Food and Agriculture Organization
of the United Nations

OVERVIEW
OF SOIL CONDITIONS OF ARABLE LAND IN UKRAINE

STUDY CASE FOR STEPPE
AND FOREST-STEPPE ZONES

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
BUDAPEST, 2020

Required citation:
FAO. 2020. *Overview of soil conditions of arable land in Ukraine – Study case for steppe and forest-steppe zones.* Budapest.
https://doi.org/10.4060/ca7761en

ISBN 978-92-5-132215-4

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FOREWORD

This publication reports on the systematic collection of information about soil resource management at farm level with the objective of providing an efficient land market relationship in Ukraine, based on transparency and protecting landowners.

ACKNOWLEDGEMENTS

This publication was prepared by the FAO Regional Office for Europe and Central Asia (REU). Development of the report was coordinated by Tania Santivañez, Agricultural Officer and Regional Initiative 3 Delivery Manager. The main authors are Victoria Panasenko (external expert) and Oksana Ryabchenko, who provided valuable inputs. Important feedback was also provided by Raimund Jehle, Zsuzsanna Keresztes, Mikhail Malkov and Khushnid Sattarov.

Production of the document was coordinated under the supervision and guidance of Vladimir Rakhmanin, Assistant Director-General and Regional Representative for Europe and Central Asia.

INTRODUCTION AND OBJECTIVES

The land in Ukraine is renowned for its high-yield soils. National surveys between 1957 and 1961 identified more than 800 types of soils, with a prevalence of black soils, which accounted for over 60 percent. According to the National Scientific Centre, Institute for Soil Science and Agro-chemistry Research, named after O.N. Sokolovsky, the humus content in the arable layer varies from 0.6 to 6 percent, the humus reserves in the profile vary from 30 tonnes/ha to 600 tonnes/ha, and the capacity of the humus profile varies from 15 cm to 150 cm, depending on the region (Medvedev *et al*., 2018).

However, since the last large-scale study and subsequent updates at the end of the 1970s, the soil cover has undergone significant changes. Despite the lack of recent soil cover surveys and studies, leading soil scientists currently estimate that water erosion affects 13.4 million ha, including 10.6 million ha of arable land.

In 2017, Ukraine produced 60 million tonnes of grain, of which 40 million tonnes were exported. Experts estimate that Ukraine has a potential capacity to produce 100 million tonnes of grain per year. While Ukraine has one of the greatest areas of arable land in the world, it is vital to ensure that it can maintain the current level of crop production taking into consideration climate change and the intensification of agribusiness.

In consideration of the above, the project GCP/UKR/004/GEF "Integrated natural resources management in degraded landscapes in the forest-steppe and steppe zones of Ukraine" was launched by GEF and implemented by FAO in May 2018. The project aims to achieve land degradation neutrality in Ukraine, particularly in steppe and forest-steppe zones.

Although there are data indicating the soil and land conditions in Ukraine, many farmers manage their land resources with no systematic knowledge of soil conditions. This results in soil quality depletion and degradation, leading to decreasing sustainability and worsening livelihood conditions in rural areas.

A pre-project assessment was proposed, entailing an overview of soil conditions in steppe and forest-steppe zones with the aim of developing structural approaches to the soil monitoring system in Ukraine. The approach presented herein can be applied at farm level in line with the national soil monitoring system. All the proposed indicators can be systemized and collected by the responsible authorities. Based on the technical potential of existing laboratories, it could be widely adopted and further incorporated into the national environmental monitoring system to provide the required information on soil conditions.

Objectives of the Overview:

- Report on the soil conditions on arable lands developed for the pilot sites in the steppe and forest-steppe zones.
- Motivate farmers to use proposed generic approaches for monitoring soil conditions.
- Provide the wide range of users with objective information about the arable land gathered by monitoring the soil conditions.

The main consumers of this Overview are farmers; they can use the science-based patterns to monitor the soil conditions of their fields and agrolandscape and optimize production activities while adopting sustainable natural resource management approaches.

The Overview comprises three main sections:

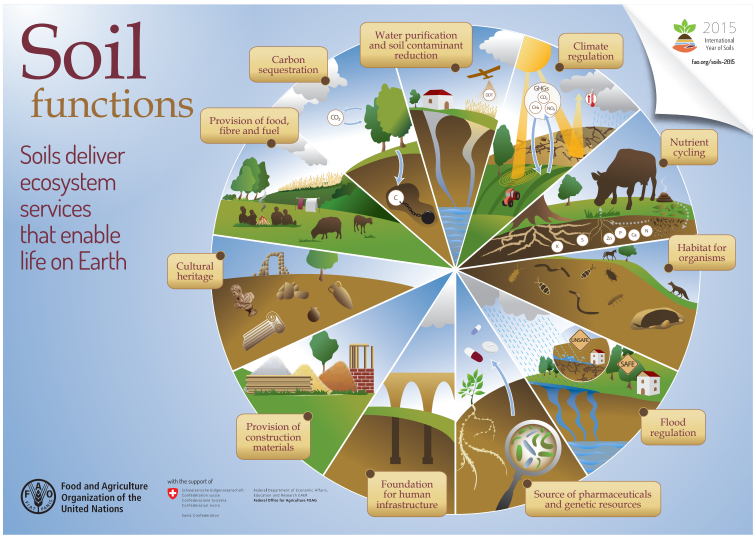
- **Part 1** provides general information about the causes and conditions of the soil erosion process in Ukraine and about available soil resources within the different agro-ecological zones.
- **Part 2** presents brief guidelines of the core methods and data obtained from the pilot plots for the present Overview, including topographical, landscape, geological and agroproduction data, and describes the approaches adopted for data collection and processing.
- **Part 3** is a case study of the steppe and forest-steppe zones based on the results obtained from the complex land conditions analysis of the five pilot farms.

PART 1. SOIL EROSION PROCESSES IN UKRAINE: CONTEXT AND PROFILE DETERMINATION

1.1 FACE OF SOIL EROSION

The vital role of soils – with 95 percent of food produced on soils – can be determined by their productivity, which is directly linked to their fertility. In addition, soils perform a number of other extremely important functions and affect the state of other components of the biosphere (Figure 1). Soil degradation leads not only to destabilization of the food security of the population, but to a violation of the natural balance of the biosphere.

Figure 1. Soil functions



Source: FAO, 2015.

According to FAO, 33 percent of the earth's surface is characterized by erosion. Nine main types of soil degradation have been identified by FAO (Figure 2), namely: loss of organic carbon, loss of nutrients, erosion, salinity, acidification, loss of biodiversity, compaction, contamination and coating, and they all result in loss of soil fertility and land dysfunction (FAO, 2018).

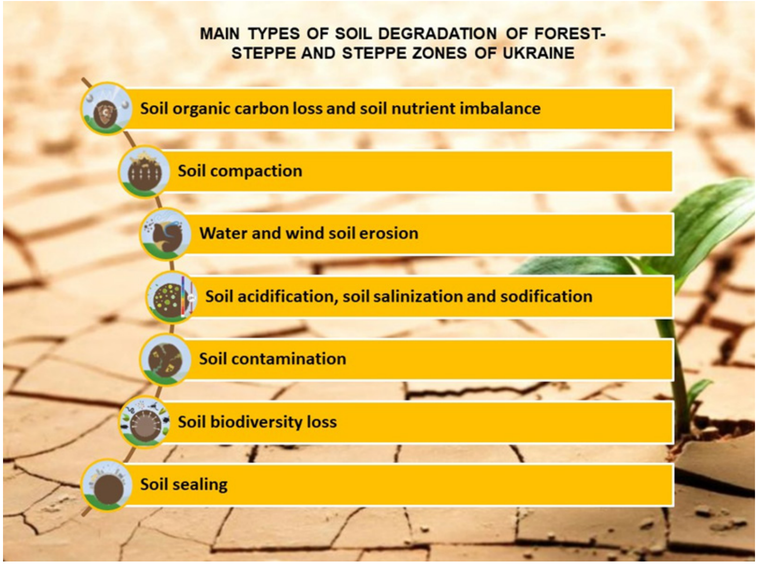
The land in Ukraine is renowned for its high-yield soils. National surveys between 1957 and 1961 identified more than 800 types of soils, with a prevalence of black soils, which accounted for over 60 percent. According to the National Scientific Centre, Institute for Soil Science and Agro-chemistry, the humus content in the arable layer varies from 0.6 to 6 percent, the humus reserves in the profile vary from 30 tonnes/ha to 600 tonnes/ha, and the capacity of the humus profile varies from 15 cm to 150 cm, depending on the region (Medvedev *et al.*, 2018).

However, since the last large-scale study and subsequent updates, the soil cover has undergone significant changes. Despite the lack of recent soil cover surveys and studies, leading soil scientists currently estimate the water erosion affects 13.4 million ha, including 10.6 million ha of arable land.

More than 80 percent of the agricultural land in Ukraine is arable land, and in many regions, this figure exceeds 90 percent. The areas most affected by erosion (≤ 70%) are located in the southern and eastern regions. The annual share of the expansion of eroded land in Ukraine varies from 80 000 ha to 90 000 ha. Of the land areas affected by erosion, 4.5 million ha are medium or severely eroded, including 68 000 ha which has completely lost the humus horizon (Medvedev *et al*., 2018).

The total loss of humus due to mineralization and soil erosion is over 32–33 million tonnes – the equivalent of 320–330 million tonnes of organic fertilizers.

Figure 2. Soil degradation types in Ukraine



Source: FAO, 2018.

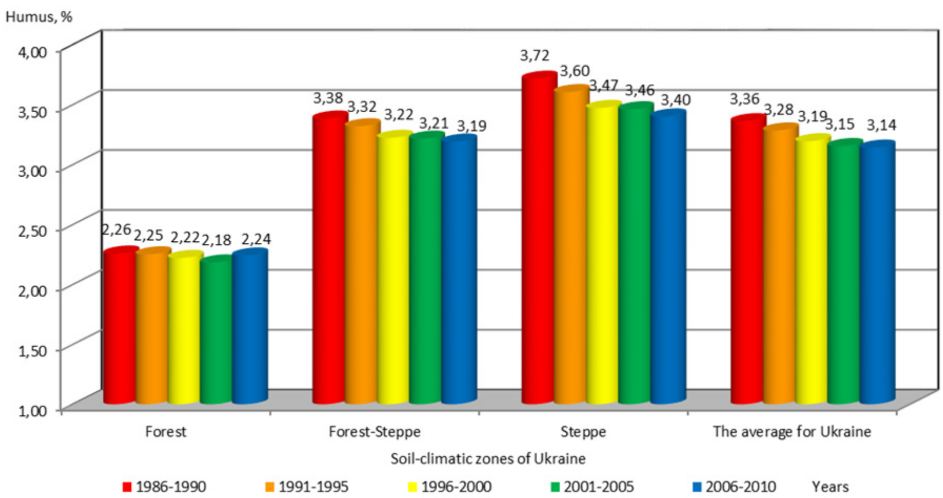
All the types of soil degradation distinguished by FAO (Figure 2) are common in Ukraine. However, some are the result of the specific local climate and agrolandscape: for example, salinity or wind erosion are typical of the steppe zone of Ukraine, while acidification is a common problem for the forest-steppe zone.

The major problem resulting from soil fertility reduction in Ukraine is the loss of humus and nutrients caused both by reductions in biofertilizer application combined with uncontrolled and often baseless usage of chemical fertilizers. For the period 1990–2010, the weighted average humus content in Ukraine decreased by 0.22 percent in absolute values, which is especially noticeable in the steppe zone (Figure 3).

Water and wind erosion have a significant effect on soil degradation in Ukraine. Common phenomena, water and wind erosion spread rapidly over all the arable land, leading to the gradual washing away and destruction of the upper fertile soil layer and exposing land users to new risks and challenges.

Unfortunately, since there is no permanent and structural soil monitoring procedure, no official data are available on the areas affected by water and wind erosion. Nevertheless, current field observations provide strong evidence of the increasing appearances of water erosion (Figure 4).

Figure 3. Dynamics of humus content in Ukraine soils



Source: Ministry of Agriculture of Ukraine, 2010.

The climate and soil characteristics of the steppe zone of Ukraine make it the area most subject to wind erosion. In 2007, extensive areas suffered from a powerful dust storm that covered the Mykolaiv, Kherson, Zaporizhzhia and Donetsk oblasts (regions) (Figure 5). Loss of soil was approximately 200–300 tonnes/ha, accounting for 2–4 cm of the upper fertile soil layer.

Figure 4. Water erosion manifestations in the Poltava oblast

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Figure 5. Consequences of the dust storm in the Mykolaiv oblast (23–27 March 2007)

Source: Grekov et al., 2011.

1.2 SOIL RESOURCES AND THE REASONS FOR SOIL EROSION DEVELOPMENT

1.2.1 SOIL TYPES MAPPING

With regard to the Ukrainian soil map, three important factors must be taken into consideration:

- wide variety of soil types (Figure 6);
- classification differences compared with international standards; and
- absence of recently updated soil map data.

According to the large-scale soil survey in Ukraine, carried out in 1957–1961, there are about 650 types of soils and 4 000 taxonomic units. Chernozem soils (black soils or mollisols, i.e. black-coloured soils containing a high percentage of humus and high percentages of phosphoric acids, phosphorus, and ammonia), which have the highest potential fertility, cover 27.8 million ha or 46 percent of the total area of the country.

Figure 6. Soil map of Ukraine

Source: Soil map of Ukraine, edited by Krupsky, 1977 (Polupan, Solovey and Velychko, 2005).

1.2.2 BACKGROUND

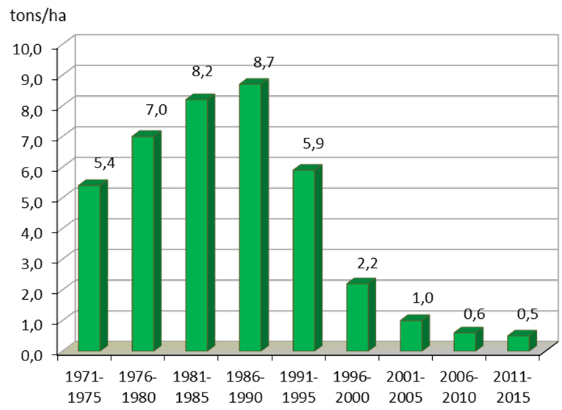
Climate change is one of the principal reasons for the intensification of natural soil erosion processes; especially when combined with unstable and intensive use of soil, climate change can have synergistic effects. As the effects of climate change strengthen and continue, the soil cover may undergo the following changes:

- intensification of erosion processes;
- further reduction of humus content;
- extension of the area affected by soil compaction;
- increase in areas of acidic and saline soils, and/or in areas suffering from lack of moisture etc.

Soil erosion processes are accelerating in Ukraine for various reasons:

- High percentage of arable lands (the highest in the world, accounting for 56 percent of the total territory or 79 percent of the agricultural land area).
- Shortage of organic fertilizers, such as livestock manure (falling from almost 9 tonnes/ha in 1990 to 0.5 tonnes/ha in 2015, Figure 7). Consequently, the main sources of compensation for humus loss are crop residues, by-products (e.g. biocomposts) and green manure crops. However, they are not applied throughout

Figure 7. Biofertilizer application dynamics in Ukraine

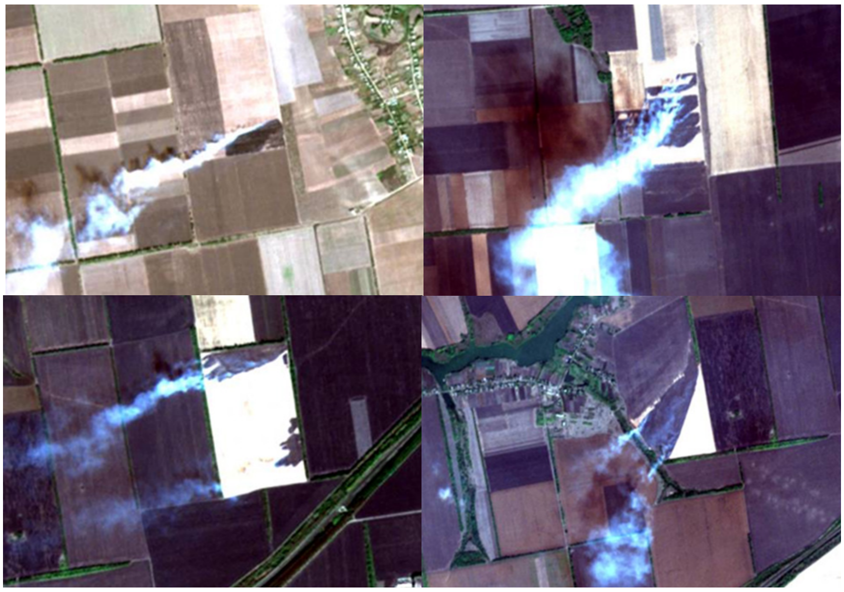


Source: State Statistics Service of Ukraine, 2016.

the country. Moreover, the acute shortage of organic fertilizers is further complicated by the over use of nitrogen fertilizers.

- Lack of efficient regulation mechanisms and structural state policy. Legislative acts do exist in Ukraine to encourage enterprises to adopt environmentally sustainable rational approaches to resource use in agriculture production (e.g. the white documents expressing Land, Water and Air Codes in addition to laws on Environmental Protection, Land Protection, Protection of Atmospheric Air etc.). Thus, in terms of land use, the Land Code of Ukraine (LandCode, 2002) and the Law of Ukraine on Land Protection (LandLaw, 2003) specify the main measures for the economic stimulation of the protection and use of land and the increase of soil fertility by landowners and land users. However, at the same time, the practical implementation of the measures is restrained by the lack of a legally established procedure.
- Open crop residues burning. Open stubble burning in cultivation – which leads to the destruction of soil biota and the combustion of humus in the upper fertile soil layer (Figure 8) – is common practice in Ukraine, despite the fact that it is prohibited by law and offenders are subject to fines.

Figure 8. Open burning of stubble and straw on fields

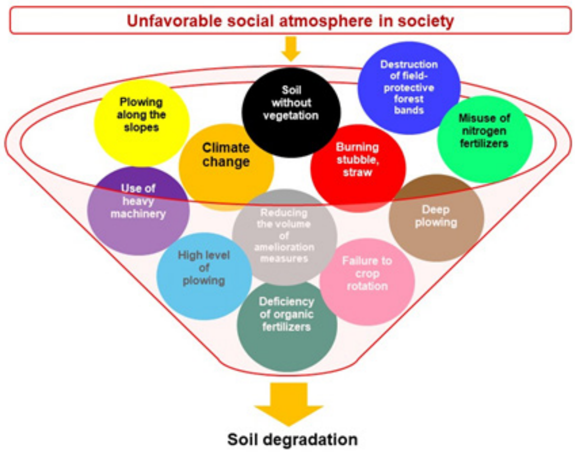


Notes:
Novoukrainskiy district, Kirovohrad region, 27 September 2017 (top left and right);
Belgorod-Dniester district, Odessa region, 30 September 2017 (bottom left);
Dobrovelychkivskyi area, Kirovograd region, 30 September 2017 (bottom right).

Source: Earth Observing System - Land viewer, 2017

The wide range of factors causing soil degradation are all related to the negative social environment (Figure 9).

Figure 9. Main factors causing soil degradation



Source: FAO, 2018.

1.2.3 FOCUS POINTS

The type of soil erosion depends on the environmental conditions of the different regions. Ukraine comprises three main environmental zones (Figure 10):

- steppe (highest proportion of arable land);
- forest-steppe (second highest proportion of arable land); and
- forest (also known as Polissya) (third highest proportion of arable land).

The **forest zone (Polissya)** covers the northern part of Ukraine. It comprises six oblasts (Volyn, Rivne, Zhytomyr, Chernigov, Zakarpattya and Sumy), plus part of Kyiv, and covers 12.3 million ha (19% of the territory of Ukraine).

Characteristics of forest zone:

- Continental climate – annual precipitation of 550–750 mm, average annual temperature of 6–7 °C, vegetation period of 190–205 days and the sum of active temperatures 2 250–2 600 °C.
- Most humid area in Ukraine (especially the western part) – subject to swamping due to the low-lying relief, high precipitation and low evaporation.

The **steppe** zone covers the southern part of Ukraine including the coastal borders and comprises nine oblasts (Luhansk, Donetsk, Kherson, Mykolaiv, Odessa, Dnipropetrovsk, Zaporizhya, Kharkov [part of] and Kirovogradska [part of]).

Characteristics of steppe zone:

- Warmest region in the country – probability of drought 40–70 percent and average annual precipitation 350–540 mm.
- Area where effects of climate change are most felt – in the last decade, a new thermal zone appeared in Odessa and Kherson with the sum of active temperature at over 3 400 °C; the number of days with a maximum daytime temperature of 35–40 °C doubled, and this could lead to dangerous hydrometeorological phenomena.
- Water deficit – of all the arable land in the steppe, about 79 percent (12.5 million ha) has a deficit of ≤ 450 mm of precipitation per year, while 17 percent (2.8 million ha) has a deficit of > 450 mm of precipitation per year.
- Sloping land – 48 percent of agricultural land has a slope of over 1 ° and 38 percent (> 11 million ha) is subject to erosion, including about 5 million ha affected by wind erosion (Baluk, Medvedev and Miroshnichenko, 2010).
- Wind erosion – dust or sand storms occur on 20–35 days during the year, producing wind erosion.
- Water erosion – widespread, caused mainly by the stormy nature of precipitation in the summer (the energy of storms measures 250–1 500 J/m^2).
- Unstable soil surface – the result of interaction between wind and water erosion occurring mainly in winter and spring, especially winters without snowfall.

The **forest-steppe** zone mainly covers the middle part of Ukraine and comprises twelve oblasts (Lviv, Ivano-Frankivsk, Sumy [part of]), Kharkiv [part of]), Poltava, Kyiv, Cherkasy, Vinnytsia, Khmelnytsk, Ternopil, Chernivtsy [part of]), Kirovograd [part of]).

Characteristics of forest-steppe zone:

- Climate – moderate warm, precipitation from 600 mm in the west and north to 500–450 mm in the south and east; more evaporation than in Polissya, therefore no excessive moistening; average annual temperature 7–8 °C; duration of vegetation season 200–210 days, sum of active temperatures 2 600–2 800 °C (up to 3 000 °C in the south).
- Soil cover – fertile, high-yielding black soils, among others.
- Natural erosion processes accelerated by human activities – degradation characterized by acidification.
- Wind erosion – moderate, developing at wind speeds of over 10 m/s; northeasterly and southeasterly winds most likely to produce erosion; localized phenomenon mostly occurring in early spring.
- Sloping land – 76 percent of land is sloping, including about 30 percent characterized by eroded soils to varying degrees.
- Water erosion – predominant, the result of drainage of thawed waters and the stormy nature of precipitation (energy of storm rainwater reaches 1 500 J/m^2); affects more than 4 million ha, with deflation of about 1 million ha of land.
- Most favourable area for agricultural activities – arable lands account for 60–80 percent of total area.
- Highest level of shifting (in terms of resource availability and seasonality) – the result of climate change, water accessibility and intensive agriculture.

The agricultural capacity of Ukraine is concentrated in the steppe and forest-steppe zones. These areas are at the same time at significant risk due to the fast-changing climate conditions. For this reason, the steppe and forest-steppe zones urgently require soil monitoring and land-use control. The project has focused on the steppe and forest-steppe zones, given their high susceptibility to degradation processes and the saturation by agricultural producers. Project pilot sites were selected in the steppe and forest-steppe zones (Figure 10) with a view to identifying the current soil conditions.

Figure 10. Location of pilot sites in Ukraine

Source: FAO, 2018.

PART 2. DETERMINING PARAMETERS FOR OVERVIEW OF SOIL CONDITIONS

2.1 PILOT FARMS SELECTION

In order to implement the project, "Integrated management of natural resources of degraded lands of forest-steppe and steppe zones of Ukraine", information was collected about the agrolandscapes of five pilot sites located in two soil–climatic zones of Ukraine: forest-steppe and steppe (Figure 10).

Forest-steppe zone:

- **Farm 1FS** – experimental polygons of the Ukrainian research institute for the prediction and testing of techniques and technologies for agricultural production (Leonid Pogorilyy UkrNDIPVT, in Grebinkivska village council, Vasylkivsky district, Kyiv oblast).
- **Farm 2FS** – privately owned agricultural enterprise (POAE Burlutske, in Velykoburlutska village council, Velykoburlutsky district, Kharkiv oblast).

Steppe zone:

- **Farm 1S** – agricultural company (Podolivska, in Ilyichevska, Gusarivska, Bogodarivska and Barvinska village councils, Barvinsky district, Kharkiv oblast).
- **Farm 2S** – agricultural private joint stock company (APJSC Ukraine, in Mostivska village council, Domanivsky district, Mykolaiv oblast).
- **Farm 3S** – experimental farm in Velykyi Klyn village (institute of water problems and melioration, National Academy of Agriculture Sciences, in Tavriysky and Gladkivsky village councils, Goloprystansky district, Kherson oblast).

Each pilot farm is characterized by a different type of ownership, which may be relevant in future studies of the relationship between landownerships, agriculture technology applied and soil conditions.

Three different approaches were applied for soil condition assessment:

- **Standard** – combination of digital monitoring and plot overviewing, with agrochemical and ecotoxicological analysis of the testing site (applied on farms 1FS, 2FS and 2S).
- **Visual** – rapid digital inspection of fields to gauge current situation of erosion processes (applied on farm 1S).
- **Extended** – the most applicable or basic methods for this study; compared with the standard approach, comprises two extra parameters (physicochemical soil estimation and characteristics according to granulometric composition) (applied on farm 3S).

The extended method is the most suitable in terms of soil monitoring in extremal environmental conditions; it also enables inspection of agrolandscapes for agroproduction practices combined with agroforestry activities.

2.2 DATA COLLECTION, ANALYSIS AND RELIABILITY EVALUATION

As part of the process of monitoring land covering and land productivity, the information about the pilot sites related to the following:

- field schemes;
- high resolution satellite images of the pilot farm areas;
- cartograms of agroproduction groups of soils or other soil maps;
- topographic maps;
- meteorological data;
- crop structure and yields statistics;
- production technological maps;
- fertilization and plant protection systems.

In the initial stages of the project, all five sites were requested to provide the above information. The data were then analysed, information gaps were identified and possible sources for obtaining the missing data were pinpointed, including open source Internet resources, state institutions and institutes.

The cartographic data requirements – form and type – were defined as follows:

- **Satellite images:** including visible bands, with spatial resolution of ≤ 10 m and no cloud coverage, WGS84 geographic coordinates system, geographic projection (latitude/longitude) WGS84/EPSG: 4326.
- **Cartograms** of agroproduction groups of soils: in jpg format, including data on soil survey correction from 1970 to 1990 (scale 1: 25 000), a legend with the names of all agroproduction soil groups, and a code marked on each mapped agroproduction soil group.
- **Topographic maps:** declassified maps of the General Staff of Ukraine, developed in 1970–1980, jpg format, scale 1: 100 000, Pulkovo 1942 coordinates system.

Where possible, data sources were identified and a list compiled. Data collection was then carried out based on this list. The reliability of the information received from the pilot farms was assessed to see if it complied with the above-mentioned requirements.

2.3 DIGITAL MAPS DEVELOPMENT

For the analysis and assessment of the farm agrolandscapes, soil–climatic conditions, relief and field-protective forest belt systems, all the cartographic materials collected were merged to develop electronic maps of the farms. It was thus possible to combine and synthesize all kinds of information and define a set of conditions for growing crops and the environment.

Digital maps were developed using ArcMap software. The process included selection and downloads of satellite images in geographic coordinates systems, georeferencing of raster cartographic maps to satellite images, vectorization of these cartographic materials and combination of all the newly created layers (Annex 1)

All raster maps (maps of agroproduction soil groups and topographic maps) were georeferenced into WGS84 geographic coordinate systems, geographic projection (latitude/longitude) WGS84/EPSG: 4326. Georeferencing was based on the set of control points obtained from the satellite images that had been preloaded from open Internet resources.

The vectorization of cartographic materials and the creation of shape files were done in the WGS84 geographic coordinate system in the following order:

1. Boundaries of the pilot farm fields.
2. Boundaries of the agroproduction soil groups.
3. Isohypses (contour lines of identical heights in the relief) from topographic maps.

Field boundaries were detected based on satellite images, raster land lot schemes or raster field schemes.

Digital soil maps of the pilot farms were developed using the georeferenced satellite images. The raster scheme of agroproduction soil groups overlapped with previously mapped field schemes. The vectorized/digitized cartogram of agroproduction soil groups made it possible to estimate the soil cover variability on each field (Annex 1).

Vectorization of the isohypses (contour lines) involved topographic map georeferencing to the satellite image and overlapping with the electronic field scheme. ArcMap tools were used for isohypses vectorization.

Finally, the layers of digitized field schemes, the boundaries of agroproduction soil groups and the isogyps from topographic maps were overlapped with satellite images of the study area. This made it possible to analyse various kinds of information and draw objective conclusions.

Test site selection was carried out based on a comprehensive assessment of the soil typology, agrolandscape, relief, climate conditions etc. Soil sampling points were determined using existing soil survey materials, relief maps (topographic maps) and high-resolution satellite imagery. Fields exposed to water and wind erosion were identified using satellite imagery.

Areas of relief were identified as potentially erosion-hazardous: the risk of erosion is particularly high where there are multidirectional slopes, dome-shaped fields, narrow and short watersheds. The field boundaries – with an overlapping layer of soil cover – tended to correlate with the contours of relief elements. Soil sampling locations were determined based on magnitude and orientation of soil difference, slope elevation and water erosion manifestation on the satellite images. A fieldwork map was created to support the tasks in the field. Using the geographical coordinates of each sampling point, an electronic fieldwork map was loaded to a GPS-navigated tablet, which could then be used to detect a location on the field map.

To create all maps ArcPad software was used.

2.4 SOIL PARAMETERS

A review of the scientific literature on agrosoil zoning of the Kyiv, Kharkiv, Mykolaiv and Kherson oblast was carried out, and literary sources, scientific works and soil maps of Ukraine were consulted. A brief description of the soil cover was compiled and the prevailing soil types were determined. On this basis, it was possible to assess the representativeness of the soil cover of the selected pilot farms for the region and soil–climatic zones (forest-steppe and steppe zones).

The analysis of the soil cover of the pilot farms comprised two stages:

- First, the electronic Public Cadastral Map of Ukraine (freely accessible online)[1] was analysed.
- Second, the schemes of agroproduction soil groups[2] were processed; the scale is more detailed (1: 25 000) and they more closely reflect the variegated soil cover of the study areas.

The development of soil erosion processes was analysed according to the schemes of agroproduction soil groups, which indicate the degree of soil lost through erosion. In addition, topographic maps with height isohypses and recent satellite imagery in visible band – which visually reflect manifestations of water erosion of the soil – were used. Further, an overview of the landscape and soil cover of the pilot farms was conducted during field surveys.

For the standard assessment, soil samples were analysed for 14 indicators in four different categories:

- agrochemical (content of nitrate, moving forms of phosphorus, potassium, humus content);
- physicochemical (pH, content of Ca^{2+} and Mg^{2+} cation exchangers),
- physical (granulometric composition); and
- ecotoxicological (heavy metals content - Zn, Cu, Pb, Cd, pesticide residues).

All soil samples were analysed for four indicators: nitrate nitrogen content, mobile phosphorus, potassium and humus content. Other indicators were determined only in some samples, depending on soil–climatic zone (pH), constancy (granulometric composition) and low dynamics of these parameters (heavy metals, exchange cations).

For the extended approach, additional physicochemical indicators were provided: pH_{water}, pH_{salt}, hydrolytic acidity, absorption capacity, absorbed basics, solid residual matter and water extraction.

Soil sampling was conducted in accordance with National Standards (DSTU 4287: 2004) (Annex 2) “Soil quality. Soil sampling”. Samples were taken at depths of 0–30 cm of the arable horizon and placed in paper bags with appropriate labels and sent for analysis in the laboratory.

2.5 AGRICULTURAL PRODUCTION CONDITIONS

The pilot farms provided almost homogeneous input parameters on agricultural production conditions (Table 1), namely: scheme of fields/land lots, crops grown during 2016–2018, yields, technology map, and fertilizer and plant protection systems. Other sources provided the data relative to soil types and conditions, landscape and forest belts, in addition to remote sensing data.

It should be noted that farms 1FS and 2S are state-owned scientific institutions, while the other three pilot farms (2FS, 1S, 2S) are privately owned companies.

[1] http://map.land.gov.ua/kadastrova-karta

[2] The names of agroproduction soil groups are indicated in accordance with the Nomenclature List, approved by the Decree of the Cabinet of Ministers of Ukraine on 17 October 2012: No. 1051 "On Approval of the State Land Cadaster Management".

Table 1. Production information provided by pilot farms

No.	Type of the information	Availability at the farm*	Credibility	Data format
Farm 1FS				
1.	Field schemes	+	reliable	Land use scheme, jpg
2.	Satellite images over the study areas	–	–	–
3.	Schemes of agroproduction soil groups and other soil maps	–	–	–
4.	Topographic maps over the study areas	–	–	–
5.	Meteorological data	–	–	–
6.	List of crops and yields	+	reliable	Table, Excel
7.	Agricultural machinery	+	reliable	Table, Excel
8.	Systems of fertilizers and plant protection	+	reliable	Table, Excel
9.	Information on the availability and condition of protective forest belts	–	–	–
Farm 2FS				
1.	Field schemes	+	reliable	Electronic land lots schemes
2.	Satellite images over the study areas	–	–	–
3.	Schemes of agroproduction soil groups and other soil maps	–	–	–
4.	Topographic maps over the study areas	–	–	–
5.	Meteorological data	–	–	–
6.	List of crops and yields	+	reliable	Table, Excel
7.	Agricultural machinery	+	reliable	Table, Excel
8.	Systems of fertilizers and plant protection	+	reliable	Table, Excel
9.	Information on the availability and condition of protective forest belts	–	–	–
Farm 1S				
1.	Field schemes	+	reliable	Electronic land lots schemes
2.	Satellite images over the study areas	–	–	–
3.	Schemes of agroproduction soil groups and other soil maps	–	–	–
4.	Topographic maps over the study areas	–	–	–
5.	Meteorological data	–	–	–
6.	List of crops and yields	+	reliable	Table, Excel
7.	Agricultural machinery	+	reliable	Table, Excel
8.	Systems of fertilizers and plant protection	+	reliable	Table, Excel
9.	Information on the availability and condition of protective forest belts	–	–	–
Farm 2S				
1.	Field schemes	+		
2.	Satellite images over the study areas	–	–	–
3.	Schemes of agroproduction soil groups and other soil maps	–	–	–
4.	Topographic maps over the study areas	–	–	–

No.	Type of the information	Availability at the farm*	Credibility	Data format
5.	Meteorological data	–	–	–
6.	List of crops and yields	+	reliable	Table, Excel
7.	Agricultural machinery	+	reliable	Table, Excel
8.	Systems of fertilizers and plant protection	+	reliable	Table, Excel
9.	Information on the availability and condition of protective forest belts	–	–	–
Farm 3S				
1.	Field schemes	+		
2.	Satellite images over the study areas	–	–	–
3.	Schemes of agroproduction soil groups and other soil maps	–	–	–
4.	Topographic maps over the study areas	–	–	–
5.	Meteorological data	–	–	–
6.	List of crops and yields	+	reliable	Table, Excel
7.	Agricultural machinery	+	reliable	Table, Excel
8.	Systems of fertilizers and plant protection	+	reliable	Table, Excel
9.	Information on the availability and condition of protective forest belts	–	–	–

*Note: * + represents "information provided by the farm"; – represents "no information at the farm".*

PART 3. OVERVIEW OF SOIL CONDITIONS

3.1 FOREST-STEPPE ZONE

Farm 1FS (Standard)

The Kyiv region, where the pilot farm is situated, is located in the transitional soil-climatic zone and stretches from Polissya through the forest-steppe, resulting in a wide variety of soil cover from low-yield sod-podzolic soils to typical fertile chernozem soils. The soil cover of the Kyiv region comprises compound complexes and mosaics, characterized by shallow contours, a high degree of differentiation of soil types, and a significant contrast of soils. The full variety of soils covers 23 major agroproduction soil groups.[3]

Based on the soil–climatic conditions, the region is divided into **five agro-soil regions:**

- northern polissky;
- southern polissky (transitional to the forest-steppe zone);
- plain chernozem soils;
- southern forest-steppe; and
- left-bank terraces.

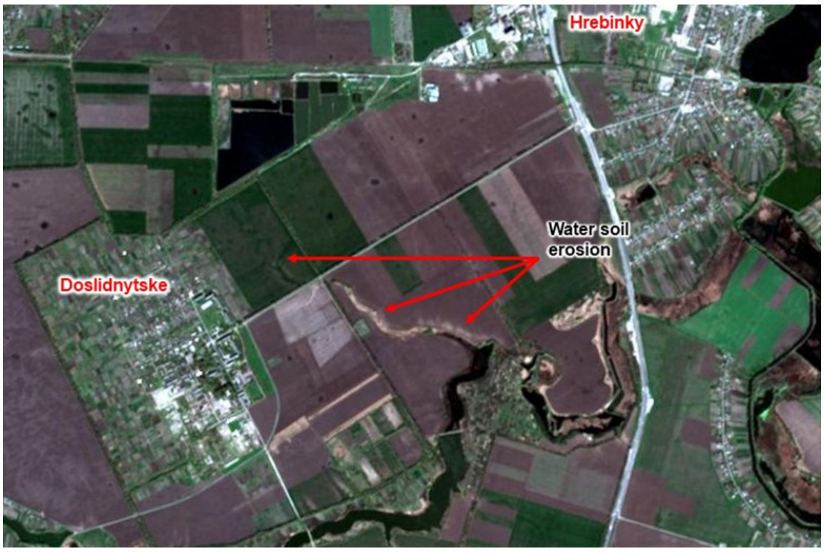
Farm 1FS is located in the plain chernozem soils region, which is part of the forest-steppe zone. The forest-steppe zone area of the Kyiv region has homogeneous soil cover and the main soil types are typical chernozem soils and alfisols (grey forest soils).

The moderate climate, adequate humidification and natural vegetation have contributed to the formation of zonal chernozem soils with a complete soil profile. According to the agroproduction soil groups map designed by the State Research and Design Institute of Land Management[4], the soil cover of the test areas is mostly homogeneous, not variegated, and is represented by the zonal soils of the forest-steppe zone of Ukraine – typical chernozem soils, low and medium loamed, slightly and moderately eroded subtypes. The gullies and river floodplains of the study areas are characterized by meadow soils and meadow chernozem soils and their alluvial subtypes, as well as sod and meadow soils and their gleysol and alluvial subtypes.

The land-use management is characterized by plain aligned landscape: the fields are aligned, with almost no slopes, or no significant slopes on most of the fields. The satellite images indicate the absence of erosive process development throughout the study areas. Weak- and medium-eroded soils are observed on short slopes near the channels of water bodies (Figure 11). These areas do not significantly change the characteristics of the soil cover of the territory.

3 There are no state standards for grouping according to the content.
4 http://www.zem.kiev.ua/

Figure 11. Erosion processes detected on satellite image, farm 1FS (18 April 2018)



Source: Earth Observing System - Land viewer, 2018

The deep, humus-rich soil profile indicates that there is no intense manifestation of degradation processes in the form of surface water erosion. In many cases, the availability of such soils depends on the landscape, and they are typical of flat and wind-protected plots.

The preliminary analysis of the potential fertility and soil safety of the site was performed based on five samples taken from five different fields, since the majority of the experimental fields are located in one agro-industrial group of soils, that is, the typical chernozems low and middle loamed on the plain relief. The exception is sample No. 15, which was selected on the short slope of field No. 5, in the water erosion zone characterized by medium eroded soils (Figure 11). Consequently, with the exception of sample No. 15, the development of erosion processes on this pilot farm is not due to natural factors, but is the result of anthropogenic activity.

Agrochemical analysis of soil samples from the test fields (recorded during the reconnaissance survey) revealed high and increased humus content (Table 2). The lowest humus content was found in sample No. 15, which may be due to the washouts of the upper humus horizon. The soil solution of all soil samples was slightly alkaline, that is, consistent with the norm. No evident patterns emerge with regard to nutrient content (nitrogen, phosphorus, potassium) in the soils as a result of agricultural technologies. Although nutrient content is low, it does not indicate soil exhaustion or a degraded condition; it corresponds to the concept of effective fertility and is possibly connected to the inefficiency of the existing crop rotation or fertilizer systems.

Table 2. Soil characteristics of farm 1FS (agrochemical indicators)

No.	Soil sample No.	Field No.	Agrochemical indicators of soil fertility								
			Humus		pH of acids		$N\text{-}NO_3$*	P_2O_5		K_2O	
			%	Level	pH	Level	mg/kg	mg/kg	Level	mg/kg	Level
1	14	2B	3.9	increased	7.5	low alkaline	10.3	16.9	average	110.29	average
2	15	5	3.4	increased	7.2	low alkaline	14.3	20.3	average	111.43	average
3	16	3A	3.5	increased	7.4	low alkaline	10.2	110.9	very high	333.3	high
4	17	2A	4.3	high	7.4	low alkaline	4.4	20	average	159.19	average
5	18	1A	3.9	increased	7.4	low alkaline	1.8	12.8	low	162.69	average

*Note: * There are no state standards for grouping according to the content.*

The level of heavy metal contamination (e.g. Zn, Cu, Pb) in soil samples is generally weak; only Zn is between weak and moderate (Table 3). However, none of the elements exceeds the maximum permissible concentration (MPC). For the main project, research and analysis may be limited to zinc on the 1FS fields, taking into account the possibility of its horizontal and vertical migration. Nevertheless, the data on the state of the soils reveal an acute shortage of mobile forms of zinc across most of Ukraine's territory and it can be concluded that there is a very low risk of contamination of agricultural products by this element.

In 16 soil samples, traces of three pesticides – DDD, DDE and flutriafol – were detected. The latter two are derived from DDT, which it is forbidden to use. It is a very stable organochlorine compound and although it has not been used for several decades, traces continue to be found in the soils of fields where it was once used. Nevertheless, the content of these substances does not exceed permissible levels.

No manifestations of other non-erosion soil degradation processes were visible on the satellite images; to detect these processes, field soil surveys must be carried out. The farm 1FS fields are adapted for the testing of new soil-protection technologies depending on the soil cultivation system, crop rotation and organic matter preservation practices.

Table 3. Soil characteristics of farm 1FS (ecotoxicological indicators)

No.	Soil sample No.	Field No.	Soil safety parameters										
			Heavy metals (gross form)								Residual pesticides		
			Zn[1]		Cu[2]		Cd[3]		Pb[4]				
			mg/kg	Pollution level	mg/kg	Pollution level	mg/kg	Pollution level	mg/kg	Pollution level	Detected pesticide	mg/kg	ND norms
1	14	2Б	20.42	moderate	8.84	weak	0.13	weak	5.16	weak	–	–	–
2	16	3A	–	–	–	–	–	–	–	–	DDE	< 0.01	0.1
											DDT	< 0.01	0.1
											Flutriafol	0.016	0.1

Notes: [1] MPC (Zn, gross form) – 55 mg/kg.
[2] MPC (Cu, gross form) – 38 mg/kg.
[3] MPC (Cd, gross form) – 3.0 mg/kg.
[4] MPC (Pb, gross form) – 22.0 mg/kg.

Farm 2FS (Standard)

The Kharkiv region is located in the northeastern part of the left bank of the Dniper river within the two climatic zones: forest-steppe and steppe. This results in a diversity of soil cover with over 150 varieties of soils. The greatest variety is observed in the forest-steppe zone of the Kharkiv region. The northern forest-steppe part of the region comprises typical chernozem soils, alfisols, dark grey podzols and regraded chernozems, and podzol chernozems.[5]

As the arable land expanded during the 1970–1980s and the relief of the region underwent significant dissection, soil erosion became an increasing phenomenon, dangerous for vast areas. Agricultural arable land currently accounts for almost 80 percent of the property in the region.

Farm 2FS is located in the eastern transitional forest-steppe sub-area. According to the map of agroproduction soil types, the soil cover of the fields is represented by medium-humus typical chernozem soils, strongly regraded heavy loam chernozem soils and light clay soils and chernozem their slightly and medium eroded subtypes. There are also dark grey podzols, chernozem podzols and regraded medium eroded chernozems. Locally, there are non-alkaline and slightly alkaline chernozem soils on tight clay with different washout rates.

The territory of the farm is clearly structured and the fields usually fit in with the natural plots forms and borders, adapting to the landscape. Despite the well-developed gully-valley system, soil bodies appear as large homogeneous massifs, which create soil cultivation conditions suited to the use of large-scale agricultural machinery. Based on

5 Kryn (Gryn), 1955.

preliminary observations of the land and an analysis of the archival data – in particular, satellite images – it can be concluded that the principles of precision agriculture should be introduced. The steep slopes along the ravines are subject to intensive processes of erosion requiring agrotechnical and reclamation measures.

Figure 12. Erosion processes detected on 2 satellite image, farm 2FS (14 April 2018)

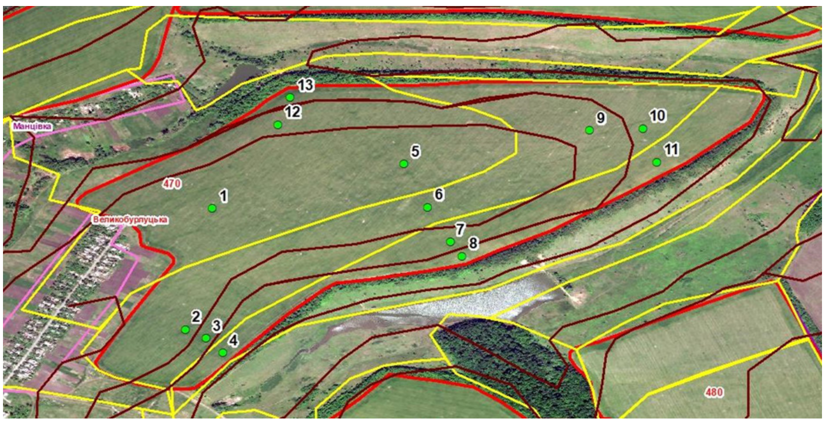
Source: Earth Observing System - Land viewer, 2018.

The pilot farm is characterized by significant relief dissection with well-defined areas of erosion – both linear and surface (Figure 12).

Many farm fields are located in broad inter-gully areas forming large sloping areas. All the slopes have a characteristic feature: they tend to be slightly inclined (0–2 °) in the upper part of the slope and to slope at an angle of 5–7 ° in the lower part. This contributes to the development of degradation processes, specifically, linear and surface water erosion. As the erosion develops, the soil surface layer dries in the summer, cracks and recompacts; this causes water absorption to deteriorate, leading to a significant reduction in potential fertility. The introduction of mineral fertilizers produced much less economic effect than had been calculated, due to the deterioration of hydrous and physical properties. Moreover, additional agrotechnical measures are necessary to deconsolidate the soil and improve the aeration and moisture content; the result is inevitable increases in production costs. The lack of soil protection technologies in the farm's agricultural management system means that it is not possible to achieve potential crop yields with limited financial resources.

Based on visual observations and analysis of the meteorological situation in March–April 2018, and on years of expert evidence, it may be concluded that the spring is characterized by less intense snow melting and slower air warming; as a result, the soil is physically mature in time for spring field operations. A local microclimate forms with a favourable water regime in the soils, leading to good germination and, possibly, the absence of air and soil droughts during cob and kernel development in grain crops. These local climatic features can be managed to favour crop production. Soil cover properties, in combination with weather and climate conditions in the region, need to be thoroughly investigated during project implementation. A soil-protecting, balanced agri-cultural system needs to be developed, capable of increasing the productivity of agricultural crops, optimizing the use of mineral fertilizers, increasing the profitability of agricultural production and reducing the level of soil cover degradation to neutral.

Figure 13. Scheme of samples location within study area



480 – *field boundaries;* – *boundaries of the agro-production soil groups;* – *isohypses with height;* 5 – *sampling point location and number*

Source: FAO, 2018.

The field selected for the reconnaissance survey and soil sampling for agrochemical analysis was located on a multidirectional slope; the sampling points were located along the north-, south- and east-facing slopes (Figure 13).

The plateau has a very high humus content, due in part to the type of soil: typical chernozems (Table 4). The redistribution of organic matter on the slopes depends on the length and angle of the slope. For example, on the long south-exposed slope, the difference between the organic matter content on the plateau and on different parts of the slope is clearly visible, while on the short south-facing slope, humus content does not change significantly. The soils on the northern slope have a thicker morphological profile and thicker humus genetic horizons, good structure of the surface horizon and water permeability; as a consequence, the slope has little exposure to surface or linear erosion, because the water flow from snowmelt or showers does not gain the kinetic energy required for the development of degradation.

Table 4. Soil characteristics of farm 2FS (agrochemical indicators)

No.	Soil sample No.	Field No.	Agrochemical indicators of soil fertility								
			Humus		pH of acids		$N\text{-}NO_3$*	P_2O_5		K_2O	
			%	Level	pH	Level	mg/kg	mg/kg	Level	mg/kg	Level
1	1	5.4	very high	5.4	slightly acid	9.1	83.5	average	129.19	high	average
2	2	4.9	high	6.7	neutral	14.2	485	very high	347.52	very high	average
3	3	4.5	high	7.3	low alkaline	9	65.1	very high	969.81	very high	high
4	4	4.9	high	7.1	low alkaline	10.1	17.5	average	214.28	increased	average
5	5	5.4	very high	5.7	close to neutral	3.4	59.5	very high	116.54	increased	average
6	6	3.8	increased	7.3	low alkaline	6.4	12.8	low	217.03	increased	average
7	7	4.3	high	7.3	low alkaline	8	7.5	low	199.58	average	average
8	8	4.2	high	7.2	low alkaline	4.1	21.7	average	235.51	increased	high
9	9	5.4	very high	6.7	neutral	28.7	42.5	low	142.84	high	average
10	10	5.3	very high	6.7	neutral	9.9	64.5	average	117.48	increased	average
11	11	5.5	very high	5.6	close to neutral	19.3	44.5	low	156.41	average	high
12	12	5.3	very high	7.2	low alkaline	5.9	13.1	low	229.36	increased	average
13	13	5.2	very high	7	neutral	14	16.6	low	253.9	increased	average

The pH value varies from slightly acidic on the plateau to neutral and low alkaline on the slopes. There is no clear distribution of nutrition elements over the soil bodies; indeed, nutrient distribution may depend on the land management systems.

Ecotoxicological analysis of the soil showed that the gross content of zinc and copper corresponds to average and moderate levels of contamination, but does not exceed the MPC – although the zinc level does come very close (Table 5). The content of cadmium and lead corresponds to a low level of pollution and does not exceed the MPC. However, given that the content of heavy metals is significantly higher than the background level, further study is required, in particular, with regard to the possible migration of elements to the lower horizons of the soil when performing the main project. This means that the situation with heavy metals requires further observation due to their ability to migrate.

Traces of systemic fluorophosphate fungicide have been detected in five soil samples, but the content does not exceed the MPC.

Table 5. Soil characteristics of farm 2FS field 470 according to ecotoxicological indicators

No.	Soil sample No.	Field No.	No.										
			Heavy metals (gross form)								Residual pesticides		
			Zn		Cu		Cd		Pb				
			mg/kg	Pollution level	mg/kg	Pollution level	mg/kg	Pollution level	mg/kg	Pollution level	Detected pesticide	mg/kg	ND norms
1	1	41.82	average	15.66	moderate	0.2	weak	8.74	weak	–	–	–	–
2	2	39.14	moderate	14.63	moderate	0.22	weak	6.65	weak	–	–	–	0.1
3	10	42.89	average	16.01	moderate	0.14	weak	8.51	weak	–	–	–	0.1
4	5	–	–	–	–	–	–	–	–	Flutriafol	0.018	0.1	0.1

3.2 STEPPE ZONE

Farm 1S (Visual)

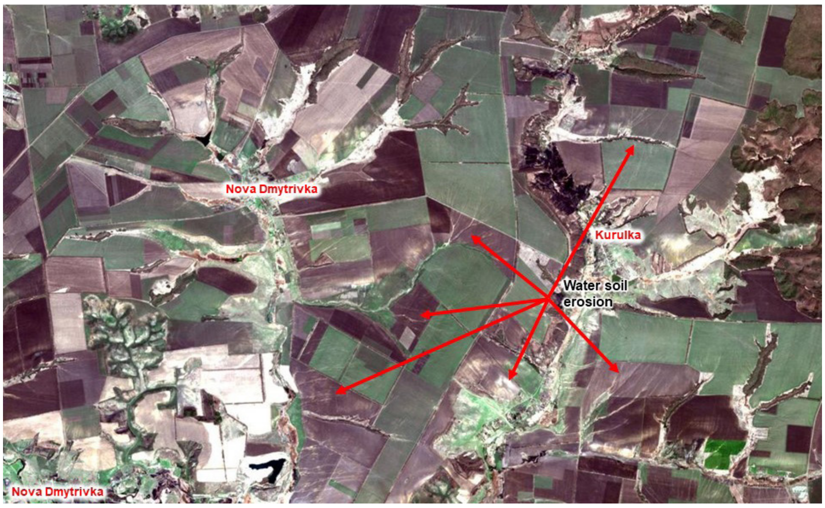
The territory of farm 1S is located in the eastern steppe agro-soil area of the Kharkiv region. According to the map of agroproduction soil groups, the prevailing soils in the pilot farm fields in Ilyichevsk, Podolivska and Ivanivska village councils are: chernozem typical heavy loam soils and light clay soils and their different eroded subtypes; and chernozem typical low- and medium-humus soils, heavy loam soils and their slightly alkaline soil bodies. Locally, there are non-alkaline and slightly alkaline chernozem soils on tight clay with different washout rates. Along the gullies there are dark grey podzols and regraded chernozems, as well as podzol chernozems and regraded slight- and medium-eroded heavy loam chernozem soils. There are alluvial chernozems and heavy loam and slightly clay meadow chernozem soils in the valleys.

Most fields are average size, rectangular and well surrounded by weather-resistant shelter belts. There are steep slopes with signs of water erosion that are clearly tracked on the satellite images in the fields adjacent to the gullies and valleys (Figure 14). Surface erosion is detected on the images: the surface is lighter toned in areas with medium and strongly eroded soils. Slightly eroded soils have a dark grey background colour on satellite images and, therefore, they can usually only be identified with traditional soil surveys. Linear erosion is easier to detect on satellite images: it is possible to identify all the phases of linear erosion formation, from small streams to intensive deep-cut erosion. The length and angle of the slopes play a major role in shaping modern agrolandscapes. Erosion processes also depend on the agrotechnics of crop cultivation, the granulometric composition of the soils and the parent rock of the territory.

In some fields, it is evident that even the presence of a complete field-protective forest belt does not protect the soil from the development of linear erosion (Figure 15). Water streams cut through the forest strips, leave the small meadow and continue along the slope, breaking into the parent rock. In steep-sloped areas, it is not enough to implement surface agrotechnical measures: it is vital to determine which factors prevent moisture absorption and contribute to the development of erosion.

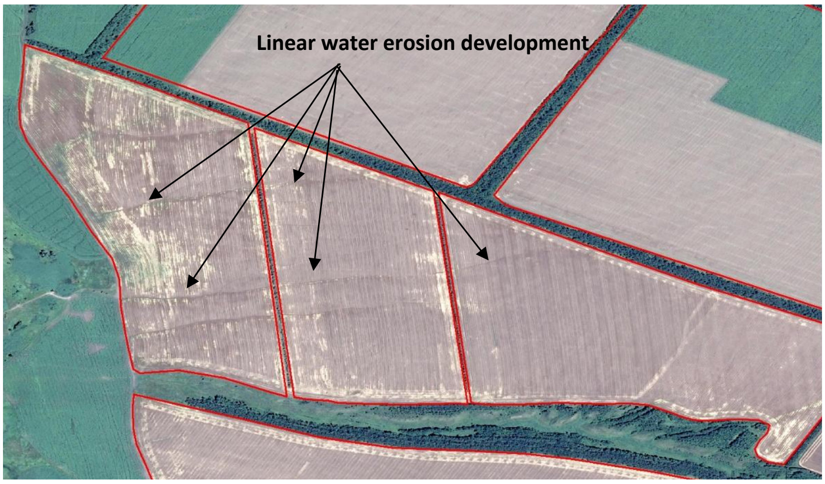
Some fields have a multidirectional spherical surface with sloping hills and a small surface area of watersheds. Some indicate the presence of closed depressions with manifestations of secondary salinization and delayed moisture absorption compared with other parts of the field. Once the soil has dried, a crust and a dense network of cracks form. The snow cover in the second decade of March is about 30 cm thick and ≥ 95 cm thick in the depressions. Intensive melting of snow in the third decade of March significantly influences the surface conditions

Figure 14. Erosion processes detected on satellite image, farm 1S (14 April 2018)



Source: Earth Observing System - Land viewer, 2018.

Figure 15. Linear water erosion development, farm 1S



Source: FAO, 2018.

of the fields. On the fallow fields, there are localized manifestations of linear erosion, with erosion washouts reaching depths of 30–40 cm. On slopes with roads crossing at a 90 ° angle, a significant erosion scar is created requiring engineering solutions to remove thaw and storm waters. Observation of the territory and analysis of the satellite images reveal that eroded and flooded areas only occur where there are negative relief elements and landslides.

The development of other degradation processes of physical and physical–chemical genesis – for example, secondary salinization, soil compacting, presence of heavy metals or pesticides, and loss of biodiversity – can be identified directly in the field surveys or based on laboratory analysis of soil samples.

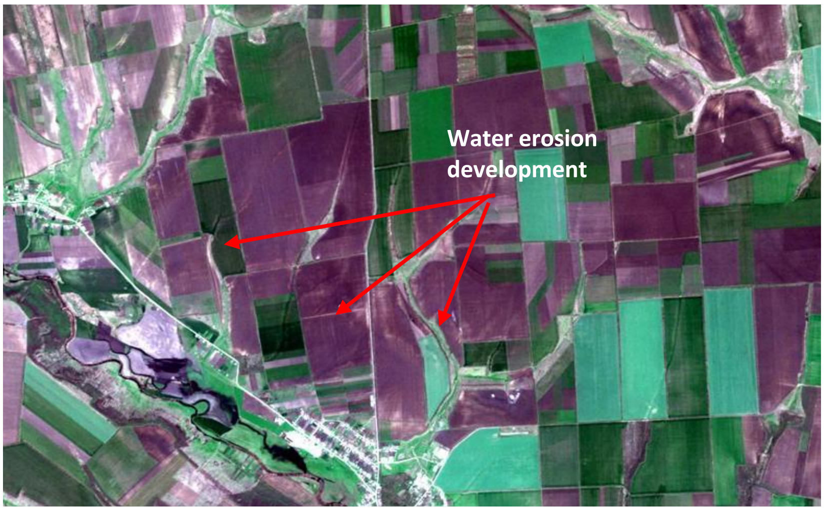
Farm 1S is the largest of the pilot farms in terms of area. Visual inspection of the territory and the high-resolution satellite images reveal the development of degradation processes in the form of erosion throughout the area.

Erosion can become critical, and preventive measures – even with the adoption of complex agrotechnical means – are not sufficient. Since the erosion processes affect extensive areas, detailed study of just one field in the soil survey is not sufficient to characterize the general situation with regard to degradation on the pilot farm. Agrochemical analysis of a number of soil samples is not representative and, therefore, is not appropriate. Therefore, soil samples were not collected. For an objective and reliable assessment of the soil fertility of the pilot farm, sampling must take place in all major agroproduction soil groups, taking into account the various types of erosion and land management.

Farm 2S (Standard)

The Mykolaiv region is located mainly in the northern and southern steppe zone of Ukraine, with only a small part in the northwest belonging to the forest-steppe. The dominant soil type in the region is chernozem, specifically: in the northern part of the region, the soil cover is mainly represented by deep chernozem soils; in the south, medium and low humus chernozem soils and southern chernozems dominate; and in the coastal zone, dark brown

Figure 16. Erosion processes detected on satellite image, farm 2S (13 April 2018)



Source: Earth Observing System - Land viewer, 2018.

soils prevail (soil groups map designed by the State Research and Design Institute of Land Management). The most common soils in the Mykolaiv region are typical chernozems, covering 46 percent of the region's arable land. Southern chernozem occupy 36.7 percent of the area of all soils of the region.[6]

The territory of farm 2S is located in the northern steppe of Ukraine. The soil cover is represented by medium humus light clay typical chernozem soils with varying washout rates from slightly to strongly eroded. The rate of washout depends on the angle of the slope, which fluctuates between 1° and 7 °, particularly in this area. Medium humus forest-steppe, typical chernozem soils are found in localized small spots, mainly in the lowlands.

Fields are for the main part geometric in shape with an average size of 150–170 ha. The field structure is well organized and every field is surrounded by a field-protective forest belt. The margins of fields adjacent to the valleys and gullies generally have non linear contours determined by the relief.

The high-resolution satellite images clearly show field areas with manifestations of linear and surface erosion (Figure 16). The tonality of the soil cover is heterogeneous, colourful and lighter in the washed out areas. The soil surface colour is darker in the watershed parts of the fields, slope folds and depressions – an indication of the redistribution of soil fractions by water flows. Linear erosion is visible along the entire length of the cultivated fields and cannot be masked by agrotechnical measures. This indicates a significant washout of soil mass, reaching the level of the lighter parent rocks. The images indicate that soil cultivation is generally carried out on the slopes. Some fields have a complex shape comprising a variety of slopes and they are usually located between two, or even more, linear erosion forms; this circumstance has a marked effect on the various types of erosion processes occurring in the area.

Figure 17. Linear water erosion development, farm 2S

Source: FAO, 2018.

On field No. 1 (Figure 17), it is evident that due to the formation of powerful flows, an active growth gully network has appeared. Even the presence of a well-developed forest belt does not prevent water flows from forming a new linear erosion,

[6] Soils of Mykolaiv region, 1968.

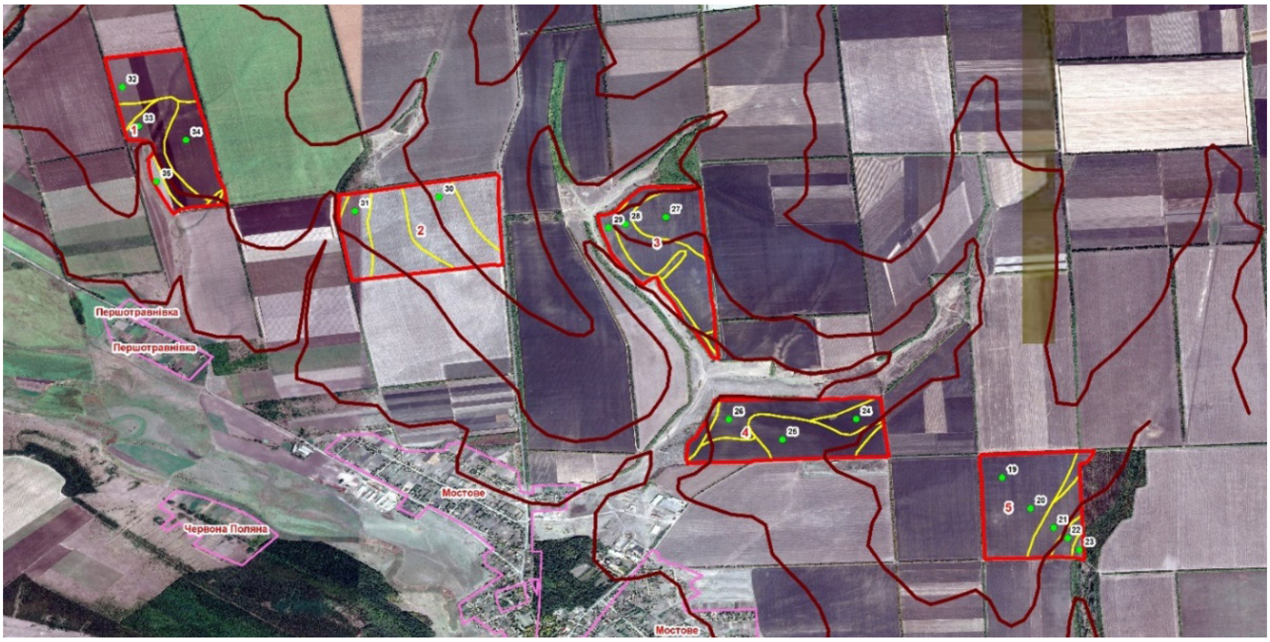
which crosses the boundary of the forest belt in two places and continues towards the valley. This development is also facilitated by the relief features.

The large columbine areas of the slopes with angles of between 0–1 ° and 5–7 °, contribute to the formation of powerful streams and flows, soil fractions washouts, loss of organic matter, the emergence of the new linear erosion forms, depletion of soil cover, and, consequently, the general state of degradation. Most of the selected fields have a full set of soil types according to erosion level: from non-eroded on the narrow plateau watersheds to weakly, medium and strongly eroded on the lower parts of the slopes (3–5 ° and 5–7 °). The loss of the upper humus horizons with well-formed agronomic structure causes the destructive rotation of soil layers, which bring to the surface a heavy granulometric composition of the parent rock; this has considerably less buffering capacity and, therefore, in adverse conditions and under the influence of external weather factors, soil and air drought becomes more intense, deep cracks form, leading in turn to greater loss of precious moisture in the steppe zone. Thus, one kind of land degradation stimulates the development of other types.

For the preliminary estimation of soil potential fertility and safety, and for the detection of possible soil degradation processes, 17 soil samples were collected on five fields in the pilot farm with varying degrees of water erosion (Figure 18). The sampling locations were determined based on the scheme of agroproduction soil groups and locations of slopes with water erosion manifestations.

Laboratory analysis of soil samples indicates a fairly good humus content of the soil cover, although it is lower than in the first two analysed farms, 1FS and 2FS. There is a close link between the reduction in organic matter in the upper genetic horizons and the development of erosion processes. The content of humus varies from high to medium (Table 6). For example, in field No. 5, soil samples were collected along the slope from the highest point in the field (sample No. 19) to the lowest (sample No. 23), and the humus content decreases from 4.5 to 3.1 percent. As in other pilot farms, any direct link between the distribution of the nutrients and the soil conditions and soil genetics is relative, because the content of macronutrients in the soil is often controlled by the amount of mineral fertilizers introduced.

Figure 18. Location of soil sampling points, farm 2S



– borders and field number; – boundaries of the agroproduction soil groups;
– isohypses with height; – sampling point location and number

Source: FAO, 2018.

Table 6. Soil characteristics of farm 2S (agrochemical indicators)

No.	Soil sample No.	Field No.	Agrochemical indicators of soil fertility								
			Humus		pH of acids		$N\text{-}NO_3$	P_2O_5		K_2O	
			%	Level	pH	Level	mg/kg	mg/kg	Level	mg/kg	Level
1	19	5	4.5	high	8	medium alkaline	3.0	61.5	average	157.8	high
2	20		4.2	high	7.9	medium alkaline	7.4	48.5	low	130.5	high
3	21		4.3	high	8.1	strong alkaline	2.5	6.1	very low	250.65	increased
4	22		3.3	increased	8.1	strong alkaline	5.4	4.2	very low	229.81	increased
5	23		3.1	increased	8.1	strong alkaline	13.0	3.8	very low	205.84	increased
6	24	4	3.5	increased	8.1	strong alkaline	9.9	42.5	low	139.88	high
7	25		3.4	increased	7.4	low alkaline	6.4	49.5	low	116.16	increased
8	26		2.6	average	8.1	strong alkaline	12.5	2.7	very low	186.37	average
9	27	3	4.7	high	6.8	neutral	12.6	42	low	119.45	increased
10	28		3.0	average	7	neutral	10.5	42	low	141.69	high
11	29		3.1	increased	8.1	strong alkaline	6.5	3	very low	198.33	average
12	30	2	4.6	high	8.1	strong alkaline	7.3	14.5	very low	284.21	increased
13	31		3.5	increased	8.1	strong alkaline	4.7	2.7	very low	249.97	increased
14	32	1	4.7	high	7.1	low alkaline	5.2	53.5	low	162.11	high
15	33		5.0	high	7.9	medium alkaline	1.8	154.2	very high	1292	very high
16	34		4.3	high	7	neutral	3.3	12	low	282.04	increased
17	35		3.0	average	8.1	strong alkaline	2.5	2.7	low	210.25	increased

The regularity of the content of heavy metals in soils is comparable to the other pilot farms. Zinc content ranges from moderate to average, and copper and lead content ranges from low to moderate (Table 7). These elements do not exceed the MPC. The multifold increase in heavy metals content in soils in comparison with the background should be taken into account in the implementation of the main project.

In sample No. 30, analysed for the content of residual pesticides, no such pesticides were detected; the problem of soil fertilization with the residual pesticides was not observed. Nevertheless, one sample from one field cannot guarantee the safety of other fields.

Table 7. Soil characteristics of farm 2S (ecotoxicological indicators)

No.	Soil sample No.	Field No.	Heavy metals (gross form)								Residual pesticides		
			Zn		Cu		Cd		Pb				
			mg/kg	Pollution level	mg/kg	Pollution level	mg/kg	Pollution level	mg/kg	Pollution level	Detected pesticide	mg/kg	ND norms
1	20	5	43.16	average	15.87	moderate	0.15	low	9.57	moderate	–	–	–
2	26	4	28.73	moderate	10.84	low	0.17	low	6.94	low	–	–	0.1
3	28	3	34.88	moderate	13.76	low	0.13	low	7.73	low	–	–	0.1
4	31	2	35.36	moderate	13.6	low	0.18	low	7.35	low	–	0.1	0.1
5	34	1	35.59	moderate	14	moderate	0.24	low	8.66	moderate		–	0.1
6	30	2	–	–	–	–	–	–	–	–	not found	0.1	0.1

Farm 3S (Extended assessment)

The southern part of the Kherson region has a continental climate typical of the sub-boreal dry steppes: sub-arid with warm arid summer and cold winter; annual rainfall of 200–350 mm; annual evaporation of 1 000–1 200 mm; average annual temperature of about 5 °C; significant daily and seasonal temperature amplitudes. The water regime is characterized by non-flushing drizzly precipitation. When air temperatures exceed 10 °C, humidity is classified as dry – an indicator of a hydrothermal coefficient (GTK) range of 0.7–1.0.

The vegetation is a grassy dry steppe with few species and sparse herbage.

The relief is plain with a highly developed microrelief in the form of depressions, saucers and estuaries – the result of initial uneven rock salinity combined with intensive activity of earth movers. The nature of the microrelief (in particular, the presence of flat-bottomed closed depressions) has led to the high complexity of the soil cover: the heaths feature dark chestnut and other soils. The soil-forming rocks are loess loams and loess, saline sea breeds – products of the weathering of the sandstones, limestones and marls. The southern part of the Kherson region has dark-chestnut weak soils and medium salinity soils.

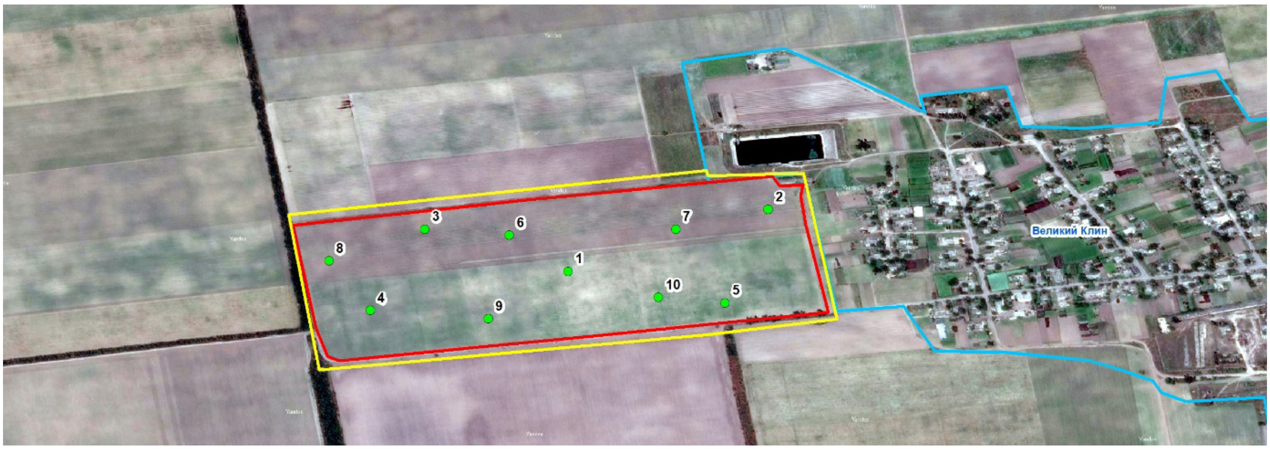
The profile of chestnut soils is similar to chernozem soils: poorly developed turf; humus of chestnut colour with a brownish grey gradation; powdered and fine-grained; boils under the influence of acid; sandy; layered with a thickness of 15–30 cm; upper transitional, greyish brown, with a thickness of about 10 cm; large brittle, prismatic, compacted, sandy clayey, with carbonates in the form of concretions; lower transitional, homogeneously coloured with brownish yellow, prismatic, compacted carbonates in the form of concretions (white stars), possibly salinized, with a thickness of about 50–100 cm; soil-forming rock, saline carbonate sandy loam. Chestnut soils are characterized by the carbonates lying directly under the N horizon, many of which accumulate gypsum and water-soluble salts and have satisfactory water-physical properties.

The dry steppe zone is important in the country's agriculture. The arable lands have mostly dark chestnut soils, which are the most fertile and the best providers of soil moisture. Wheat, millet, sunflower, melons and other crops are grown. Yields depend on water availability, as frequent droughts in the drylands lead to unstable agriculture. To some extent, this problem is solved by the development of snow-retaining structures, the planting of forest belts, the use of special agricultural machinery and correct crop rotation. A radical measure in water regime regulation is irrigation, which must be designed to anticipate and prevent all possible negative consequences: secondary salinization, salinization and waterlogging of soils.

The territory of the pilot farm, including the experimental field, is characterized by a calm plain relief and a lack of complex elements. The relief of the experimental field is very smooth; the soil cover is monotonous. According to the archival maps of agroproductive groups of soils, the soils of the experimental field belong to the agroproductive group of dark chestnut weakly deflated sandy soils.

There are ten collected soil samples on the experimental field. In order to carry out soil sampling in the field-protective forest belts, the location of the forest belts and the soil sampling points within them were also marked on the electronic map (Figure 19).

Figure 19. Soil sampling scheme on the experimental field



– *field boundaries;* – *agro-productive group of soils;* 5 – *sample number and location*

Source: FAO, 2018.

According to the results of the soil analysis, some soil samples were identified as light clay (Table 8). The humus content is low and very low (0.7–1.5%), and the nitrogen content is very low (Table 9). In comparison, the organic matter content reaches 2.5–3.5 percent in heavy dark chestnut soils.

Table 8. Soil characteristics of experimental field according to granulometric composition

No.	Soil sample No.	Particle size, mm, number, %							Granulometric composition
		Sand		Dust			Mule	Amount of particles < 0.01	
		> 0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	< 0.001		
1	1	58.87	22.06	7.81	2.10	2.09	7.07	19.07	sandy
2	2	47.61	28.07	9.32	8.96	3.13	2.90	24.31	light clay
3	3	61.66	19.62	7.63	1.87	2.15	7.07	18.72	sandy
4	4	47.15	27.82	10.57	8.33	2.97	3.15	25.03	light clay
5	5	62.74	18.77	7.48	1.78	2.16	7.07	18.49	sandy
6	6	50.50	26.50	9.95	7.34	2.91	2.80	23.00	light clay
7	7	49.41	27.07	8.24	8.51	3.74	3.03	23.52	light clay
8	8	54.68	22.06	7.81	4.20	4.18	7.07	23.26	light clay
9	9	46.57	28.07	9.32	8.96	4.17	2.90	25.36	light clay
10	10	57.64	19.62	7.63	3.74	4.30	7.07	22.74	light clay

Consequently, the light granulometric composition of soils and the low humus content indicate the low water retention capacity of these soils and their ability to overheat in the summer under open backgrounds and high temperatures (i.e. unfavourable conditions for crop cultivation). Very low rainfall and high evaporation further complicate the situation and it may be worth considering the introduction of irrigation in this area.

The content of moving forms of phosphorus in these soils ranges from medium to very high – depending on the agricultural machinery used – and the content of potassium-mobile compounds is very high (Table 9). Soils are characterized by a severe shortage of mobile forms of sulphur.

Table 9. Soil characteristics of farm 3S (agrochemical indicators)

No.	Indicators																		
	pH_{water}		pH_{salt}	Hh, mmol/ 100 g of soil	Humus		N alkaline hydrolyzed		N-NO_3		P_2O_5		K_2O		S	
	pH_{water}	Level			%	Level	mg/kg	Level	mg/kg	Level	mg/kg	Level	mg/kg	Level	mg/kg	Level
1	7.1	low alkaline	6.2	0.97	1.06	low	66	very low	3.4	very low	30	average	412	very high	0.864	very low
2	7.7	average alkaline	6.6	0.47	0.95	very low	63	very low	4.1	very low	45	in-creased	636	very high	0.029	very low
3	7.8	average alkaline	6.9	0.43	1.06	low	67	very low	4.0	very low	67	very high	564	very high	0.446	very low
4	7.0	neutral	6.1	1.10	1.18	low	69	very low	4.1	very low	103	very high	546	very high	0.238	very low
5	7.3	low alkaline	6.4	0.75	0.71	very low	56	very low	3.6	very low	48	high	520	very high	0.655	very low
6	7.2	low alkaline	6.3	0.81	0.71	very low	57	very low	3.2	very low	34	in-creased	460	very high	2.534	very low
7	7.7	average alkaline	6.8	0.47	0.95	very low	64	very low	3.8	very low	52	high	660	very high	1.699	very low
8	7.7	average alkaline	6.8	0.44	0.95	very low	65	very low	3.9	very low	108	very high	488	very high	0.029	very low
9	6.9	neutral	6.8	1.13	1.58	low	77	very low	4.0	very low	105	in-creased	500	very high	0.238	very low
10	6.8	neutral	6.0	1.31	1.20	low	70	very low	3.3	very low	51	high	432	very high	0.446	very low

Soils do not indicate the presence of water-soluble salts in the profile; indeed, based on the content of soluble salts, the soils are classified as unsalted (Table 10).

Table 10. Soil characteristics of Farm 3S (physicochemical indicators)

No.	Soil sample No.	Sampling depth, sm	Capacity of absorption	Absorbed basics			Solid residual matter, %	Water extraction content						
								Anions and cations, mmol per 100 g of soil / %						
				Ca	Mg	Na		HCO_3^-	Cl^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	K^+
			mmol per 100 g of soil											
Soil profile 1														
1	11	0–30	8.1	6.0	1.0	0.01	0.024	0.20 / 0.012	0.10 / 0.004	0.11 / 0.005	0.12 / 0.002	0.12 / 0.001	0.08 / 0.002	0.09 / 0.004
2	13	30–60	11.5	8.0	2.5	0.02	0.033	0.35 / 0.021	0.15 / 0.005	0.09 / 0.004	0.38 / 0.008	0.12 / 0.001	0.08 / 0.002	0.01 / 0.001
3	15	60–90	–	17.5	4.0	0.01	0.045	0.30 / 0.018	0.15 / 0.005	0.35 / 0.017	0.25 / 0.005	0.38 / 0.004	0.08 / 0.002	0.09 / 0.003

No.	Soil sample No.	Sampling depth, sm	Capacity of absorption	Absorbed basics			Solid residual matter, %	Water extraction content						
				Ca	Mg	Na		Anions and cations, mmol per 100 g of soil / %						
			mmol per 100 g of soil					HCO_3^-	Cl^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	K^+
Soil profile 2														
4	12	0–30	9.1	6.0	1.5	0.01	0.022	0.20 / 0.012	0.10 / 0.004	0.09 / 0.004	0.12 / 0.002	0.12 / 0.001	0.08 / 0.002	0.07 / 0.003
5	14	30–60	12.8	8.0	3.0	0.02	0.035	0.35 / 0.021	0.15 / 0.005	0.14 / 0.007	0.25 / 0.005	0.25 / 0.003	0.08 / 0.002	0.06 / 0.002
6	16	60–90	–	17.0	3.5	0.01	0.038	0.30 / 0.018	0.15 / 0.005	0.22 / 0.011	0.25 / 0.005	0.25 / 0.003	0.08 / 0.002	0.09 / 0.003

The results of the ecotoxicological analysis of the soil samples revealed no values in excess of the maximum permissible concentration (MPC). The Pb content is 3–4 times lower than the MPC, and the Cu and Zn content are 50–100 times lower (Table 11): the soil on the test field is not contaminated by heavy metals.

Table 11. Soil characteristics of farm 3S (ecotoxicological indicators)

No.	Soil sample No.	Indicators, mg/kg		
		Pb[1] (moving form pH 4.8)	Cu[2] (moving form pH 4.8)	Zn[3] (moving form pH 4.8)
1	1	0.30	0.03	0.55
2	2	1.18	0.08	0.66
3	3	1.49	0.04	0.66
4	4	1.12	0.08	0.61
5	5	1.84	0.13	0.63
6	6	0.82	0.14	0.67
7	7	2.06	0.08	0.68
8	8	2.02	0.08	0.69
9	9	1.79	0.09	0.62
10	10	1.96	0.13	0.64

Notes: [1] MPC Pb, moving form – 6.0 mg/kg.
[2] MPC Cu, moving form – 3.0 mg/kg.
[3] MPC Zn, moving form – 23 mg/kg.

The analysis of the cartographic materials, satellite images and field surveys revealed no water erosion on the experimental field and adjoining territories (Figure 20). On the other hand, another form of physical soil degradation emerged: wind erosion or deflation. Indeed, the very name of these soils – determined by a large-scale soil survey in 1957–1961 – suggests that they are deflated. Deflation is facilitated by the light granulometric composition of the soil, the low humus content and the colloids content. Under these conditions, it is imperative to adopt measures to improve the humus content of the soil and to plant field-protective forest belts.

Figure 20. Sentinel-2 satellite image of farm 3S (28 August 2018)

Source: FAO, 2018.

CONCLUSION

Based on the multidirectional pre-design studies at the testing plots, and on the analysis of all existing cartographic, climatic, organizational and economic information, of farm soil survey archival materials, and of high-resolution satellite imagery, the following conclusions can be drawn:

- In Ukraine, land degradation processes are currently underway with varying degrees of intensity, depending on socio-economic, economic–administrative, natural, anthropogenic and other factors.
- Both steppe and forest-steppe zones are characterized by water and wind erosion, with reduced humus content in zones of water erosion development.
- The driest parts of the steppe in general – and the fields of Farm 3S in particular – the main type of degradation is deflation of soils, that is wind erosion. Furthermore, the potential soil fertility of the experimental field is estimated as low.
- Laboratory analysis of soil samples based on safety indicators (ecotoxicological indicators) revealed that the content of gross forms of heavy metals (e.g. cadmium and lead) corresponds to a low level of pollution and is considerably lower than maximum permissible concentrations (MPC). On the other hand, weak, moderate and even average content of gross forms of zinc and copper was detected. Although their content is below the MPC, more in-depth study is required in different soil conditions and taking into account the possibility of horizontal and vertical migration.

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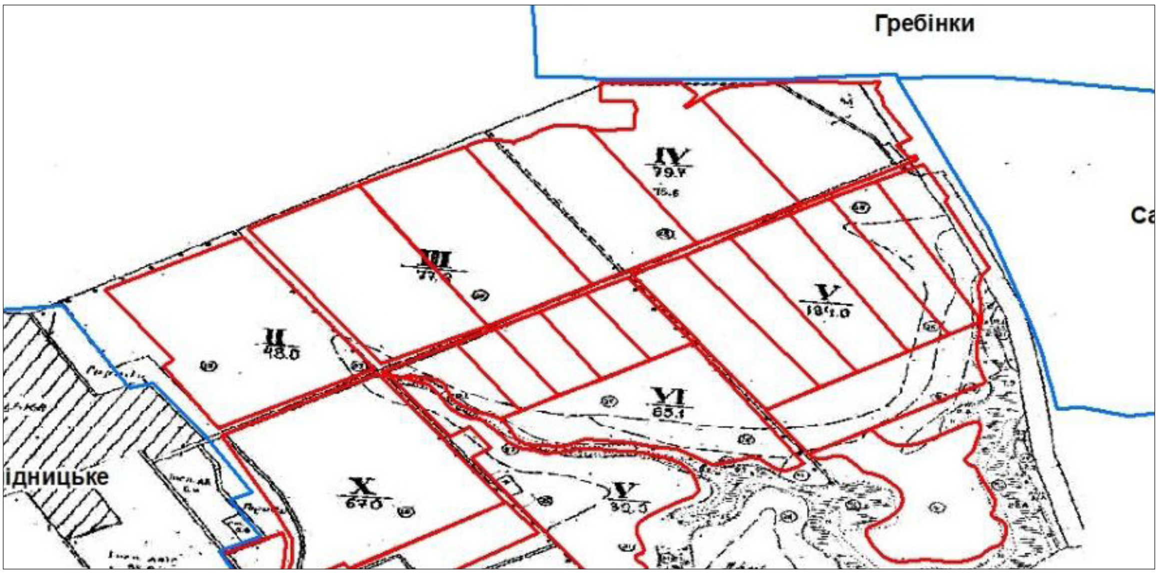
ANNEX 1

Farm 1FS

Figure A1.1 Vectorized scheme of experimental fields on satellite image[7]

Source: FAO, 2018.

Figure A1.2 Georeferenced map of agroproduction soil groups



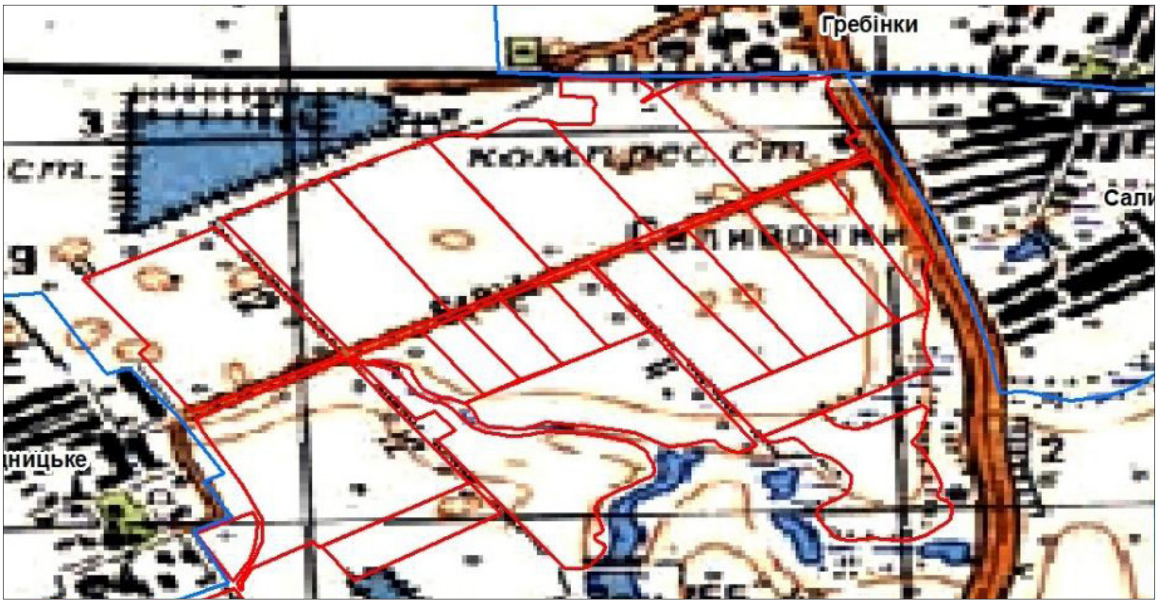
Source: FAO, 2018.

7 All images were carried out as part of the current study: FAO. 2018. World Soil Day 2017: Events around the globe in pictures. Rome. (also available at http://www.fao.org/3/i8630en/I8630EN.pdf).

Figure A1.3 Vectorized boundaries of agroproduction soil groups

Source: Cartogram of agroproduction soil groups – Main Research and Design Institute of Land Management; field scheme – own research.

Figure A1.4 Georeferenced topographic map of the study area



Source: FAO, 2018.

Figure A1.5 Vectorized isohypses lines of topographic map

Source: FAO, 2018.

Figure A1.6 Vectorized field boundaries, agroproduction soil groups and isohypses of topographic maps combined with satellite image

Source: FAO, 2018.

Farm 2SF

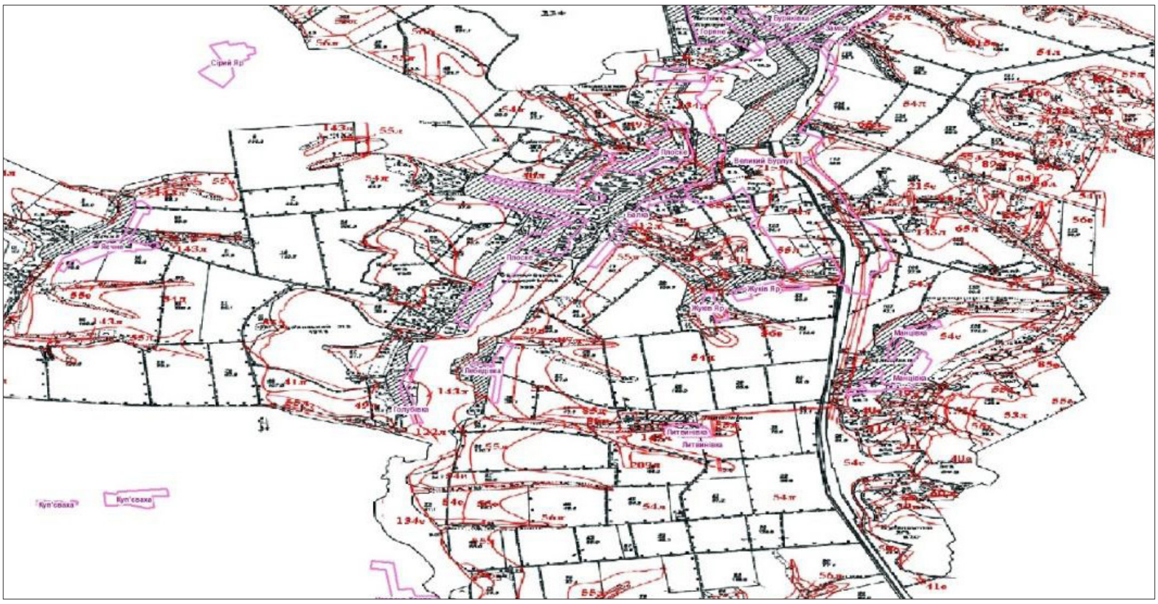
Figure A1.7 Vectorized scheme of land lots, combined with satellite image

Source: FAO, 2018.

Figure A1.8 Vectorized scheme of fields on satellite image

Source: FAO, 2018.

Figure A1.9 Georeferenced map of agroproduction soil groups

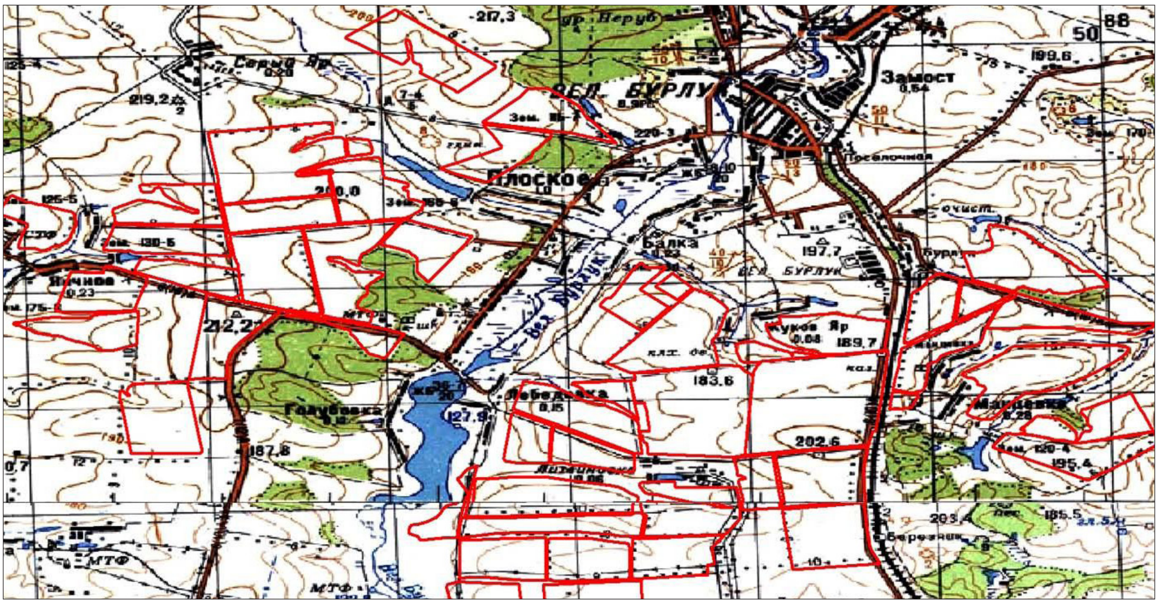


Source: Cartogram of agroproduction soil groups – Main Research and Design Institute of Land Management; field scheme – own research.

Figure A1.10 Vectorized boundaries of agroproduction soil groups

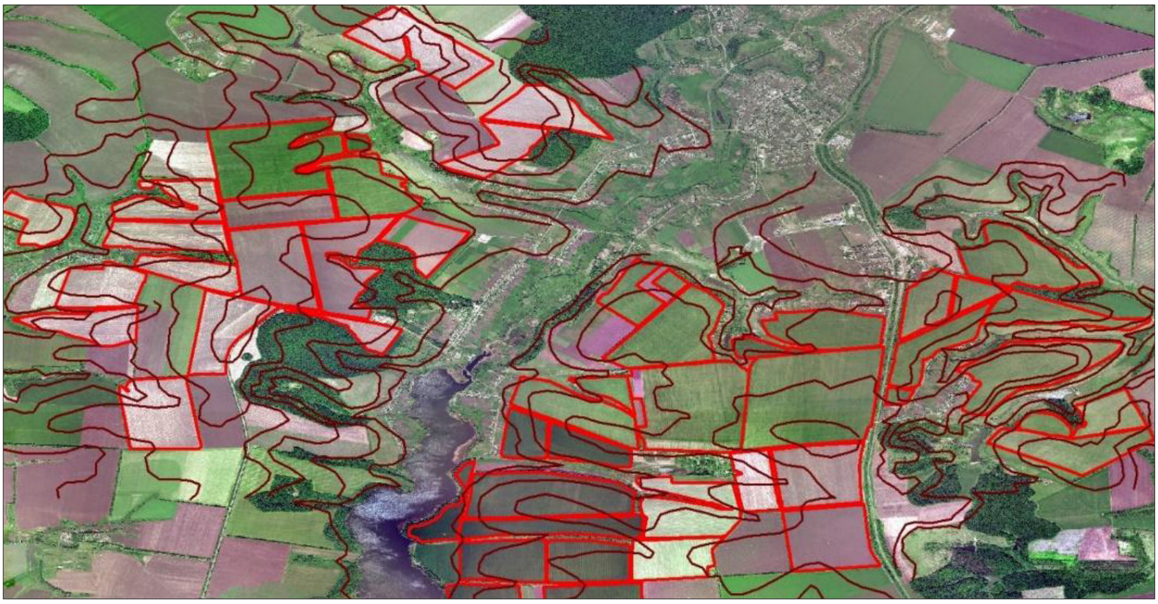
Source: FAO, 2018.

Figure A1.11 Georeferenced topographic map of the study area



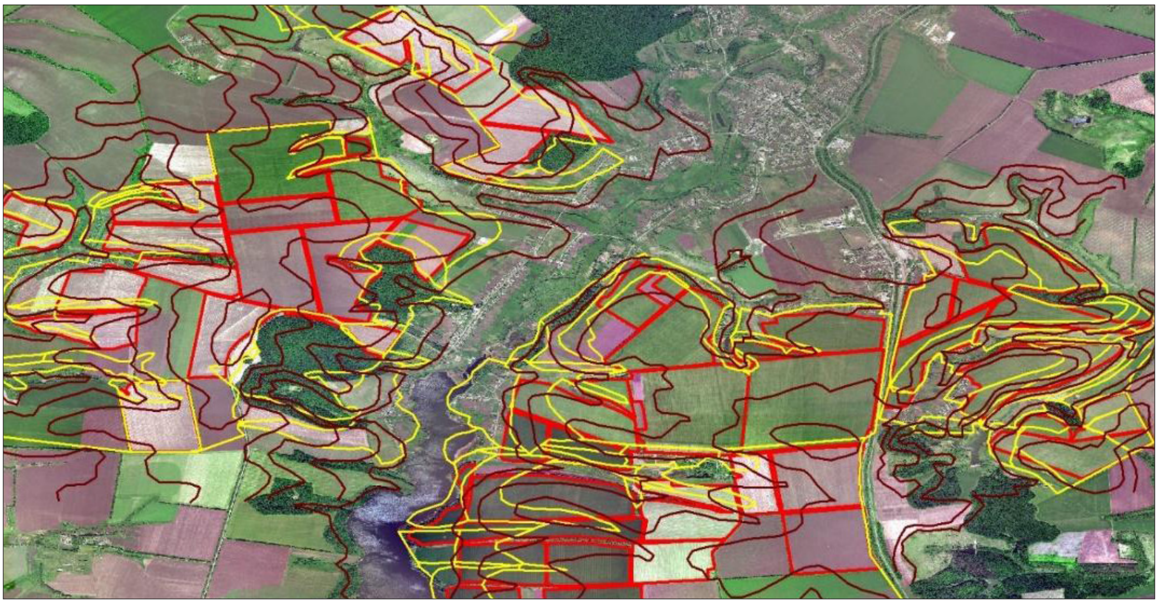
Source: FAO, 2018.

Figure A1.12 Vectorized isohypses lines of topographic map



Source: FAO, 2018.

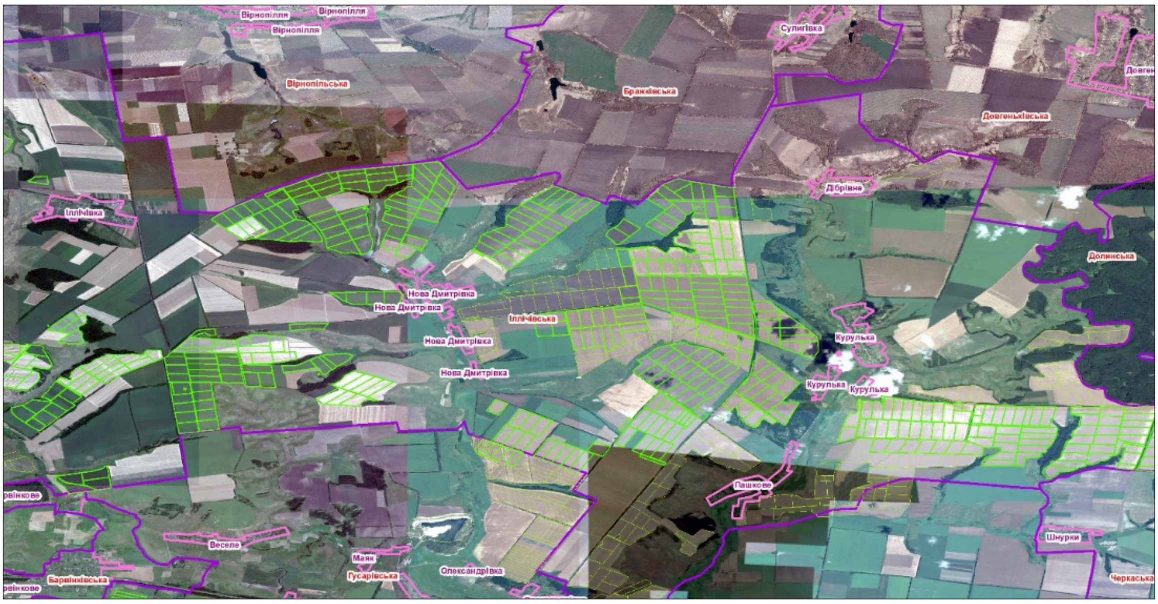
Figure A1.13 Vectorized field boundaries, agroproduction soil groups and isohypses of topographic maps combined with satellite image



Source: FAO, 2018.

Farm 1S

Figure A1.14 Vectorized scheme of land lots, combined with satellite image

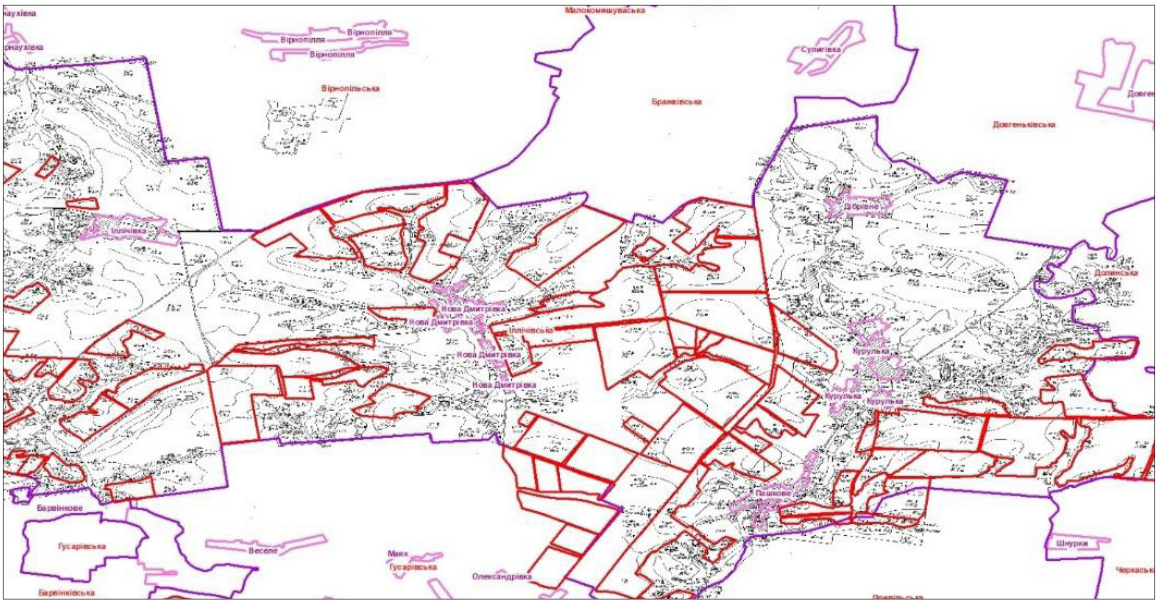


Source: FAO, 2018.

Figure A1.15 Vectorized scheme of fields on satellite image

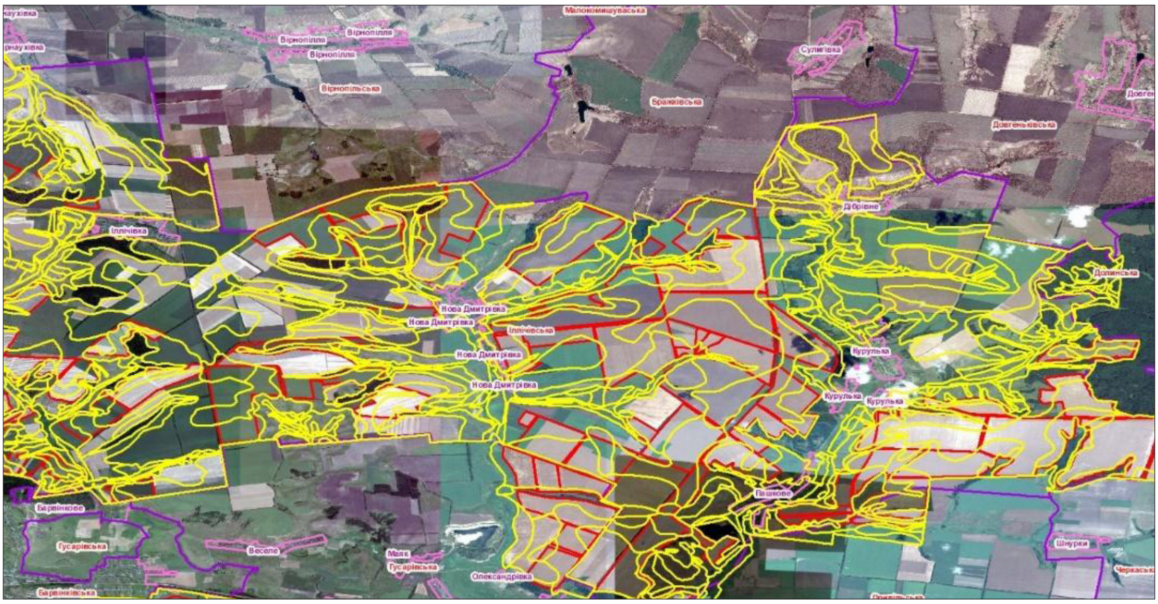
Source: FAO, 2018.

Figure A1.16 Georeferenced map of agroproduction soil groups of the farm in Illichivsk village council



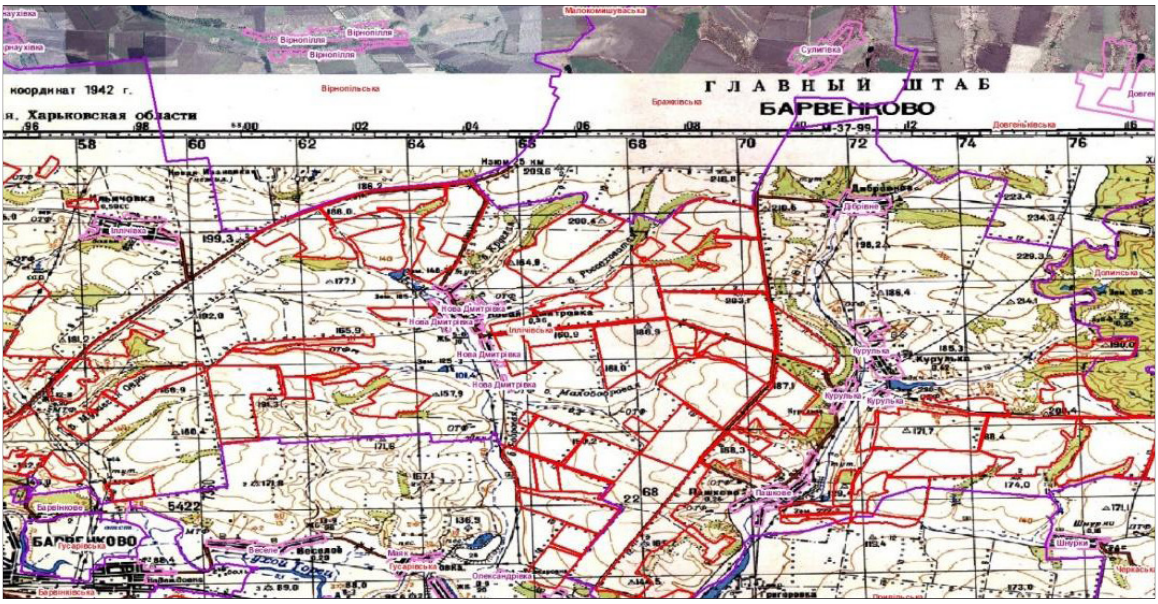
Source: Cartogram of agroproduction soil groups – Main Research and Design Institute of Land Management; field scheme – own research.

Figure A1.17. Vectorized boundaries of agroproduction soil groups of the farm in Illichivsk village council



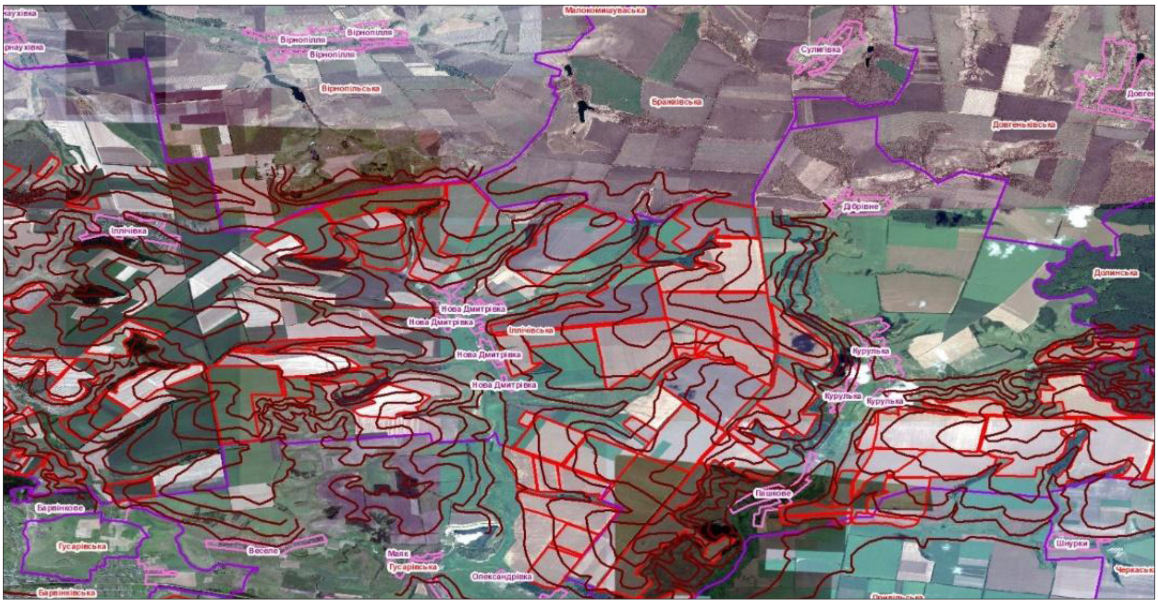
Source: FAO, 2018.

Figure A1.18 Georeferenced topographic map of Illichivsk village council



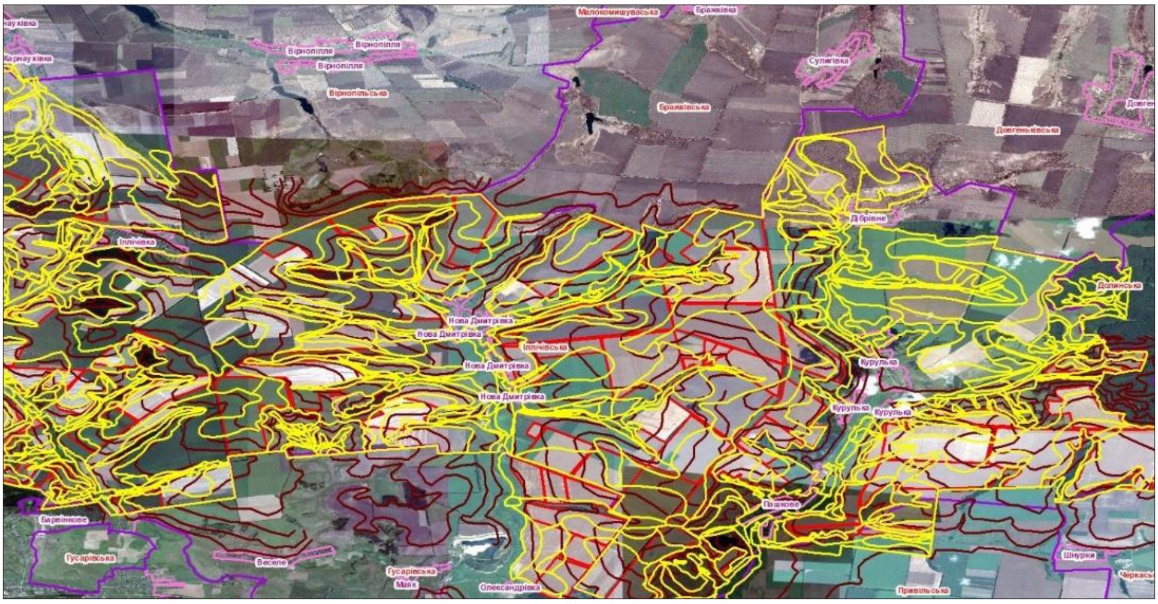
Source: FAO, 2018.

Figure A1.19 Vectorized isohypses lines of topographic map of Illichivsk village council



Source: FAO, 2018.

Figure A1.20 Vectorized field boundaries of Illichisk village council, agroproduction soils groups and isohypses of topographic maps, combined with satellite image



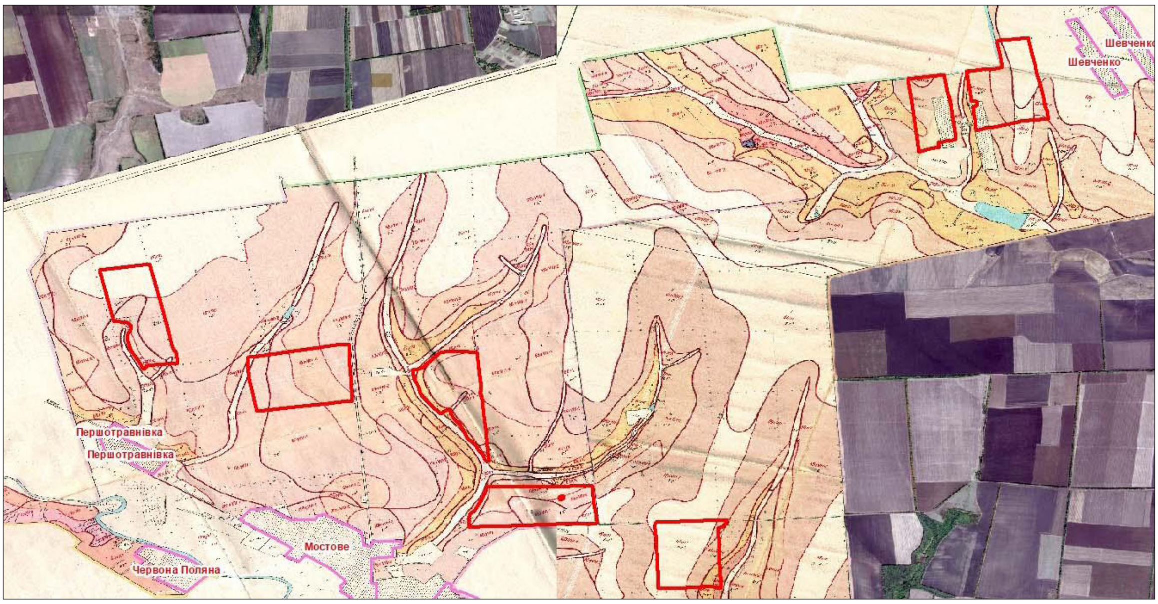
Source: FAO, 2018.

Farm 2S

Figure A1.21 Vectorized scheme of fields on satellite image

Source: FAO, 2018.

Figure A1.22 Georeferenced map of agroproduction soil groups

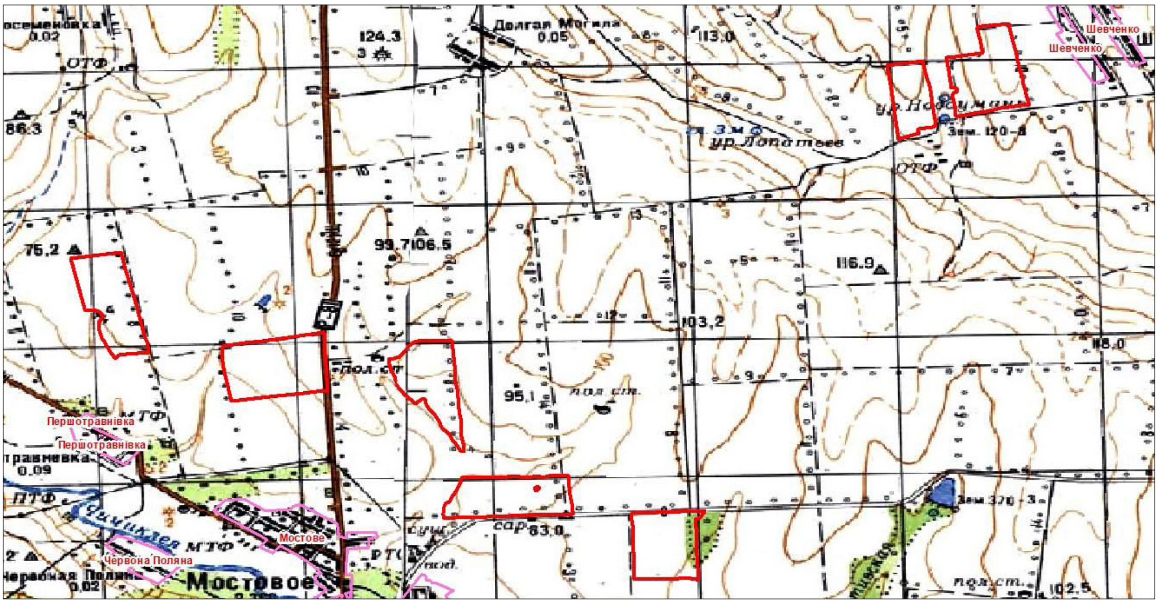


Source: Cartogram of agroproduction soil groups – Main Research and Design Institute of Land Management; field scheme – own research.

Figure A1.23 Vectorized boundaries of agroproduction soil groups

Source: FAO, 2018.

Figure A1.24 Georeferenced topographic map of the study area



Source: FAO, 2018.

Figure A1.25 Vectorized isohypses lines of topographic map

Source: FAO, 2018.

Figure A1.26 Vectorized field boundaries, agroproduction soils groups and the isohypses of topographic maps, combined with satellite image

Source: FAO, 2018.

ANNEX 2

Table A2.1 Analysis scheme of soil sample by indicators

№ з/п	Indicator	Analysis method	№ з/п	Indicator	Analysis method
1	Granulometric composition	DSTU* 4730:2007	10	Alkaline hydrolyzed nitrogen	DSTU 7863:2015
2	pH_{water}	DSTU/ISO 10390:2007	11	Nitric nitrogen (NO_3)	DSTU 26951-86
3	pH_{salt}	DSTU/ISO 10390:2007	12	Phosphorus (P_2O_5)	DSTU 4115-2002
4	Hydrolytic acidity	DSTU 7537:2014	13	Potassium (K_2O_3)	DSTU 4115-2002
5	Absorption capacity	DSTU/ISO 11260-2001	14	Moving forms of S	DSTU 8347:2015
6	Absorbed basics	DSTU 7604: 2014	15	Heavy metals (Pb)	DSTU 4770.9:2007
7	Solid residual matter	DSTU 26423-85	16	Heavy metals (Cu)	DSTU 4770.6:2007
8	Water extraction content (HCO_3, Cl, SO_4, Ca, Mg, Na, K)	DSTU 26424-85, DSTU 26425-85, DSTU 26426-85, DSTU 26427-85, DSTU 26428-85	17	Heavy metals (Zn)	DSTU 4770.2:2007
9	Humus content	DSTU 4289:2004			

*Note: * National standard.*

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ISBN 978-92-5-132215-4

9 789251 322154

CA7761EN/1/05.20