation index and indices calculated from the brightness of colour within the red and near-infrared spectra. The latter also reflects the condition of vegetation, which can be either poor (due to high salinity) or good (due to low salinity of soils) (Fig. D.4). Approaches to the assessment of soil salinity by use of the normalized difference vegetation index (NDVI) and the condition of vegetation (primarily, agricultural crops) have been described in numerous publications (e.g., [2, 7, 13, 14] etc.).

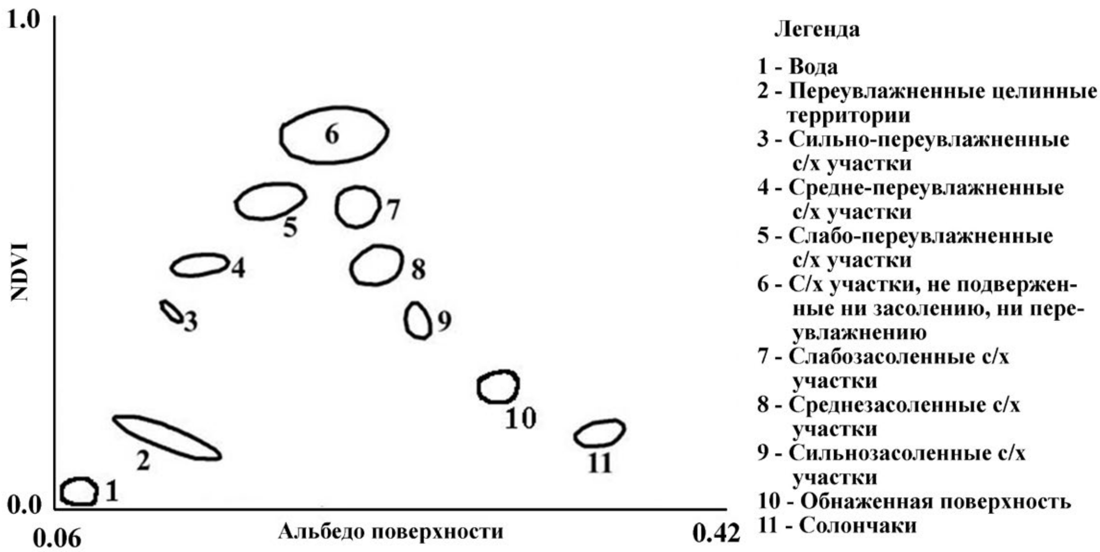



*Fig. D.4. The relationship between albedo and the normalized difference vegetation index (NDVI) in different surface categories: 1 – water; 2 – 5 – soils overmoistened to different degrees; 6 – soils in good condition; 7 – 11 - soils having different degrees of salinity [14].*

Salt-affected soils under halophytic plant communities (Salicornia, Spartina, Suaeda, Salsola, etc.) are characterized by a weak correlation between the vegetation index and soil salinity, because halophytes (in contrast to salt-tolerant crops such as cotton, maize and sugar cane) are only weakly dependent on differences in soil salinity levels (Fig. D.5).

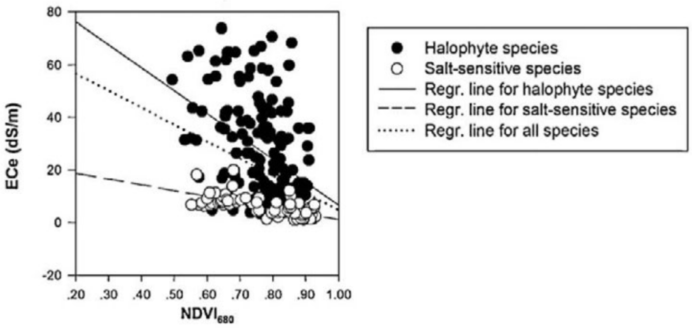



*Fig. D.5. The distribution of the NDVI values (measured using a hyperspectral portable radiometer) and the electrical conductivity of saturated soil-paste extract (ECe) under different plant communities (halophytes and salt-tolerant crops) [22].*

## Solonetz complexes

Approaches to mapping and monitoring Solonetz complexes (combinations of alkaline soils) on the basis of remote sensing data are still insufficiently developed, as compared to the above- described cases of saline soils. Existing approaches are based on the fact that different soils within Solonetz complex support different plant communities and that the condition of plants is closely associated with the degrees of soil salinity or alkalinity [5, 20] (Fig. D.6).

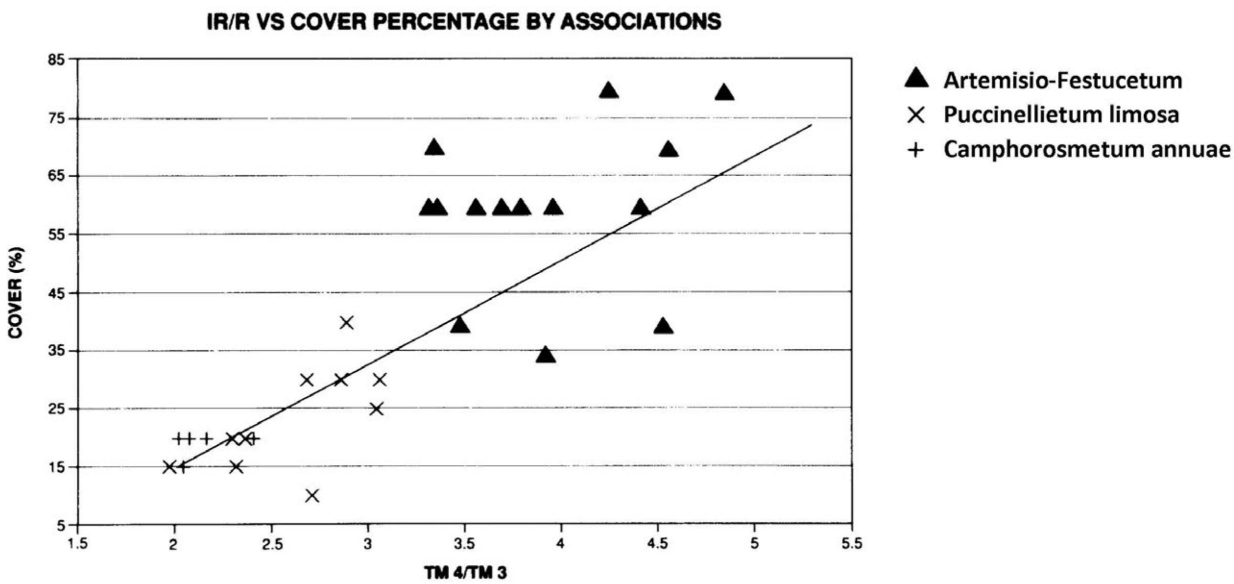
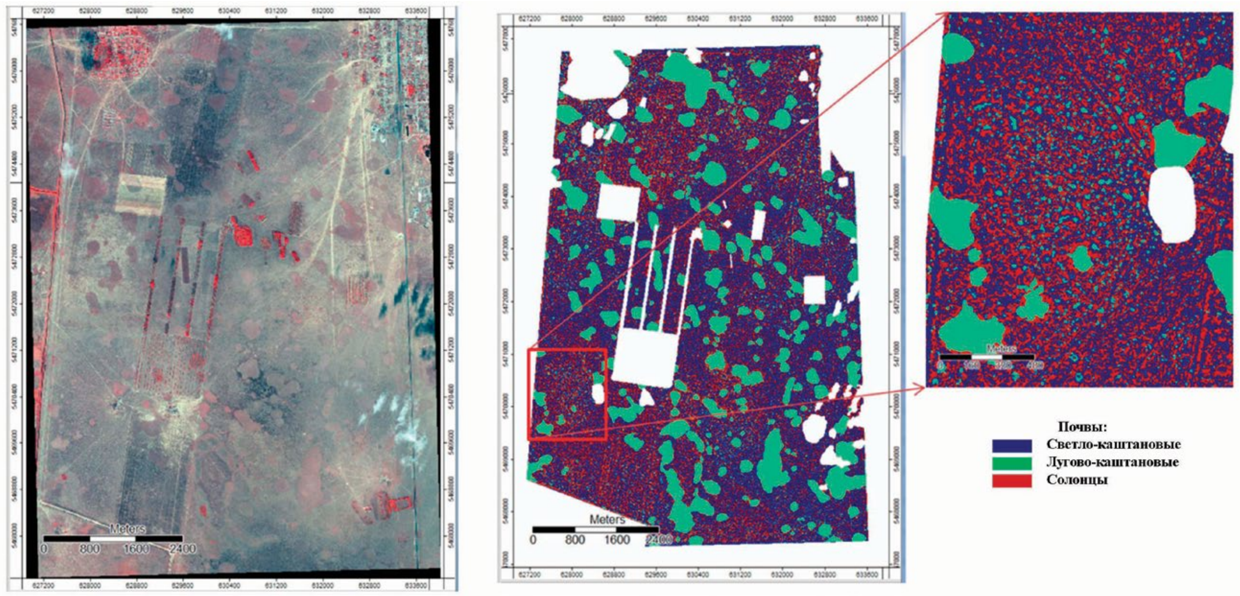



*Figure D.6. The distribution of the TM4/TM3 values (760-900 nm/630-690 nm) and the cover (5) of different plant communities within Solonetz complex in Hungary (with spectral measurements conducted using an Exotech-100 radiometer) [20].*

Solonetz complexes in the north of the Caspian Sea region have been mapped with the use of satellite imagery (Quickbird, GeoEye, Pleiades) that provided the basis for calculating the differences in vegetation indices (with higher values for Meadow Chestnut soils due to a dense cover of meadow vegetation) and brightness indices within the near-red spectrum (with lower values for Solonetz under moss-lichen communities). Guidelines for digital mapping of Solonetz complexes in the north of the Caspian Lowland on the basis of processing high-resolution satellite images can be found in the handbook on digital soil mapping (Fig. D.7) [8].




*Quickbird Image (synthesized 4-3-1)* *Digital map of Solonetz complex*

***Fig. D.7. An example of a digital soil map of Solonetz complex compiled using the Quickbird Imagery [8].***

## D.2. Computer image analysis using different methods of Supervised Classification for mapping salt-affected soils of the Kurdamir District (Azerbaijan)

**S.A. Safarli, F.N. Salimov and I.A. Talibov (Azerbaijan)**

This paper describes the results of mapping soil cover and soil salinity within the Kurdamir District, Azerbaijan, with the use of computer analysis of high-resolution images provided by a WorldView satellite sensor. The scientific basis of this study is outlined in several publications [1, 3, 4, 6, 15].

The Kurdamir District is located to the north-west of Baku, in Shirvan region of Azerbaijan (Fig. D.1). The Kurdamir District has a total area of 1.63 thousand km2 with arable lands, pastures and other types of land use (Table D.1).

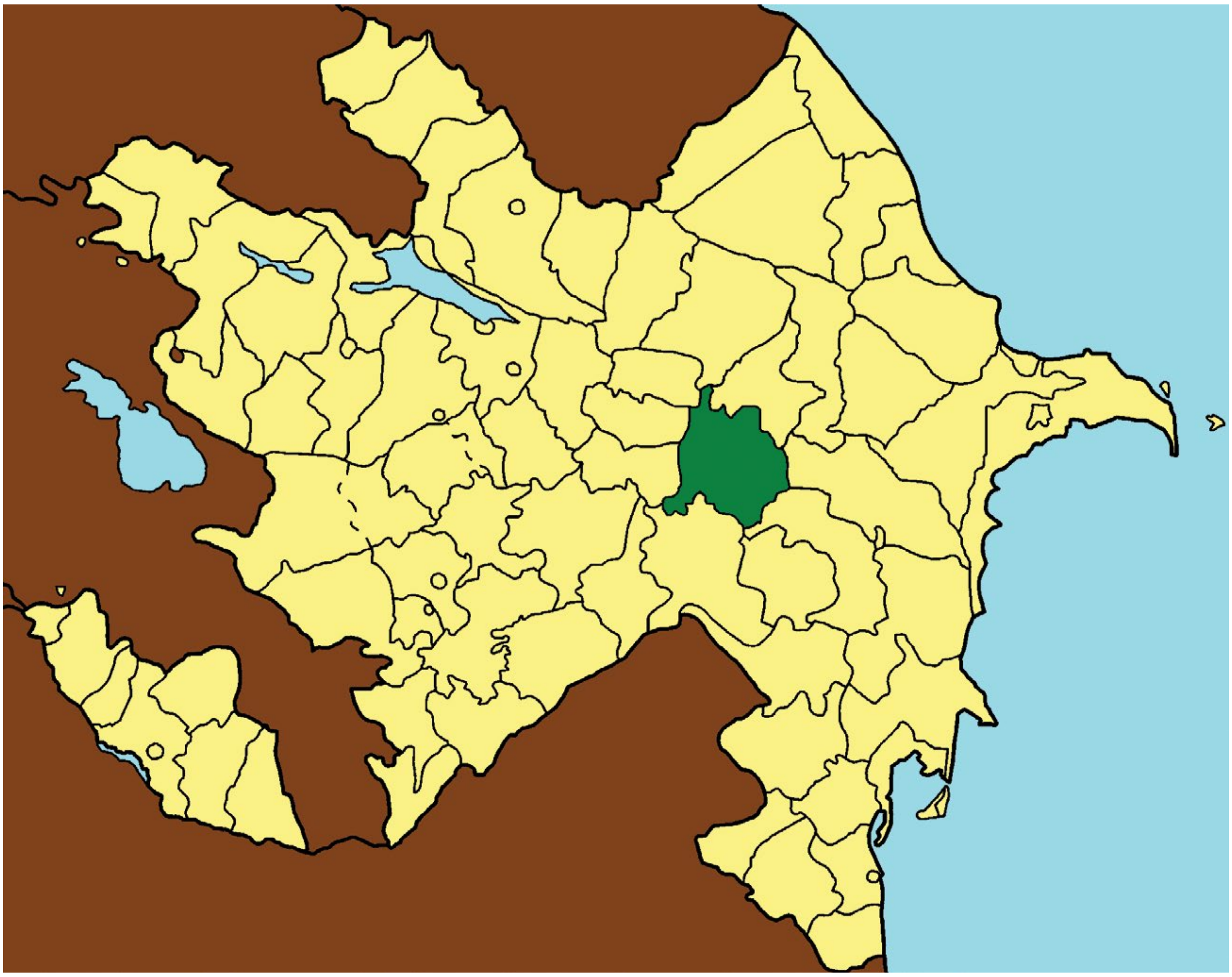


*Fig. D.8. The Kurdamir District location in Azerbaijan.*

## *Table D.1. Land use distribution within the Kurdamir District*

| № | Parameters | Units of measure | Years | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
| 1 | The total land area | ha | 116190 | 116190 | 116190 | 116190 | 116190 | 116190 | 116190 |
| 2 | Including agricultural lands | ha | 83359 | 83359 | 83359 | 83359 | 83359 | 83359 | 83359 |
| 3 | Croplands | ha | 28997 | 43401 | 48074 | 47946 | 44491 | 48362 | 49833 |
| 4 | Perennial plantations | ha | 2403 | 2178 | 2144 | 2146 | 2254 | 2373 | 2384 |
| 5 | Pasture | ha | 51959 | 37780 | 33141 | 33267 | 36614 | 32624 | 31142 |
| 6 | Forest belts | ha | 739 | 739 | 739 | 739 | 739 | 739 | 739 |
| 7 | Fallows | ha | 22500 | 22500 | 22500 | 22500 | 22500 | 22500 | 22500 |
| 8 | Other | ha | 9592 | 9592 | 9592 | 9592 | 9592 | 9592 | 9592 |

The soil cover of the Kurdamir District is dominated by Meadow Greyzems (28 thousand ha) and Light Meadow Greyzems (23 thousand ha), which have irrigated areas of 15 and 14.7 thousand ha, respectively. Salt-affected soils are found mostly in the southern part of the district and have a total area of 3.6 thousand ha.

New methods of soil mapping based on the computer analysis of high-resolution satellite images were tested at the study site (300 $km^2$) located to the east of Kurdamir town. A network of field test points was set within the study site to ensure that the complete range of soil types and land use types was represented. The network included a total of 100 points located along 6 transects across the site with varied spacing that was designed to adequately represent changes in soil type and use. Field data recorded at each point included GPS coordinates, land use type, crop species, plough depth and the presence of surface salt concentrations and salt- tolerant plant species. Most points were also photographed.

Soil samples were taken from the surface (0-5 cm) and the 5-10 cm depth at each point, with three extra samples at a distance of less than 1 m around each point. The contents (%) of salt ions (Cl- and $SO4^{2-}$) and carbonates ($CaCO_3$) and pH were then determined in the samples. At selected test points, morphological descriptions and photographic documentation of soil profiles 50 cm deep (the maximal possible pit depth due to high soil density) were also carried out.

All surface horizons studied were salt-affected (although their salt concentrations were below 2%, i.e., did not meet the salic criterion). Mean salt concentrations determined at each point varied from 0.8 to 1.55%, with electrical conductivity (EC) values from 16 to 31 dS/m, which indicated a strong salinization of soils. The surface horizons were highly calcareous, with calcium carbonate contents of 10-13%.

The WorldView-2 multispectral satellite image of 18.08.2011 was analysed. The image underwent standard radiometric, atmospheric and geometric corrections and ortho- transformation.

Processing of the digital image with the aim of soil mapping was performed using the Erdas Imagine 9.2 program and included the following stages:

1. Supervised Classification of Images on the basis of visual separation of image sets.
2. Parallelepiped Classification of Images (where brightness values were used for determination of image class boundaries) with the aim of distinguishing bare and vegetated surfaces.
3. Image Segmentation using the eCognition algorithm to distinguish uniform areas followed

by visual and statistical comparison of the output image with soil salinity values at 100 test points. The results of correlation analysis showed that salinity values within the 5-10 cm soil layer were not connected with spectral characteristics of the surface. Moreover, it was found that the output image mainly reflected the changes in soil taxa (types or subtypes) and land use types.

4. Inclusion of land use type into the eCognition algorithm. Several land use classes were identified: fields of cotton and wheat, ploughland, abandoned fields, scrub, meadows, bogs, etc. Histograms for most classes, apart from ploughland, had similar spectral characteristics and could not be differentiated.

5. Nearest Neighbor Image Classification by land use type. The identified classes were as follows: ploughland, fields of cotton and wheat, meadows and pastures, bogs, abandoned lands, forest and scrub. The area of each class was determined.

6. Nearest Neighbor Image Classification by soil type, with land use type taken into account. As a result, 17 soil classes were identified. There were unambiguous and ambiguous classes, with the latter including two or three soil types. The unambiguous classes included Meadow Greyzems, Greyzemic Meadow soils and Light Meadow Greyzems (classified with the precision levels of 90%, 79%, 83%, respectively) as well as Wet Meadow soils identified with the highest precision (94%) and Dark Greyzemic Meadow soils identified least certainly (with a precision level below 60%).

The soil cover and soil salinity map of the study area. The data obtained were used to show the distribution of salt-affected soils on the latest soil map of the Kurdamir District, which was created by combining old and new information sources. This map was designed to represent the main soil types and subtypes and the degrees of soil salinization at a 1:50000 scale (Fig. D.9).

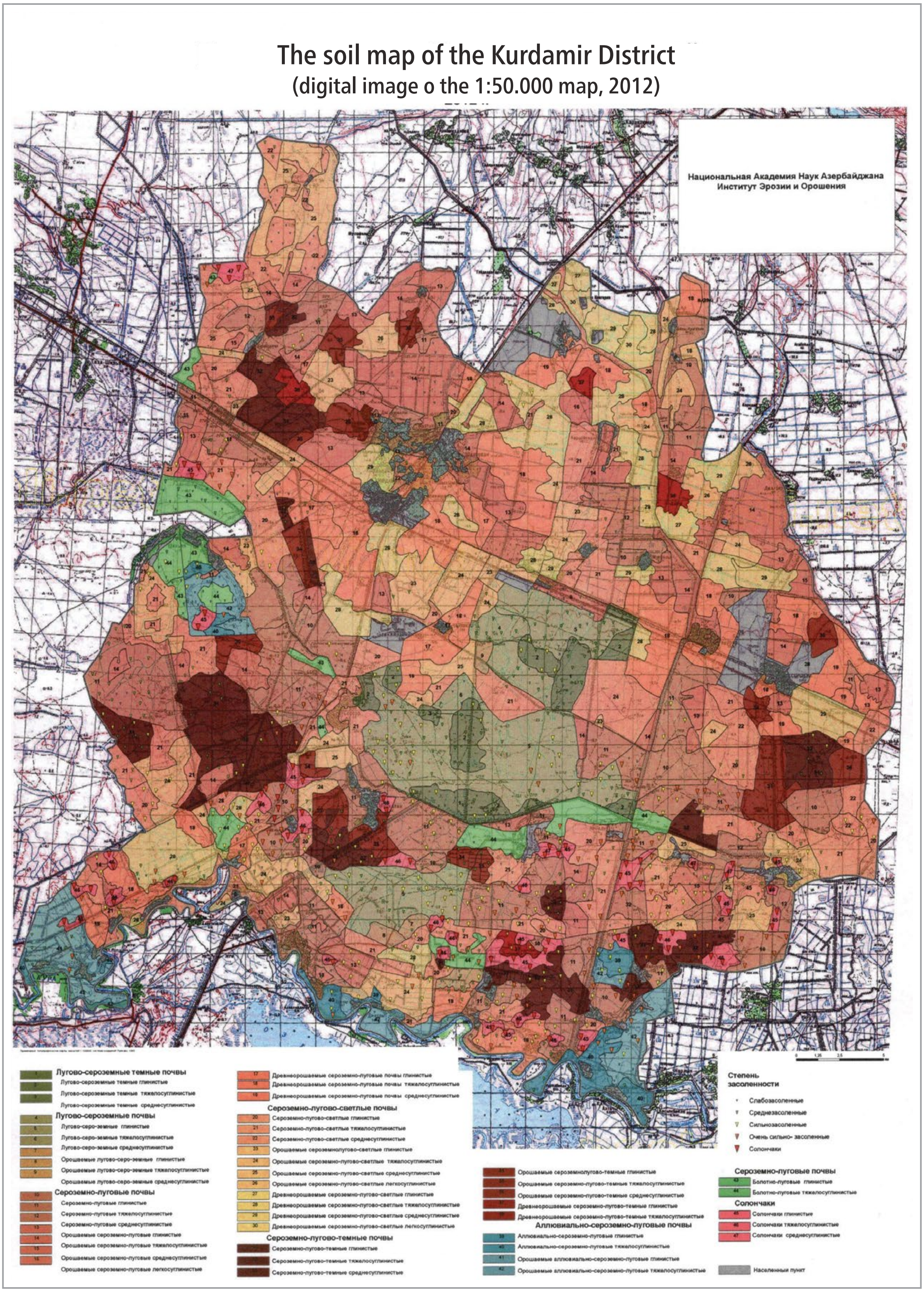



*Fig. D.9. The soil and land use map of the Kurdamir District*

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# Annex E.
# Innovative methods and technologies of agroforestry on saline and alkaline soils (by the example of the Caspian Lowland, Russia)

## E.1. Tree clusters (‘zelyonye zonty’) planted on Meadow Chestnut soils within Solonetz complexes – an example of sustainable agroforestry in the Caspian Lowland

**M.K. Sapanov and M.V. Konyushkova (Russia)**

Currently, there is a need to develop agroforestry practices within arid regions on the basis of the concept of adaptive management of natural resources that can help to create self-sustaining forest ecosystems capable of surviving for several decades and even centuries without human intervention.

To date, it is generally been believed that only short-lived forest ecosystems that require continuous and expensive agrotechnical and agroforestry management can be created. It has been estimated that artificial replanting is needed every 20 to 40 years even for the most drought- resistant tree species such as common oak (*Quercus robur*), green ash (*Fraxinus pennsylvanica*), Siberian elm (*Ulmus pumila*) and ash-leaved maple (*Acer negundo*) and every 15 years for shrubs on zonal soil types within dry steppe and semidesert areas [2, 3, 5]. In practice, most tree plantations fail to survive for as long as most agroforestry manuals suggest, unless annual water- saving measures are applied. The inability to apply such measures usually results in the rapid decline of many plantations.

In the context of modern approaches to sustainable agroforestry, tree plantations in arid regions should, in our opinion, meet the following requirements: (1) to be able to provide essential ecosystems services, (2) to be cost-effective, (3) to be ecologically harmless and (4) to be durable [4]. Such requirements can be satisfied by the following:

1) Essential services of forest ecosystems can be realized via an enhancement of their productivity or social value;

2) The cost-effectiveness of tree cultures can be achieved by having post-planting maintenance-free growth. Their management should be the same as that for normal forests. In other words, the survival of trees should not be dependent on agroforestry management.

3) The plantations can be ecologically harmless if a correct balance can be achieved between water supplies for the trees and the surrounding vegetation. This is of great importantance, because tree plantations should neither suffer from impaired water supply (e.g., as a result of an increase in water salinity), nor receive a higher water supply than the surrounding areas (e.g., as a result of increased snow accumulation under trees).

4) The durability of plantations can be provided by the use of long-lived species of trees and shrubs that are also capable of natural regeneration (vegetative reproduction and seeding). The normal growth of plantations is achieved by having a correct balance between water supply and consumption.

The creation of such conditions is a realistic prospect, especially, within complex soil cover areas that include non-saline Meadow Chestnut soils within local topographic depressions. Therefore, the composition of soil cover should always be taken into account when selecting suitable locations for agroforestry sites (including so-called 'zelyonye zonty').

'**Zelyonye zonty**' (literally, 'green umbrellas') is the Russian term for an agroforestry practice that involves planting clusters of trees within pastures, near waterholes, cattle and sheep sheds and other places where farm animals can rest and shelter from the sun during the hottest part of summer days. This type of agroforestry is practiced in dry steppe, semidesert and desert regions. The tree clusters can include from 8 to 40 groups of 9 to 25 trees. Tree spacings are 3-6 m between trees within a group and 6-20 m between groups of trees (so- called wind corridors). Each group of trees can cover an area of 100-900 m2 and an entire cluster of tree groups can cover a total area of 0.3-1.2 ha. The planting design of tree clusters varies depending on the type of farm animal. For cattle and sheep, closed-canopy/open floored clusters are planted, consisting of robust tree species of arid zones that can produce phytoncides. Typically used species include fruit trees such as Armenian plum (*Prunus armeniaca*), cherry plum (*Prunus cerasifera*), pear tree (*Pyrus* sp.), apple tree (*Malus* sp.) and mulberry tree (*Morus* sp.) and also leaf-fodder plants such as Siberian elm (*Ulmus pumila*), black locust (*Robinia pseudoacacia*) and honeysuckle (*Lonicera* sp.). On poultry farms, shrubs that produce berries, e.g., currants (*Ribes* sp.), shadbush (*Amelanchier* sp.) and cherry (*Cerasus* sp.) are planted to form a dense ground tier and an open canopy. Tree saplings 3-5 years old and at least 3 m tall are planted on relatively fertile and moist soils in spring or autumn after deep ploughing. The use of tree clusters begins two years after planting. The estimated canopy areas (m2) required to shelter one animal are as follows: 2.5-3 per sheep, 1.5-2 per lamb, 10-12 per cow, 4-6 per veal and 0.2-0.3 per chicken. This agroforestry practice was first developed in the Astrakhan Region of the former USSR in 1958 [1].

In the northern part of the Caspian Lowland, loamy deposits are dominated by Solonetz complexes that include soils with different properties: Solonetz with saline surface horizons and low fertility, Light Chestnut soils with various degrees of alkalinity and salinity and moderate fertility and Meadow Chestnut soils with no salinity or alkalinity, but high fertility (Fig. E.1). Transitions from one soil type to another usually occur every 2 to 20-30 m, i.e., within very short distances.

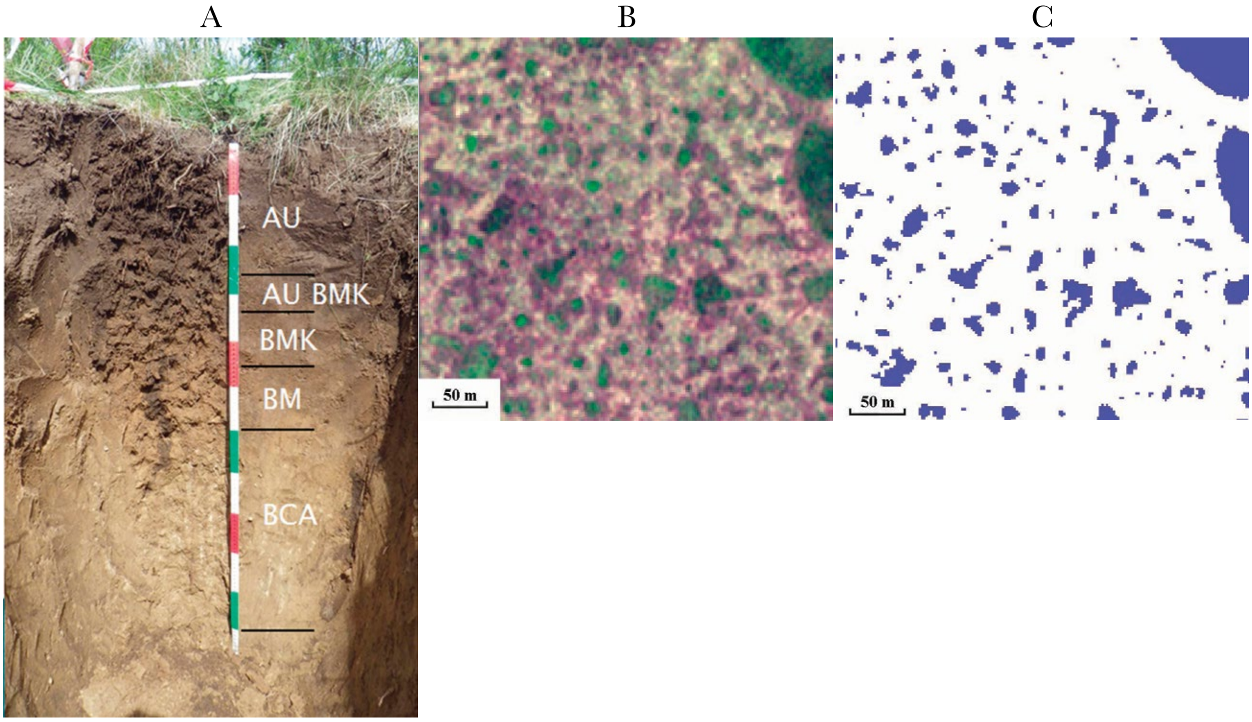


***Fig. E.1. Non-saline non-alkaline Meadow Chestnut soil (A), Pleiades high-resolution satellite image ( B) and map ( C). Borsi, West Kazakhstan. Soil horizon designations: AU – dark humus; BMK – xeric metamorphic; BM – structural metamorphic; BCA – carbonate-accumulative.***

Agroforestry practices on lands with shallow groundwater table under arid conditions at the Dzhanybek Research Station have shown that forest plantations can survive for more than 60 years on Meadow Chestnut soils within local topographic depressions (Fig. E.2). Existing shelter belts planted in the 1950s received agrotechnical treatments only during the initial few years following planting, with only prophylactic tree cutting undertaken thereafter.

Fragments of these shelter belts have survived on Light Chestnut soils within depressions and have sometimes extended even further due to colonization of adjacent soils by shrubs, e.g., Tartarian honeysuckle (*Lonicera tatarica*). Such shelter belt fragments differ in sizes, species composition as well as growth and survival rates of trees. Of special interest are plantations consisting primarily of Siberian elm (*Ulmus pumila*), which tends to die relatively early, and common oak (*Quercus robur*), which tends to live for far longer.


***Fig. E.2. A Quickbird satellite image from 2006 showing the remaining part of the Stalin Shelter Belt on Meadow Chestnut soils at the Dzhanybek Research Station ( 49.3928 N, 46.7892 E)***

The shelter belt fragments dominated by common oak are generally better preserved. Although top branches of both common oak and Siberian elm tend to dry out, oak can survive in such condition for decades, while elm can not. In the Caspian Lowland, some oaks with dried tops are known to live for 70-80 years. Therefore, dried top of an oak is not necessarily a sign of approaching death, but rather a reaction to periodic drought stress (however, a very severe drought can of course kill common oak as well as Siberian elm).

Statistical analysis has revealed a significant correlation ($r=0.66$, $p=0.05$) between the diameter of oak trunks and the size of topographic depressions, where these trees grow. There is a less significant correlation ($r=0.54$, $p=0.1$) between the height of trees and the size of the area that they occupy. Therefore, the diameter and height of oaks can also be affected by other factors such as the shape of depressions and the species composition of the shelter belt.

Trees that grow within small topographic depressions (micro-hollows) are always shorter in comparison to trees growing within medium-sized depressions (meso-hollows that have areas of 1 ha or more). For example, such allometric relationships are found in *Malus*, *Acer*, *Elaeagnus* and *Lonicera* species that are 1.5 times taller in meso-hollows than in micro-hollows.

Meadow Chestnut soils within micro-hollows have been fully colonized by forest vegetation. Tree roots can extend slightly beyond micro-hollows into Light Chestnut soils, but they are prevented from spreading further to Solonetz due to their high salinity, according to our observations on root distribution along a trench across these soil types.

The long lifespan of trees planted within micro-hollows can be explained by the additional supply of soil moisture (even despite groundwater salinity) that helps the trees to compensate for water loss via evapotranspiration. Such artificial plantations have natural analogies, e.g., thickets of *Spiraea hypericifolia*, *Prunus spinoza*, *Rhamnus cathartica* and *Rosa cinnamomea* that are commonly found within small depressions in the Caspian Lowland.

The survival of such a long-term maintenance-free clusters of planted trees (including oak) and shrubs within small depressions can serve as a basis for recommending the wider application of agroforestry in arid zones dominated by Solonetz complexes.

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# Annex F.
# Dissemination of knowledge on the amelioration of salt-affected and waterlogged soils in the Kyrgyz Republic

**K.M.Kulov (Kyrgyzstan)**

## Background

The Kyrgyz Republic can be subdivided into three large regions on the basis of clearly distinct soil-ameliorative conditions: Northern, Southern and Central Tian Shan. These regions have different geology, hydrology, topography and local climates. Salt-affected and waterlogged soils are found mostly within the Northern region (Chuy Valley), where they cause significant damage to agricultural production, reductions in crop yields and abandonment of degraded land [3].

State-level responsibility for the amelioration of irrigated lands lies with the recently restored institution of the Republican Ameliorative Hydrogeological Expedition (RAHE), which is engaged in monitoring and preventing the rise of the groundwater table (GWT), waterlogging and salinization of irrigated lands.

The RAHE produces an annual update of the Registry of Ameliorative Condition of Irrigated Lands, where spatial distribution patterns of the GWT and soil salinity and alkalinity levels within different regions are presented. These data are used in planning ameliorative measures on an annual basis by the RAHE in collaboration with the Regional Water Authority (RWA).

Land amelioration is financed from the state budget, in particular, by the Agency for the Registration of Rights to Immovable Property (GosRegister of the Kyrgyz Republic), which collects land value taxes.

## Current condition of irrigated lands

According to the Ameliorative Registry of Kyrgyzstan, the total area of lands in unsatisfactory ameliorative condition increased by 20 thousand hectares from 1990. By 2010, saline and alkaline soils occupied 12% and 8% of the total arable land area, respectively. Salt-affected soils were concentrated within the Chuy Valley and districts of Talas, Kara-Buura, Batken, Aravan and Suzak. The most extensive development of soil salinization and waterlogging occurred in the western part of the Chuy Valley and the Batken District in the south of Kyrgyzstan. So-called 'amorphous salinization' was observed within the Kulanak Valley of the Naryn District [2].

The main cause of the degradation of irrigated lands is the rise of the mineralized (saline) groundwater table due to the generally dilapidated state of irrigation systems and inefficient water use. The condition of irrigation systems has rundown over time due to a lack of finance for their necessary maintenance. Excessive irrigation rates result not only in the GWT rise, but also in soil erosion and water loss from drainage systems. The situation can be improved by soil rehabilitation via leaching together with the repair of drainage systems and optimizing water use in irrigation systems. Existing recommendations for the prevention of irrigation-induced erosion are also applicable for solving problems of GWT rise, soil salinization and drain blockages by silt.

### Research and dissemination of best practices

Studies on irrigated lands affected by salinization, alkalinization and waterlogging have been conducted at the L.K. Gossu Research Institute of Irrigation in Kyrgyzstan since the 1970s. The knowledge obtained is disseminated over the country and serves as a basis for practical recommendations [1, 4].

### Recommendations for the amelioration of salt-affected lands (based on experimental research in Besh-Terek, Moskovsky District, Kyrgyztan, 1983-2006)

The experimental research had the following objectives:

- Assessment of the ameliorative condition of soils at the Besh-Terek site with the use of the following parameters: 1) spatial distribution patterns of soil salinity and alkalinity, 2) total salt concentrations in groundwater, drainage water and irrigation water, 3) spatial distribution of humus, available nitrogen, phosphorus and potassium contents within the plough layer and 4) drainage efficiency;
- Determination of soil requirements for leaching treatments and calculation of irrigation rates for soil leaching;
- Determination of soil requirements for gypsum application and calculation of gypsum application rates;
- Determination of soil requirements for fertilization, calculation of fertilizer application rates and suggestion of the best fertilization technique;
- Establishment of the best practice of horizontal drainage maintenance;
- Mapping soil salinity within the 0-100 cm layer during the course of leaching treatments.

Resulting recommendations on best practice led to effective land use and management for a period of 30 years. Large-scale soil leaching was carried out at the research site in the 1970s and 1980s, with operation of the drainage system supervised by the Institute of Irrigation. Up until the present time, the former experimental plots are in better condition than lands of a similar kind.

### Solving problems of the amelioration of salt-affected lands (by the example of experimental research in Kelechek, Panfilovsky District, Kyrgyzstan)

Experimental research aimed at improving the ameliorative condition of lands includes the following tasks:

- Identification of salt accumulation processes in soils;

- Mapping soils according to the degrees and types of their salinity;
- Collecting data on the humus content within the plough layer of soil;
- Investigations of spatial distribution of alkalinity within the plough layer;
- Collecting data on available nutrient concentrations within the plough layer;
- Establishment of best practice for horizontal drainage maintenance.

The data obtained serve as the basis for making recommendations for the prevention of soil salinization, alkalinization and waterlogging and for improving the soil fertility of the experimental research site of Kelechek. Such recommendations include the following:

i. Depending on the degree of soil salinization, leaching to remove salts requires irrigation rates between 100 and 4000 $m^3$/ha. The best time for undertaking soil leaching treatments is autumn-winter, when they can be combined with soil moistening treatments. If irrigation rates of 800-3000 $m^3$/ha are prescribed for soil moistening, then they should be adjusted to coincide with rates recommended for leaching;

ii. Desalinization treatment of alkaline and saline-sodic soils with the content of $CO_3^{2-}$+$HCO_3^-$ =1meq/100 g of soil and Na=1meg/100 g of soil should involve gypsum application at the rate of 800 kg/ha. Soils with lower salinity and alkalinity levels should receive agrotechnical treatments: application of organic and physiologically acidic mineral fertilizers and cultivation of perennial herbs (e.g., alfalfa and sweet clover). The best time for applying ameliorators is when the soil is ploughed after crop harvesting;

iii. Plants should be supplied with balanced nutrition, with fertilizers applied at rates corresponding to plant requirements. Excessive fertilization of soils results in the pollution of water and the environment, especially within agricultural areas;

iv. Soil drainage and desalinization treatments should be performed in compliance with the rules of drainage system exploitation: (i) timely cleaning of drains; (ii) removal of silt and other blockages from drains, especially, from outlets of drainage systems to ensure free water flow, prevention of water losses from closed drains, (iv) regular control of drainage system efficiency, etc.

v. Soil testing on farms should be obligatory, with the following aims: (i) determination of soil fertility level, (ii) prescription of doses of fertilizers and ameliorators (gypsum, glauconite, etc.) and (iii) recommendation of type and rate of irrigation that will prevent losses of soil and water from fields.

## Recommendations for the amelioration of salt-affected lands within the Kulanak Valley (Naryn District, Kyrgyzstan)

On the basis of climate-forming factors (according to Z.A. Ryazantseva) the Kulanak Valley is attributed to Climate Region 4 - 'Inner Tian Shan', Subregion - 'Middle Naryn Bolson', Belt Type 4, with a sum of temperatures of 2500°C, a mean July temperature of +20°C and a precipitation to evaporation ratio of 0.24. The site is found at altitudes of 1770-1900 m a.s.l. (the Chuy Valley is 650-900 m a.s.l.) and has a total area of 11500 ha, with a patchy distribution of strongly and medium saline soils that have a total area of 4500 ha.

Soil salinization develops under the influence of parent materials, which contain soluble salts, combined with specific water and temperature conditions. The thickness of the sediment layer overlying bedrock varies from 0.5 m in the foothills to 10 m by the Naryn River.

The main method of the desalinization of local soils is leaching, which requires special preparations such as soil levelling, salt concentration testing, gypsum application, ploughing, harrowing, dividing fields into compartments bordered by earth ridges, installation of portable irrigation pipes within the compartments, etc.

Each type of preparatory operation requires professional expertise, experience and the input of significant financial and labour resources. Leaching and chemical amelioration treatments are needed for areas of 3700 and 1300 ha, respectively. Such large-scale operations are impossible for farmers to undertake on their own, therefore, these operations need to be undertaken by specialized amelioration groups of the RAHE.

Considering that crop yields decrease by 10-80% depending on the degree of soil salinity, it is recommended that the RAHE and the Kyrgyz Institute of Irrigation take responsibility for organizing actions to combat the loss of agricultural lands due to salinization within the Naryn Dystrict.

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# Authors of the Handbook

**Abdulaev, Umid Valievich** – Uzbek State Uzgipromeliovodkhoz Institute (UZGIP) (Tashkent, Uzbekistan), specialist in the field of design, planning and management of water and land resources, rehabilitation of irrigated lands, terrestrial hydrology and the integrated management of water resources. E-mail: uzgip@buzton.com

**Aidarov, Ivan Petrovich** – Academician of the Russian Academy of Agricultural Sciences (RAAS) and the Russian Academy of Sciences (RAS), Professor, Doctor of technical sciences, specialist in the field of landscape- and geosystem-based substantiation of ecological benefits and cost-effectiveness of combined ameliorative measures, modelling of water-salt dynamics in soils and the sustainable use of soil resources. E-mail: ivan@aidarov.com

**Aliev, Bakhram** – Doctor of Sciences, Professor, Azerbaijan University of Architecture and Construction (Laboratory of Irrigation) (Baku, Azerbaijan), specialist in the field of amelioration of salt-affected soils, irrigation and erosion of soils.

**Anisimova, Olga Viktorovna** – Candidate of Economic Sciences, National Scientific Centre 'Institute of Soil Science and Agrochemistry Research named after A.N. Sokolovsky' (Kharkiv, Ukraine), specialist in the field of economic substantiation of amelioration of saline and alkaline soils, assessment of cost-effectiveness of amelioration technologies and the implementation of innovations. E-mail: anisimova_o.v@ukr.net

**Balyuk, Svyatoslav Antonovich** – Academician of the Ukrainian Academy of Agrarian Sciences (UAAS), Doctor of Agricultural Sciences, Professor, National Scientific Centre 'Institute of Soil Science and Agrochemistry Research named after A.N. Sokolovsky' (Kharkiv, Ukraine), specialist in the field of evolution of irrigated soils, agroecological monitoring, conservation, cultivation and management of soil fertility, ecological regulation of anthropogenic pressure on soil cover, standardization and metrology in soil science, agrochemistry and soil conservation. E-mail: pochva@meta.ua, oroshenie@ukr.net

**Drozd, Elena Nikolaevna** – Candidate of Agricultural Sciences, National Scientific Centre 'Institute of Soil Science and Agrochemistry Research named after A.N. Sokolovsky' (Kharkiv, Ukraine), specialist in the field of soil conservation, soil halogenesis, ameliorative pedology, technologies of amelioration of saline and alkaline soils. E-mail: oroshenie@ukr.net, elena_drozd@ukr.net

**Filipchuk, Vladimir Filipovich** – Doctor of Agricultural Sciences, Institute of Pedology, Agrochemistry and Soil Protection named after N.A. Dimo (Chisinau, Moldova), specialist in the field of soil genesis, irrigation and the amelioration of salt-affected and waterlogged soils. E-mail: iu_rozloga@yahoo.com

Ibragimov, Rustam Isakdzhanovich - Uzbek State Uzgipromeliovodkhoz Institute (UZGIP) (Tashkent, Uzbekistan), specialist in the field of GIS, soil mapping and remote sensing methods for soil degradation assessment. E-mail: 2651803@mail.ru

**Ismail, Shoaib** – Doctor of Biological Sciences, International Centre for Biosaline Agriculture (ICBA) (Dubai, the UAE), specialist in the field of biosaline agriculture, halophyte cultivation, adaptation to climate change and salinity management. E-mail: s.ismail@biosaline.org.ae

**Ismonov, Abduvakhob Zhuraevich** – Candidate of Biological Sciences, Institute of Soil Science and Agrochemistry (Tashkent, Uzbekistan), specialist in the field of soil genesis, soil classification, chemical and physical properties of soils. E-mail: abduvahob60@mail.ru.

Kan, Vyacheslav Maksimovich – Doctor of Agricultural Sciences, U.U. Uspanov Kazakh Research Institute of Soil Science and Agrochemistry (Almaty, Kazakhstan), specialist in the field of soil science and amelioration. E-mail: kangsoil@mail.ru

**Khamzina, Tatiana Il'inichna** - Uzbek State Uzgipromeliovodkhoz Institute (UZGIP) (Tashkent, Uzbekistan), specialist in the field of soil fertility, sustainable management of land resources and the irrigation of crops. E-mail: tatyana_khamzina@mail.ru

**Khasankhanova, Gulchera Murshidovna** – Candidate of Agricultural Sciences, Uzbek State Uzgipromeliovodkhoz Institute (UZGIP) (Tashkent, Uzbekistan), specialist in the field of pedology and melioration of salt-affected soils, mapping, monitoring and assessment of land desertification/degradation and drought, adaptation to climate change. E-mail: g.khasankhanova@mail.ru

**Khuzhanazarov, Temur Mukhiddinovich** – Doctor of Technical Sciences, Samarkand State University (SSU) (Samarkand, Uzbekistan), Kyoto University (Water Resources Research Centre, Regional Ecosystem Research Laboratory) (Kyoto, Japan), specialist in the field of water resource management, hydrology, adaptation to climate change and agroecosystem modelling. E-mail: khujanazarov.timur@gmail.com

**Konyushkova, Maria Valerievna** – Candidate of Agricultural Sciences, M.V. Lomonosov Moscow State University (Faculty of Soil Science, Eurasian Centre for Food Security) (Moscow, Russia), specialist in the field of GIS, digital soil mapping, soil genesis, soil geography, mapping Solonetz complexes within the Caspian Lowland, computer image analysis. E-mail: mkon@inbox.ru

**Kucher, Anatoly Vasilievich** – Candidate of Pedagogical Sciences, Corresponding Member of the Academy of Economic Sciences of Ukraine, National Scientific Centre 'Institute of Soil Science and Agrochemistry Research named after A.N. Sokolovsky' (Kharkiv, Ukraine), specialist in the field of innovation-investment support of management of salt-affected soils, agrarian economics, environmental economics and soil degradation economics. E-mail: anatoliy_kucher@ukr.net

**Kulov, Kubanychbek Mukanbetovich** – Candidate of Technical Sciences, Irrigation Research Institute of the Kyrgyz National Agrarian University (KNAU) named after K.I. Skryabin (Bishkek, Kyrgyzstan), specialist in the field of soil irrigation and amelioration, sustainable management of land resources, prevention of land degradation and pasture management.

**Kuziev, Razman Kuzievich** – Doctor of Biological Sciences, Institute of Soil Science and Agrochemistry (Tashkent, Uzbekistan), specialist in the field of soil genesis, soil classification and the evaluation of soil resources. E-mail: kuziev_gosniipa@mail.ru; gosniipa@rambler.ru

**Lazebnaya, Marina Evgenievna** – Candidate of Agricultural Sciences, National Scientific Centre 'Institute of Soil Science and Agrochemistry Research named after A.N. Sokolovsky' (Kharkiv, Ukraine), specialist in the field of standardization and metrology. E-mail: pochva@meta.ua; M_Lazebna@ukr.net

**Medvedev, Vitaly Vladimirovich** – Academician of the Ukrainian Academy of Agrarian Sciences (UAAS), Doctor of Biological Sciences, Professor, National Scientific Centre 'Institute of Soil Science and Agrochemistry Research named after A.N. Sokolovsky' (Kharkiv, Ukraine), specialist in the field of soil monitoring, precision agriculture, agrophysics, soil fertility and ecology, methods of soil quality assessment and soil fertility management. E-mail: vvmedvedev@ukr.net

**Nosonenko, Aleksandr Anatolievich** – Candidate of Agricultural Sciences, National Scientific Centre 'Institute of Soil Science and Agrochemistry Research named after A.N. Sokolovsky' (Kharkiv, Ukraine), specialist in the field of irrigation water quality assessment, soil protection, soil halogenesis, ameliorative pedology, technology for amelioration of saline and alkaline soils and precision agriculture. E-mail: oroshenie@ukr.net

**Pankova, Evgenia Ivanovna** – Doctor of Agricultural Sciences, Honored Worker of Science of the Russian Federation, V.V. Dokuchaev Soil Science Institute (Moscow, Russia), specialist in the field of the genesis, geography, mapping and assessment of salt-affected soils in Russia, Central Asia and Mongolia. E-mail: pankova22@mail.ru

**Romashchenko, Mikhail Ivanovich** – Doctor of Technical Sciences, Professor, Academician of the Ukrainian Academy of Agrarian Sciences (UAAS), Institute of Water Problems and Land Reclamation (Kiev, Ukraine), specialist in the field of irrigated land amelioration, ecological and ameliorative assessment and monitoring, planning irrigation regimes (rates and timing) and micro-irrigation technologies. E-mail: iwpim. naan@gmail.com

**Rozloga, Yuri Grigorievich** - Doctor of Biological Sciences, Institute of Pedology, Agrochemistry and Soil Protection named after N.A. Dimo (Chisinau, Moldova), specialist in the field of geographic information systems (GIS), digital soil mapping, digital elevation models, soil genesis, soil degradation and amelioration. E-mail: iu_rozloga@yahoo.com

**Rukhovich, Dmitrii Iosifovich** – Candidate of Biological Sciences, V.V. Dokuchaev Soil Science Institute (Moscow, Russia), specialist in the field of GIS, digital soil mapping and the remote sensing application in soil resource assessment. E-mail: landmap@yandex.ru

**Saakyan, Samvel Varantsovich** – Doctor of Biological Sciences, Professor, Ministry of Agriculture of the Republic of Armenia (Yerevan, Armenia), specialist in the field of soil physics, amelioration of saline and alkaline soils, irrigation and water quality. E-mail: ssahakyan@yandex.ru

**Safarli, Seimur** – PhD, Ministry of Agriculture of the Republic of Azerbaijan, Department of Crop Production (Baku, Azerbaijan), specialist in the field of amelioration of salt-affected lands, irrigation, GIS and digital soil mapping. E-mail: seymur.safarli@agro.gov.az

**Salimov, Fuad** - PhD, Institute of Erosion and Irrigation (Baku, Azerbaijan), specialist in the field of amelioration of salt-affected lands, irrigation, GIS and digital soil mapping. E-mail: fuad1979@mail.ru

**Sanadze, Ekaterina Vasilievna** – Doctor of Agricultural Sciences, Ministry of Agriculture of Georgia (Tbilisi, Georgia), specialist in the field of soil genesis and the rational use of soil resources. E-mail: Ekaterine.sanadze@moa.gov.ge, ekasanadze@yahoo.com

**Sapanov, Mamai Kazievich** – Doctor of Biological Sciences, Institute of Forest Science RAS (Uspenskoe, Moscow Region, Russia), specialist in the field of adaptive forest management under arid conditions, agroforestry, the assessment of climatic influences on vegetation and soil cover and the hydrology of the Northern Caspian Region. E-mail: sapanovm@mail.ru

**Saparov, Abdulla** – Doctor of Agricultural Sciences, Professor, 'U.U. Uspanov Kazakh Research Institute of Soil Science and Agrochemistry' (Almaty, Kazakhstan), specialist in the field of soil science, agrochemistry and ecology. E-mail: ab.saparov@mail.ru

**Savin, Igor Yurievich** – Corresponding Member of the Russian Academy of Sciences (RAS), Doctor of Agricultural Sciences, V.V. Dokuchaev Soil Science Institute (Moscow, Russia), specialist in the field of remote sensing and monitoring of soil resources, digital soil mapping and GIS.

**Solokha, Maksim Aleksandrovich** – Candidate of Geographic Sciences, National Scientific Centre 'Institute of Soil Science and Agrochemistry Research named after A.N. Sokolovsky' (Kharkiv, Ukraine), specialist in the field of remote sensing, GIS and unmanned aerial vehicles. E-mail: solomax@ukr.net

**Solovei, Vadim Borisovich** - Candidate of Agricultural Sciences, National Scientific Centre 'Institute of Soil Science and Agrochemistry Research named after A.N. Sokolovsky' (Kharkiv, Ukraine), specialist in the field of soil genesis, classification and mapping. E-mail: gruntpokrov@ukr.net

**Soloviev, Dmitry Andreevich** – Candidate of Agricultural Sciences, V.V. Dokuchaev Soil Science Institute (Moscow, Russia), specialist in the field of remote sensing application in soil resource assessment and the environmental monitoring of soils.

**Talibov, Izzat** - PhD, Ministry of Agriculture of the Republic of Azerbaijan, Department of Crop Production (Baku, Azerbaijan), specialist in the field of amelioration of salt-affected lands, irrigation , GIS and digital soil mapping. E-mail: izzat.talibov@agro.gov.az

**Tkach, Viktor Petrovich** – Corresponding Member of the Ukrainian Academy of Agrarian Sciences, Professor, G.M. Vysotsky Ukrainian Research Institute of Forestry and Agroforestry (Kharkiv, Ukraine), specialist in the field agroforestry, functions of forests, water-protective and hydrological role of forests, floodplain forestry and salt tolerance in trees and shrubs. E-mail: uriffm@uriffm.org.ua

**Toderich, Kristina Nikolaevna** – Doctor of Biological sciences, Regional Coordinator of the International Centre for Biosaline Agriculture in Central Asia and Transcaucasia (ICBA CAT) (Tashkent, Uzbekistan), specialist in the field of pasture ecology, halophyte diversity, marginal water resources and the commercialization of underutilized salt-tolerant plant resources. E-mail: Kristina@biosaline.org.ae; ktoderich@yahoo.com

**Truskavetsky, Roman Stepanovich** – Corresponding Member of the Ukrainian Academy of Agrarian Sciences, Doctor of Agricultural Sciences, National Scientific Centre 'Institute of Soil Science and Agrochemistry Research named after A.N. Sokolovsky' (Kharkiv, Ukraine), specialist in the field of soil amelioration.

**Truskavetsky, Stanislav Romanovich** – Candidate of biological sciences, National Scientific Centre 'Institute of Soil Science and Agrochemistry Research named after A.N. Sokolovsky' (Kharkiv, Ukraine), specialist in the field of remote sensing data and GIS. E-mail: space1975@mail.ru

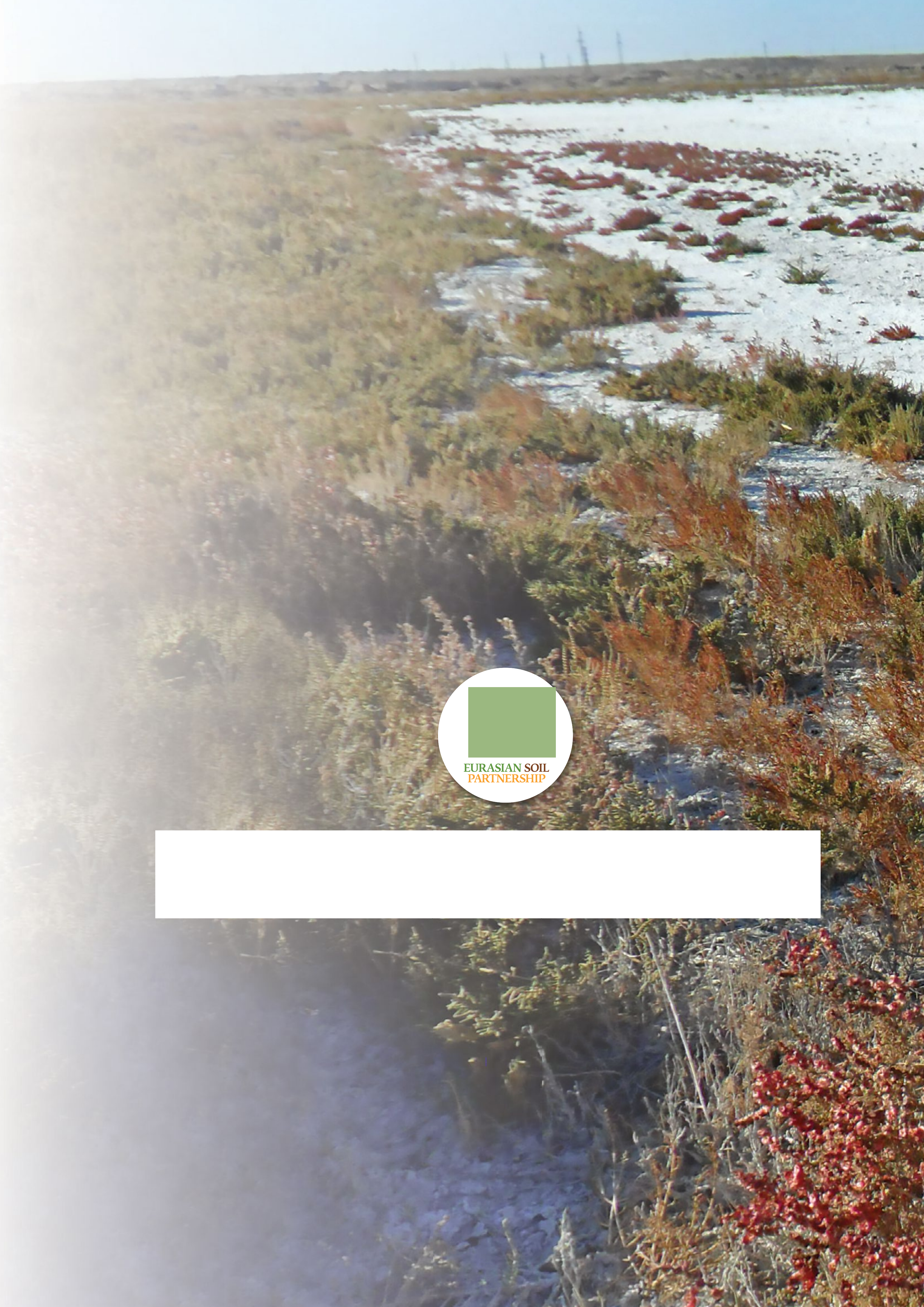
**Vorobieva, Lyudmila Andreevna** – Doctor of Biological Sciences, Honorary Professor of the M.V. Lomonosov Moscow State University (MSU) (Moscow, Russia), specialist in the field of soil acidity and alkalinity, analytical chemistry and theory of the mobility of chemical elements in soils. E-mail: vorla@mail.ru

**Vorotyntseva, Lyudmila Ivanovna** – Candidate of agricultural sciences, National Scientific Centre 'Institute of Soil Science and Agrochemistry Research named after A.N. Sokolovsky' (Kharkiv, Ukraine), specialist in the field of soil conservation, ameliorative pedology and the integrated management of land and water resources. E-mail: oroshenie@ukr.net

**Yamnova, Irina Arkadievna** – Candidate of Biological Sciences, V.V. Dokuchaev Soil Science Institute (Moscow, Russia), specialist in the field of genesis of salt-affected and gypsum- containing soils and the micromorphology of salt and gypsum pedofeatures. E-mail: irinayamnova@mail.ru

**Zakharova, Marina Anatolievna** – Candidate of Agricultural Sciences, National Scientific Centre 'Institute of Soil Science and Agrochemistry Research named after A.N. Sokolovsky' (Kharkiv, Ukraine), specialist in the field of soil conservation, ameliorative pedology, informational support of protection and use of salt-affected soils. E-mail: oroshenie@ukr.net

**Zhovtonog, Olga Igorevna** – Doctor of Agricultural Sciences, Institute of Water Problems and Land Reclamation (Kiev, Ukraine), specialist in the field of irrigation planning, ecological substantiation of irrigation regimes (rates and timing), adaptive irrigation management and integrated management of land and water resources. E-mail: ukr_rep@bigmir.net, olgazhovtonog@aim.com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