Crop yield model for Ukraine and Romania

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Abstract

This document compliments a previous report on "Baseline analysis of agri-environmental trends, impacts and vulnerabilities" (D5.2). The current report contains a technical account of models used to predict crop yield in Ukraine and Romania with the GEPIC model. The program Soil and Water Assessment Tool (SWAT) was used to build the larger model in the full Black Sea catchment and is reported in Deliverable D4.2. "Calibrated water quantity model for BSC".

Foreword

Bio-physical large-scale crop growth models have become an important tool for estimating agricultural production and water use efficiency. During the last decade, large-scale crop growth modeling has received increasing attention due to its importance in assessing current crop yields and agricultural water use, impacts of climate change, and measures to improve agricultural productivity today and in the future (Liu et al., 2007; Thornton et al., 2009; Fader et al., 2010). Large-scale studies have the advantage of providing the big picture and allow for a comparison of different regions regarding agricultural production and productivity. Small-scale national or sub-national studies on the other hand provide for a very detailed analysis and model setup due to locally collected data and rather homogenous agricultural systems (e.g. Thornton et al., 2009; Gaiser et al., 2010b). Calibration and validation of crop growth parameters and growing conditions are quite detailed and the results could be considered very reliable.

In between these two scales, there are almost no studies that could bridge findings of detailed local research to provide information on large areas covering several neighboring countries and across a range of agricultural eco-regions. Such analysis could be used to evaluate food security through intra-country collaboration on the one hand and provide information about agricultural systems in countries that lack local research efforts on the other hand. These analyses would also identify data gaps by highlighting hotspots where local studies with more detail should be carried out.

This objective of this document is to describe the technical aspects of implementing a crop model in Soil Water Assessment Tool (SWAT) (Arnold et al., 1998), and Environmental Policy Integrated Climate, formerly Erosion Productivity Impact Calculator) (EPIC) (Williams et al., 1989) to assess the impact of agricultural practices and climate change on crop yield.

1 Part 1 Ukraine

Ukraine is the second largest country in Europe (603.700 km^2) after Russia, and is larger than any country of the EU-27. It has a key location between Russia and the EU, and it has important access with many ports to the Black Sea. Ukraine's natural resources (especially fertile soil condition) provide the country great opportunities for agricultural production.

After Ukraine became independent on 24 August 1991, the country experienced an economically severe transition period during the 1990's. Then, between 2000 and 2010, its economy grew on average more than 7% annually. The main reasons behind this development included the favourable trade environment and rising consumption.

The role of agriculture in the Ukrainian economy is remarkable. Almost two thirds of the country's area is used for agricultural production. The agricultural sector contributes significantly to the employment and the GDP. Furthermore, agriculture has a pivotal role in foreign trade.

In contrary, the *agricultural trade balance* is positive and exhibits an increasing trend. Agricultural trade can be characterised mostly by exporting commodities and intermediate products, and imported high value products. Among the main exporting products oil crops and grains have a dominant share. On the import side, food/feed preparations and meat products (chicken and pig) have dominance. Ukraine's main trading partner in agricultural products is the European Union (EU) both in terms of import and export. CIS countries and the Middle East countries have an increasing share in Ukraine's exports. These issues require more attention for forecasting yields of crops in connection with climatic changes and other natural conditions.

This report provides an overview of GEPIC modelling results use to simulate production of 4 crops (winter wheat, maize, spring barley and sunflower) in the territory of Ukraine in 2000-2010 and comparison of these results with statistical data. .

The report is divided into four main parts. The first part describes methodology of studies. In the second part the discussion of simulation results are presented. In the third part authors analyzed trade and exports data and potential possibilities of Ukraine. This report is prepared in framework of EnviroGRIDS project.

1.1 Program of Research

1.1.1 Objectives and tasks

According to the Task 5.3: Agriculture (EAWAG, IGAR, ONU) of enviroGRIDS project the task was set to assess environmental impacts on agricultural production in the Black Sea catchment. For this aim modelling of agri-environmental issues with the GIS-based EPIC model is chosen. The purpose of activities is to develop instrument that can be used to model the likely impacts on agriculture under different biophysical and policy scenarios.

The objectives of the sub-regional case studies (lead: IGAR and ONU) are to apply the GIS-based Environmental Policy Impact Calculator (GEPIC) to Ukraine and Romania territory, to make a country level analysis of the agriculture sector with focus on agro-environmental issues.

The task of this sub-regional case study is to conduct for the Ukraine area the GEPIC model experiments under different input conditions for four crops: winter wheat, maize, spring barley and sunflower for estimating the effects of any input factor (fertilizer, irrigation water availability, land use, management etc.) on the crop yields.

1.1.2 Stages of Works

1.1.2.1 Stage 1. The pilot study on the example of Odessa Oblast (Odessa Region)

For refinement of modelling practice using the simulation GEPIC, as well as for identifying and selecting of simulation conditions for the territory of Ukraine as the first stage of the work a pilot study was carried out on the example of Odessa Oblast.

The pilot study included the following.

A) To perform for the territory of Odessa Oblast a series of simulation experiments using the model GEPIC (version 1.0) working with ARCGIS 9.2, and the biophysical module EPIC (version EPIC0509, 2005) for spatial resolution: 30x30 minutes, 15x15 minutes and 5x5 minutes.

The time resolution of simulation: 4 years of calculation; calculated years: 2002, 2005, 2009.

Crops used in the simulation: winter wheat, sunflower, spring barley and maize. Crop rotation isn’t taken into account.

The simulation was performed for the following four scenarios:

- No irrigation, no fertilizers;
- Irrigation, no fertilizers;
- No irrigation, fertilizers;
- Irrigation, fertilizers.

B) Analyze the simulation results at different spatial resolutions, build output rasters, rasters of the distribution of crops based on actual irrigation area according to AQUASTAT (AQUASTAT 2007), to calculate the correlation function yields, calculated by the GEPIC model and statistical yield data of Odessa Oblast.

1.1.2.2 Stage 2. Trainings

Representatives of the scientific ONU group during the work with GEPIC model participated in two training sessions in 2010 and 2011:

3-4 May 2010, first training in the University of Agronomical Sciences (Bucharest, Romania). Trainers: Christian Folberth and Dr. Yang Hong. The purpose of training was introduction to the GEPIC model of Swiss Federal Institute of Aquatic Science and Technology (EAWAG). As the model GEPIC is large and complicated and time for training wasn't enough for detailed exploration the result of this training was familiarizing with the model and some practical experience.

At this training we have received the knowledge of:

- the application of the model;
- the structure of the model and input data formats;
- preparation of model input data using specialized applications Hawths Tools, UTILS, MODAWEC and GIS;
- output data formats and how to interpret them.

Subsequent independent pilot simulation in the ONU on the example of Odessa Oblast showed the need for additional training, and at the request of the ONU research group the second GEPIC Advanced Training Workshop for ONU team was conducted by Christian Folberth and Dr. Yang Hong on 06-12.06.2011 in the EAWAG (Düdendorf, Switzerland).

In the course of training the ONU team put in order their knowledge on GEPIC model use, choice of modelling parameters and preparation of source data for modelling.

In particular, the training participants studied the following.

- Using of MIRCA2000 raster data (MIRCA 2000) in the GEPIC model as the source of landuse data.
- Using of specific GIS-functions for spatial processing and preparation of source rasters.
- Optimization of calculated period and the model parameters: harvest-index and water-nitrogen stress factors.

- Using of PHU calculator, automatic planting and harvesting dates coming out of air temperature for calculation of vegetation period.
- Using of Fixed Crop Calendar (with specification of the planting and harvesting dates in the crop operations), automatic input of water and nitrogen fertilizers, removal of plant residues after harvesting.
- Using of modern approaches to the modelling results analyses: comparison of calculated and statistical data using GIS-function – Zonal Statistics, discrimination of unreliable statistical data about agricultural crop yields.

During the advanced training the parameters of all crop operations were developed for two crops (winter wheat and maize), optimal periods of calculation using the model were calculated and harvest-indices for Ukrainian conditions selected. As the result, the determination coefficients were achieved by comparison of the modelled and statistical data – up to 0,52 (in experiments before the advanced training maximal determination coefficients reached 0,32). The GEPIC Advanced Training Workshop for the ONU specialists in the EAWAG had significantly raised the level of their knowledge and quality of modelling for the territory of Odessa Oblast, and it enables to carry out the required model experiments in crop yields and other parameters calculation for the entire Ukraine territory.

1.1.2.3 Research *for the entire territory of Ukraine*

After conducting the GEPIC advanced training workshop and correcting of modelling methodology in the period from June 2011 to February 2012 (on agreement with the experts of EAWAG) the following work was scheduled.

A) To perform for the territory of Ukraine a series of model experiments on the calculation of the yield (Yd) and evapotranspiration (ET) using the model GEPIC (version 1.0) that works with ARCGIS 9.2, and the biophysical module EPIC (version EPIC0509, 2005) for the spatial resolution of 15x15 minutes, which amounts to 1260 computational cells. The temporal resolution of simulation: 11 years of calculation, calculated years: 2000-2010.

B) Prepare for use in model experiments national data about fertilizers (N, P, K) and irrigation depth, as well as information about irrigated and upland areas according to MIRCA 2000 (MIRCA 2000).

C) The list of crops for which yield and other parameters will be modelled should include winter wheat, spring barley, sunflower and maize.

D) To produce model experiments for the following four scenarios:

- No irrigation, no fertilizers;
- Irrigation, no fertilizers;
- No irrigation, fertilizers;
- Irrigation, fertilizers.

E) To calculate the correlation function of yields, calculated by GEPIC model and using statistical data from regional statistical offices about yields of the four above-mentioned crops.

D) Analyze the simulation results and prepare a report about research.

In January 2012 the following items were also included into the list of issues to be addressed by the ONU group in the simulations at the request of EAWAG:

- A series of simulation experiments for 2009-2010 to estimate impact of fertilizer and water on yield of the above four crops.

- Construct and analyze not only the output rasters for yield, but also for the distribution of ET.

- Analyze the trend of production, exports and imports for the four selected crops.

1.2 Methodology

1.2.1 Short description of GEPIC

GEPIC is a GIS-based crop growth model integrating a bio-physical EPIC model (Erosion Productivity Impact Calculator) with a GIS to simulate the spatial and temporal dynamics of the major processes of the soil-crop-atmosphere-management system (Liu at al. 2007 a).

The EPIC model was developed by USDA–ARS [United States Department of Agriculture (USDA) - Agricultural Research Service (ARS)] and Economics Research Service in cooperation with the Texas Agricultural Experiment Station in the late 1980s. The model has been continuously upgraded over the years. The latest version is EPIC0509 (2005). EPIC is composed of physically-based components for simulating erosion, plant growth, and related processes and economic components for assessing the cost of erosion, determining optimal management strategies, etc (Guerra at al. 2005). The EPIC components include weather simulation, hydrology, erosion–sedimentation, nutrient cycling, plant growth, tillage, soil temperature, economics, and plant environmental control. EPIC operates on a daily time step on drainage areas what are assumed spatially homogenous (Williams at al. 1989).

The EPIC file structure is contained the text files determining of parameters of different physical processes: crop parameters, tillage parameters, pesticide parameters, fertilizer parameters, etc. and the following input data: general data, water erosion data, weather data, wind erosion data, soil data, and management information.

The EPIC can be used to assess the impact of weather and management strategies on agricultural production and soil and water resources. It can simulate a variety of management strategies that include crop rotations, tillage operations, irrigation scheduling, nutrient, and pesticide application rates, and timing (EUROSTAT 2008). Compared to the other models, the EPIC model uses an approach to simulate more than 100 types of crops. It has been successfully applied in simulating crop yields for various combinations of weather conditions, soil properties, crops, and management schemes in many countries all over the world (Liu and al. 2007 b).

By integrating EPIC with a GIS, the GEPIC model considers each grid cell as a homogenous site. It simulates the crop-related processes for each predefined grid cell with spatially distributed inputs. The inputs are provided to the model as raster maps as well as text files: land-use maps, elevation and slope maps, irrigation maps, fertilizer maps, climate code maps, and soil code maps. The land-use maps provide information on crop distribution (code 0 indicates absence of a specific crop; 1 and 2 indicate existence of the crop under rain fed and irrigated conditions).The elevation and slope maps show the average elevation and slope in each grid cell. The irrigation and fertilizer maps show the annual maximum irrigation depth and fertilizer application rate. The climate and soil code maps indicate the code numbers of the climate and soil files in each grid cell. These code numbers correspond to the text files of climate and soil data. Climate files contain daily weather data (e.g. daily precipitation, daily minimum and maximum temperatures) and monthly weather statistics. Soil files contain several soil parameters (e.g. soil depth, percent sand and silt, pH, organic carbon content, etc.).

The outputs of the GEPIC model are raster GIS maps representing the spatial distribution of output variables such as crop yield, crop water productivity, water transpiration, harvest index, etc. as well as text files.

To develop the GEPIC software the ESRI's GIS software ArcGIS was selected. The well-documented ArcObjects libraries were also an important reason for the selection. The ArcObjects libraries allow any available function of ArcGIS to be exploited. In addition, the functionality can be further extended by using third-party Component Object Model-compliant (COM-compliant) programming languages such as Visual Basic, C++, Java, or Python.

ArcGIS is used as an application programmer framework, input editor, and output map displayer. As an application framework, ArcGIS provides the language VBA to design the interface of GEPIC, and to design programs for input data access, text output data generation, and output map creation. As an input editor, ArcGIS is used to convert vector input data into raster data, which are the main input format.

The GEPIC software contains three components. The most obvious component is the proprietary GIS, which is a standard ArcMap window in ArcGIS. The second component is the EPIC model, which is the core of all simulations. The third component is the GEPIC interface. The interface contains toolbars and menus. The toolbars provide functional buttons to locate raster input data sets, to select the simulated area and crops, and to specify spatial resolution, and to set the locations of the EPIC file, and input and output files. It provides buttons to edit inputs into EPIC required input files, to run the EPIC model, and to generate output maps. The menu has submenus, which allow users to perform the same asks as the toolbars.

The UTIL (Universal Text Integration Language) comes with the EPIC model. The UTIL are used as a data file editor and can edit the EPIC specific input data files by executing a series of command lines (Dumeshil 1993).

The conception of the GEPIC model is illustrated in figure. 3.1. The GEPIC model can estimate crop yield and other parameters by considering the influencing factors with a flexible spatial scale ranging from field to global.

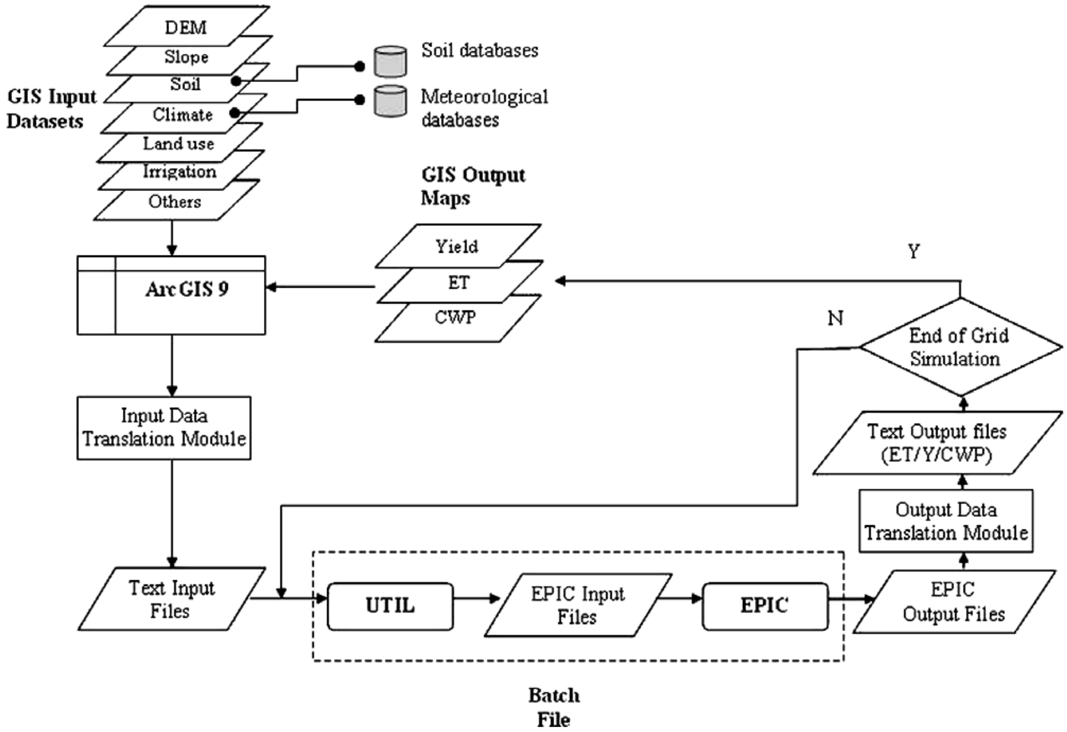


Figure 3.1. The schematic representation of the integration of EPIC with GIS

(Liu at al. 2007 b)

1.2.2 Description of the simulation for four main crops

1.2.2.1 Pilot area - Odessa Oblast

Description of the area of simulation

Odessa Oblast is located in the south-west of Ukraine from the Danube Delta to Tiligul Estuary: coastline within the area stretches for 300 km. The area of Odessa Oblast is 33.3 thousand km. The area is bordering with the Republic of Moldova and Romania on land and at sea. The main feature of the economic and geographic location of the area is its coastal and border situation.

Several large inland water bodies are situated in the area: on the left bank of the Lower Danube and in the valley between Kiliya Branch of the Danube and Dnestrovskiy Estuary there are freshwater lakes Kagul, Yalpug, Katlabuh and Kitay, as well as salty water bodies Sasyk, Alibey, Burnas, Budatskoe, Shagany; in the eastern region there are salty estuaries Hadzibey and Kuyalnik.

Average annual temperature in the Oblast varies from +8,2 ° C in the north to +10,8 ° C in the south. Average annual rainfall is from 340 mm in the south to 460 mm in the north.

The northern part of the region is situated in the forest steppe and southern is in the steppe zone. The ordinary and southern chernozems are dominating in the soil cover. The growing season of crops is from 180 to 210 days. Natural conditions are favourable for cultivation of wheat, corn, barley, millet, sunflower, and in northern and central areas for sugar beet, in the south - for grapes. These conditions essentially affect the regional specialization and the territorial organization of agricultural production.

The defining feature of the natural resources area is the availability of a huge and diverse recreational and resort potential: favourable climate, sea, curative mud and brine of estuaries, sandy beaches, mineral water, historic and cultural values.

Natural resources that have practical interest for today presented with building minerals.

Odessa Oblast is highly developed industrial region, the industry of which plays a significant role in the economy of the region.

The main sectors that form the structure of industrial production are food industry (the share of total sales 26.3%), manufacturing of petroleum products (24.0%), chemical and petrochemical industry (14.6%), http://www.multitran.ru/c/m.exe?a=110&t=95493_2_1&sc=0engineering (9, 1%).

Agriculture is one of the most important sectors of the region. Depending on climatic conditions in the area the forms of economy corresponding to the zones of farm production specialization were formed (figure 3.2):

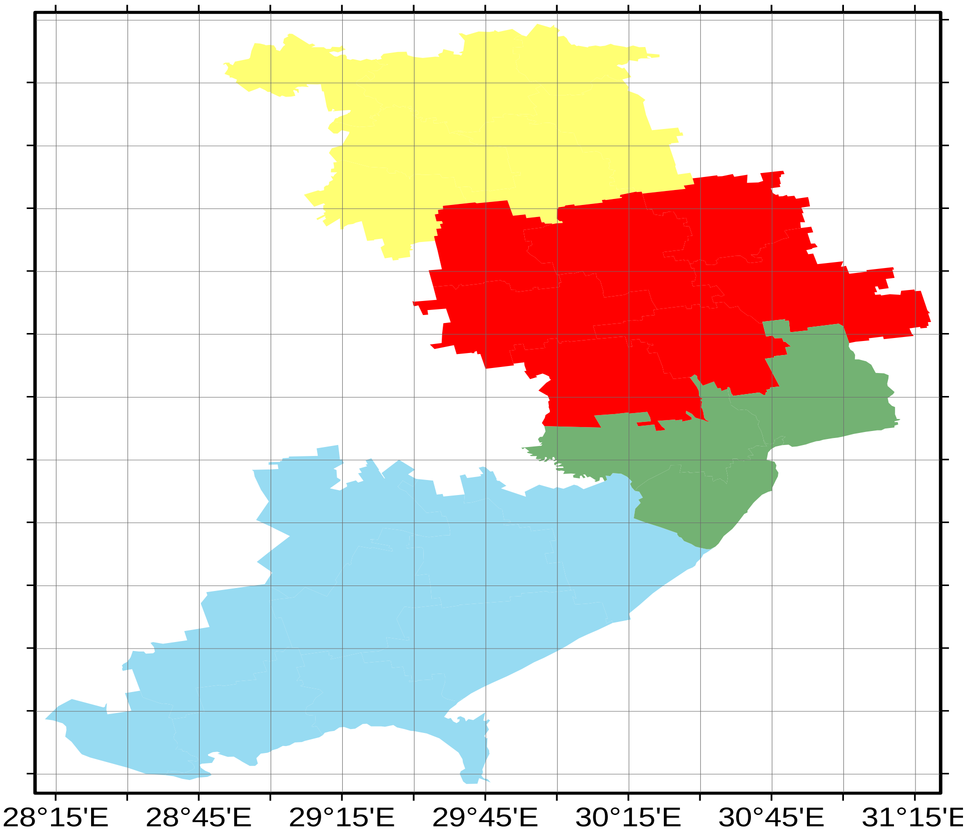


Figure 3.2. Areas of farm production specialization in Odessa Oblast. Yellow - grain and stock zone; Red - grain and stock zone with developed production of sunflower; Green - grain -vegetables - milk - poultry area; Blue - grain and stock zone with developed viticulture.

Land of the region is 3,3 million hectares including 2,66 million hectares (80,6%) - is agricultural land, including arable land is 2,1 million hectares (77,7%), layland - 29,4 hectares (1,1%) grasslands – 50,7 thousand ha (1,9%), pastures – 354,6 hectares (13,3%), perennial plants - 90,3 thousand ha (3,4%) (Shabliy at al. 1998).

1.2.2.2 Features of GEPIC model use for Odessa Oblast

Inasmuch as in Ukraine simulation using GEPIC not been before, as well as lack of full information on application of the existing versions of models GEPIC and EPIC, to reach the objectives of the ONU in the framework of the ENVIROGRIDS project it was decided to run and debug the operation of these models on the example of one culture - winter wheat in Odessa Oblast, using knowledge obtained at the training on GEPIC, 3-4 May 2010, in the University of Agronomical Sciences (Bucharest, Romania), as well as user guides available on the Internet (GEPIC 2010; EPIC 2010) and the kind assistance from Christian Folberth of EAWAG (Switzerland).

In the course of this work a series of experiments was performed, in general, gradually improving the results, although not to the desired level. Each experiment was performed for four scenarios for four years for each crop without crop rotation: only the results for the last year were used.

The conditions of experiments are described below.

Experiment 1: Automatic. In the automatic simulation experiment Automatic crop calendar was used that applies when exact planting and harvest dates are not available and uses the parameters of agricultural crops and processing of crops, which are incorporated by developers default model.

It uses automatic irrigation and input of necessary fertilizers for achievement in the model calculations of stress factors values on fertilizers and necessary moisture indicated in the control file - EPICCONT.DAT. Thus, when the plant nitrogen stress level reaches BFT (N stress factor variable), nitrogen fertilizer may be applied automatically. Similarly, for BIR - water stress factor variable. The limitation on amount of water and nitrogen fertilizer applied per unit area are annual amounts of water and fertilizer inputs specified in the irrigation and fertilizer raster datasets.

Simulation parameters:

Number of experiment	Experiment 1;
Crop	Winter wheat;
The final years of the calculation	2002, 2005, 2009, 2010;
HI - harvest index	0,45;
Type of calculation (Automatic crop calendar or Fixed crop calendar)	Automatic crop calendar;
CO^2 content in the atmosphere, ppm	350;
Stress factor on the water (BIR)	0,99;
Stress factor on the fertilizer (BFT)	0,8.

Experiment 2: Auto-manual. In the auto-manual simulation experiment we used Fixed crop calendar, which involves the use of crop parameters and character and date of processing the crops, which are specified in the crop operations *. ops file in the EPIC0509 folder (GEPIC 2010). At the same time in the *. ops file for winter wheat were the dates and method of cultivation, as well as irrigation volumes similar for all cells, according to (WATERMD 2009, State Agency of Water Management of Ukraine 2010). Thus, automatically making the necessary fertilizer applied only in achieving in the model calculations of stress factors values.

Simulation parameters:

Number of experiment	Experiment 2;

Crop	Winter wheat;
The final years of the calculation	2002, 2005;
HI - harvest index	0,35;
Type of calculation (Automatic crop calendar or Fixed crop calendar)	Fixed crop calendar;
CO^2 content in the atmosphere, ppm	374,2 и 380,3, years accordingly;
Stress factor on the water (BIR)	0;
Stress factor on the fertilizer (BFT)	1.

Experiment 3: Manual. In the manual simulation experiment we used "Fixed crop calendar", which involves the use of crop parameters and the nature and dates of processing the crops, which are specified in the crop operations *. ops file in the EPIC0509 folder.

Simulation parameters:

Number of experiment	Experiment 3;
Crop	Winter wheat;
The final years of the calculation	2002, 2005, 2009 (cell size 5x5;
HI - harvest index	0,35;
Type of calculation (Automatic crop calendar or Fixed crop calendar)	Fixed crop calendar;
CO^2 content in the atmosphere, ppm	374.2, 380.3, 388.5 years accordingly;
Stress factor on the water (BIR)	0;
Stress factor on the fertilizer (BFT)	0.

The calculation was performed as mentioned above, for the four scenarios, but in this experiment for all cells the actual amount of nitrogen, phosphate and potash fertilizer introduced on a unit area were indicated. That is, irrigation and fertilization were determined by figures specified in *. ops file.

Experiments 4, 5 and 6 were performed under the same conditions and parameters that are specified in experiment 3, for 2002 and 2005 for sunflower, spring barley and maize, respectively.

After the GEPIC Advanced Training Workshop we used the new updated terms of modelling for Odessa Oblast, using new knowledge acquired during training, which are described in paragraph 2.2.2. and in more details described in Annex 1.

Under these new conditions a series of repeated experiments № 3a, 4a, 5a and 6a were carried out to model yield crops such as sunflower, spring barley and maize, respectively.

1.2.2.3 Territory of Ukraine

Description of simulation region

Territory of Ukraine is located between 52 ° 20 'and 44 ° 20' north latitude and 22 ° 5 'and 41 ° 15' east longitude and stretches 1316 km from east to west and 893 km from north to south. The total area of Ukraine is 603,7 thousand km ², that is 5,7% of Europe and 0,44% of the world. The length of the coastline of Ukraine is 2835 km (Shabliy at al. 1998).

Ukraine is located within the East European plain, in areas of pine and mixed forests, forest steppe and steppe. In the central part of Ukraine there is chernozem belt. Just north of the chernozem belt gray forest and sod-podzol soils under mixed forests are distributed, to the south there are http://www.multitran.ru/c/m.exe?a=110&t=5475201_2_1&sc=212dark brown and brown soils under the dry steppes.

Relief of most of the territory is a plain: lowlands occupy 70%, and elevations and mountains - 25% and 5%. Mountains are located in the southwest (the Ukrainian Carpathians, the highest peak is Mount Goverla, 2061 m above sea level) and in the southern part of Crimea (Crimean Mountains, highest peak is Roman-Kosh, 1,545 m). Major lowlands are: in the south is - Prichernomorskaya, in the north - Polesskaya, in the center - Pridneprovskaya in the west - Zakarpatskaya (Shabliy at al. 1998).

Despite the dominant temperate continental climate Ukraine is characterized by fairly significant difference in the humidity of the climate, temperature, length of vegetation period, etc. Regular alternation of the influence of western (wet Atlantic) and eastern (dry continental) air in a predominantly plain territory of Ukraine causes frequent changes of cyclonic - anticyclonic and vice versa activities. In the summer it affects the change of warm air masses with wet and moderately warm Atlantic, and in winter - warm Atlantic with cold mass coming from the North and Siberia. In some years there are significant deviations of the average parameters of most long-term climatic characteristics.

Within Ukraine there are four agro-climatic zones, gradually passing into one another. In the north-western part there is a warm area with sufficient moisture. In the south-east of it extends a warm area with average moisture content. Next in a southeast direction there is very warm arid zone, and the entire southern part of the country is located in a moderately hot arid zone (Shabliy at al. 1998).

Significant role in climate formation is played by temperature regime, characterized by significant fluctuations. Temperature of the coldest month (January) almost throughout (except the southern coast) is negative (the average -2° ... -7,5°C) and of the warmest (July) is +17,5° ... +22°C. The average frost-free period ranges from 260-270 days in the southern Crimea to 170 days in the north-east. There are substantial variations of mean annual temperatures. The absolute maximum temperature reaches +36°...+42°C in summer and +6... +18°C in winter, the absolute minimum is -30°C, respectively (south) and -40°C (east). Seasonal temperature changes significantly vary across regions of the country. Periods when the average temperature exceeds +20°C in the south last up to three months, while almost absent in the west and north. Frosty period with an average temperature below 0°C mainly ranges from 2 months in the south to 5 months in the north-east of the country

(Shabliy at al. 1998).

The climate-forming regime of Ukraine is influenced by total amount of rainfall, its distribution across regions and seasons. Most of them fall in the Ukrainian Carpathians (up to 1600 mm per year) and in the Crimea (800-1150 mm). In the rest of territory it ranges from 700-750 mm (in the north-west) to 300-350 mm (in the south-east). In dry years precipitation significantly reduces: in the coastal areas of the Azov and Black Seas - up to 100 mm, 150-200 mm in the steppe and up to 250-350 mm in forest steppe (Shabliy at al. 1998).

The largest industries in Ukraine are metallurgy, power (nuclear power plants and hydropower cascade on the Dnieper River), as well as chemical and mining (coal, ore). The most economically developed regions are Donbas (Donetsk and Lugansk Oblast), Pridneprovie (Dnepropetrovsk Oblast and Zaporozhye Oblast), and also cities of Kiev, Kharkov, Odessa and Lvov.

One of the main components of Ukraine's economy is agriculture. Products of the industry satisfy domestic demand and exports to international markets. The components of agriculture are crop production (cultivation of grain, industrial and fodder crops, potatoes, fruit, etc.) and livestock (cattle, swine, sheep, poultry and other areas). The development of agriculture depends on natural-geographic and socio-economic conditions. In general, very favourable agro-climatic and soil conditions have zonal distribution. Therefore, in Ukraine there are three agricultural zones: Polesie, the forest-steppe and steppe, as well as two mountain regions: the Carpathian and the Crimean (Shabliy at al. 1998).

It is well known that Ukraine has focused a significant amount of the world's black soil, which was one of the main prerequisites for the rich agricultural tradition of our people. Up to 70% of the land fund of the state consists of agricultural land (arable land, perennial plants, pastures and hay fields), but they are used inefficiently. In addition, more than 80% of agricultural lands are under cultivation, this also affects the condition of the soil. In addition, due to employment of manual and unskilled labour and predominantly extensive economy, where production growth is provided mainly through the involvement into turnover of new land and an increase in livestock, agriculture has low productivity. The land reform being now implemented is designed to solve this problem. In recent years, land sharing (transfer to private ownership) became widespread, as well as the establishing of farms, involvement of new agricultural techniques and modern technology (Shabliy at al. 1998).

The main branch of agriculture in Ukraine is arable farming: growing cereal (wheat, rye), grain (buckwheat, rice, millet), fodder (barley, oats, corn), legumes (peas, beans).

The most important crop is wheat. Two fifths of cropland are under wheat Winter wheat is grown mainly in the forest steppe and steppe zones. To the east of these zones, where winter snow cover is mostly small, spring wheat dominates. Rye is grown mostly in Polesie and near the Carpathians, where excessive moisture is available, soil is not very fertile, and for wheat these conditions are not very favourable. Barley, corn and oats are used as fodder crops, but they have important food value. Barley is grown everywhere, but mostly in the south. The largest acreage of corn is in the northern and central parts of the steppe, forest-steppe in the south, where it gives high yields. Buckwheat is grown in very large areas of forest steppe and Polesie Region because of its insistence to moisture. Legumes (peas, beans) are grown in the steppe and in Polesie.

The level of grain production in Ukraine was formerly one of the leading places in the world - the annual harvests reached 50 million tons and more. In the 90-ies of XX century they have been halved, and only in 2004 and 2008 there were record harvest since independence (about 42 million tons of grain).

The largest area of industrial crops in Ukraine is occupied by sunflower and sugar beet. In the production of these crops Ukraine for a long time has occupied a leading position in Europe and was among the world leaders. However, the decrease in demand for Ukrainian sugar led to a sharp reduction in acreage and harvests of sugar beet. But the area under sunflower rose sharply to 70% of the acreage of industrial crops. Sugar beets are whimsical to heat, light and moisture, that is why the main regions of growth are North steppe and steppe zones. In the steppe and forest-steppe zone in the south there are the best conditions for growing sunflower.

Forage crops occupy over a third of the country's acreage. Among them, the highest proportion is of single-and perennial grasses, maize.

Thanks to its mild climate and the availability of fertile soil, Ukraine has a considerable area of gardens. Pomefruit trees (apples, pears) better bear fruit in the forest steppe and in the Polesie, and stone fruits (cherry, black cherry, plum, apricot, alycha, etc.) - in the steppe. All over the territory of Ukraine berries are grown: currants, red currants, raspberries, gooseberries, etc. In the southern and central parts of the steppe in the foothills of the Crimea and in Zakarpatye viticulture is developed (Shabliy at al. 1998).

1.2.2.4 Peculiarities of the GEPIC model use for the territory of Ukraine

Model experiments for the territory of Ukraine have been made based on the knowledge and approaches to GEPIC modelling received as the result of pilot modelling for Odessa oblast, which was done from September 2010 till May 2011, as well as using the experience gained at the GEPIC advanced training in EAWAG. Significant consultative help to the ONU working group at modelling in the post-training period was rendered by Christian Folberth of EAWAG, Switzerland.

Calculation was done for 11 years periods; only the calculation results for the last year of a period were used as the GEPIC model generally creates unreliable results in the first few years (GEPIC 2010). Duration of calculation period was drawn empirically during the GEPIC advanced training.

The following general modelling conditions were used for all crops:

- Carbon dioxide concentration was taken into account according to the scheme from «Earth's CO^2 Home Page» (CO^2 no date) according to which the positive trend of CO^2 concentration in the atmosphere made ~ 2 ppm/year.
- Due to significant latitudinal extent of the territory being modelled and different climatic conditions for crops growing the terms of planting and harvesting have not been strictly set, but calculated by model coming out of the amounts of heat required for vegetation of each crop (Potential Heat Unit - PHU) for this latitude. At that, for calculations by the model daily climatic data on minimal and maximal air temperature were used for determination of optimal planting.
- Automated irrigation was used with specifying in raster of maximal annual irrigation depth. When modelling plant growth under non-irrigated variants the water from precipitation has been taken into account; under irrigated variants the required amount of water was added by irrigation within a year maximum when calculations were reaching water stress state (BIR - water stress factor variable).
- Automated application of nitrogen fertilizers was used under non-irrigated and irrigated variants with specifying of maximal annual quantity of nitrogen fertilizers in rasters for every crop and every calculated. At that, the nitrogen fertilizers were applied as and when needed, and the need was regulated by plant stress factor on nitrogen fertilizers (BFT - N stress factor variable).
- The calculations used in the model removing of plant residues after harvesting.
- The use of plant protection from pests and diseases is not modelled.
- The values of harvest-index: HI, WSYF were selected for different years using series of experiments.
- We used a version of the GEPIC calculation - Fixed crop calendar, which provides for the use of the parameters of agricultural crops, the nature and date of processing of crops, which are specified in the crop operations *. ops files in the EPIC0509 folder (EPIC 2010). These files were developed separately for each culture: in addition to the natural features of cultivation of each plant the amount of applied phosphate and potash fertilizers was set for each calculation year of modelling.
- As mentioned above, the selection of the period of the simulation was done by a series of experiments that determined the minimum period of simulation for getting the calculation results most comparable with the statistical and the maximum period from the onset of

degradation of the soil.

- For calculation of irrigated and no irrigated scheme we used rasters produced for each crop based on the data from the University of Frankfurt for 2000 (MIRCA2000).
- For calculation of fertilized and no fertilized scheme we used rasters produced for each crop based on statistics of Ukraine.

Appendix 2 lists the parameters for all model experiments for each specific crop and year. For each run of the model the following parameters were set:

- Calculated year;
- HI - Harvest Index;
- WSYF - Lower limit of harvest index;
- Contents of carbon dioxide in the atmosphere;
- IHUS - Automatic heat unit scheduling;
- BIR - Irrigation trigger;
- BFT - Auto fertilizer trigger;
- VIMX - Maximum annual irrigation volume allowed;
- FMX - Maximum annual N fertilizer application for a crop;
- PHU - Potential heat units for planting;
- FPPC - Plant population;
- Amount of applied phosphorus fertilizers;
- Amount of applied potash;
- Amount of applied nitrogen fertilizer.

1.2.3 INPUT and OUTPUT DATA for modelling

1.2.3.1 For the territory of Odessa Oblast – pilot study

Input data

There are two types of input data used for GEPIC model: raster dataset and text data. For modelling of Odessa Oblast territory the ONU staff produced three sets of input data for the variants having different spatial resolution: 30x30 minutes, 15x15 minutes and 5x5 minutes.

As the source data for the **DEM (Digital elevation model) raster dataset** for Odessa Oblast the GTOPO30 was used - global DEM from the U.S. Geological Survey's EROS Data Centre in Sioux Falls (GTOPO30 1996). Elevations in GTOPO30 are regularly spaced at 30-arc seconds (approximately 1 kilometre or 0.00833 degrees). GTOPO30 was developed to meet the needs of the geospatial data user community for regional and continental scale topographic data. GTOPO30 is a global data set covering the full extent of latitude from 90 degrees south to 90 degrees north, and the full extent of longitude from 180 degrees west to 180 degrees east. The horizontal coordinate system is WGS84. The vertical units represent elevation in meters above mean sea level. The elevation values range from -407 to 8,752 meters (figure 3.3).

Based on the GTOPO30 the following DEM rasters were produced – figures 3.4, 3.5, 3.6 for the respective spatial resolution.

As the source data for **Slope raster dataset** the 1-km resolution HYDRO1K digital raster slope map is used, which defines the maximum change in the elevations between each cell and its eight neighbours GTOPO30 (GTOPO30 1996) (figure 3.7). The slope is expressed in integer degrees of slope between 0 and 90. On its basis slope rasters were produced for respective spatial resolution - figures 3.8, 3.9, 3.10.

As the source data for the **Country raster dataset** the codes of the Raions of Odessa Oblast were used, approximated for the spatial resolution required - figures 3.11, 3.12, 3.13.

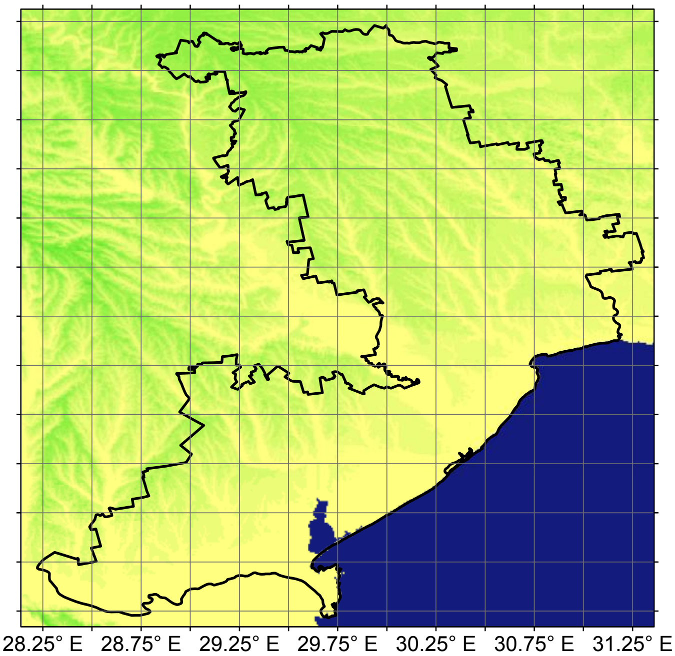


Figure 3.3. Digital elevation model GTOPO30 for Odessa Oblast area (Ukraine)

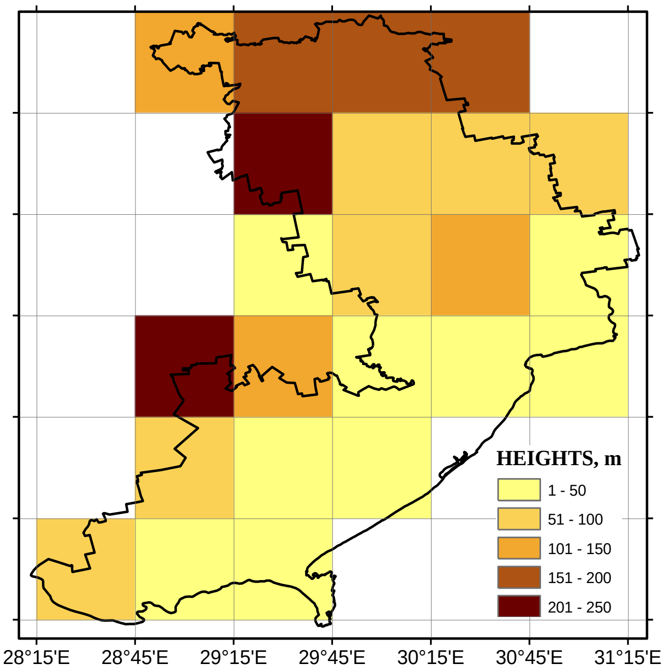


Figure 3.4. DEM raster dataset for Odessa Oblast with resolution 30x30 min

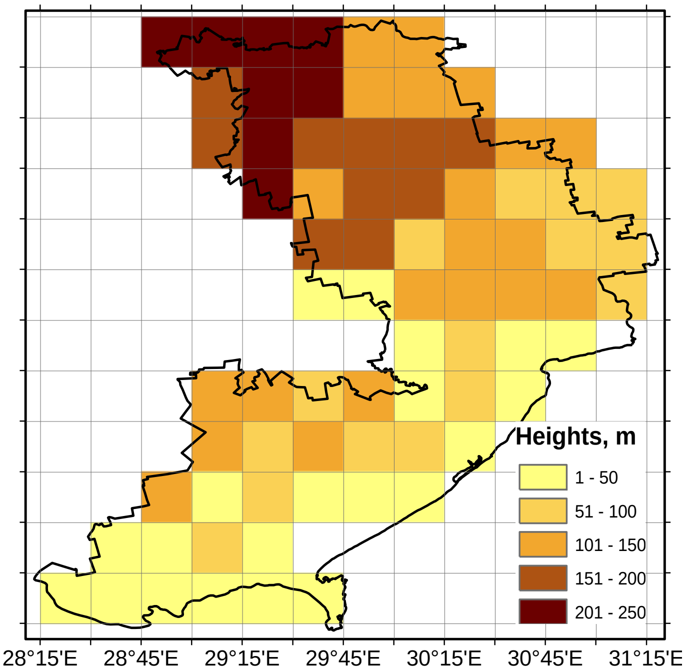


Figure 3.5. DEM raster dataset for Odessa Oblast with resolution 15x15 min

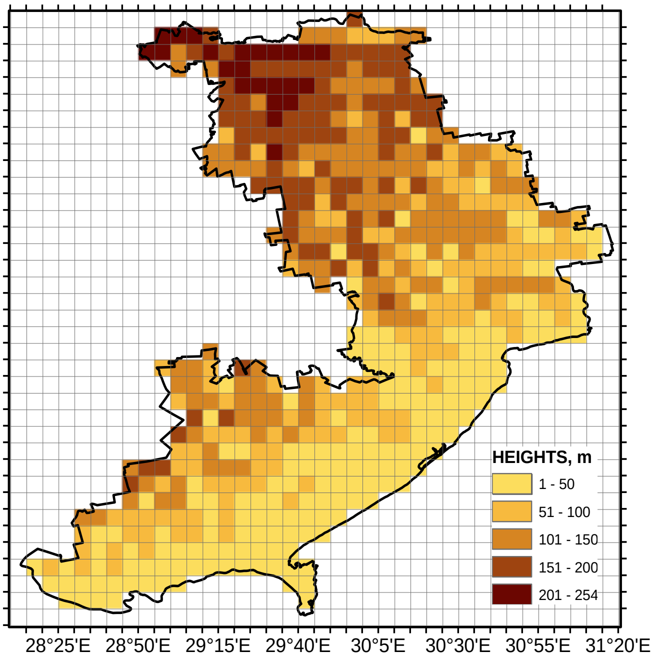


Figure 3.6. DEM raster dataset for Odessa Oblast with resolution 5x5 min

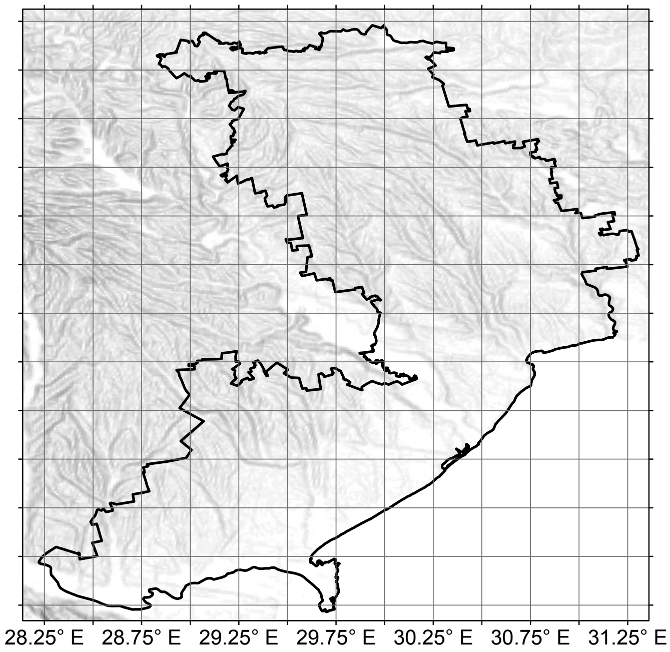


Figure 3.7. The slope dataset GTOPO30 for Odessa Oblast area (Ukraine)

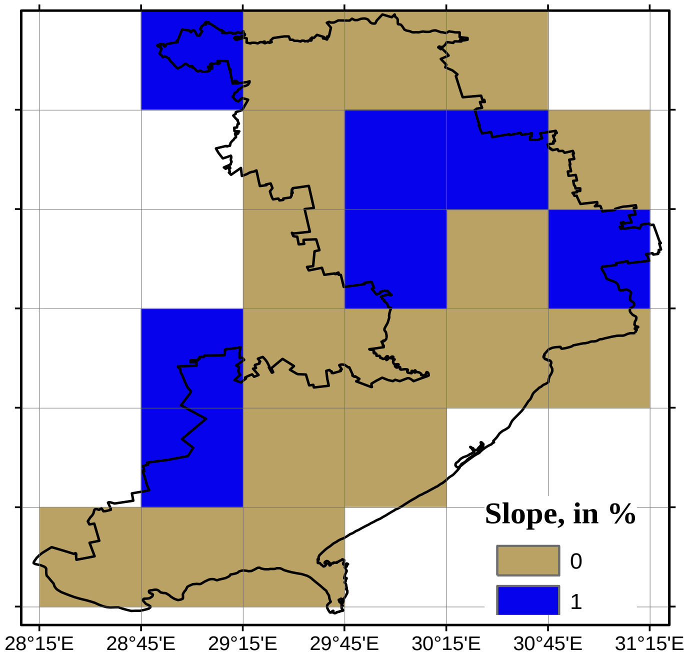


Figure 3.8. Slope raster dataset for Odessa Oblast on resolution 30x30 min

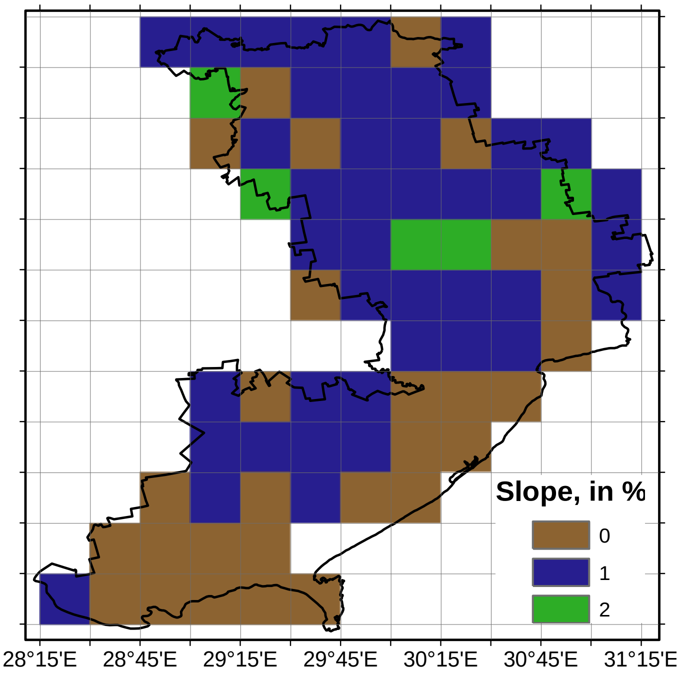


Figure 3.9. Slope raster dataset for Odessa Oblast with resolution 15x15 min

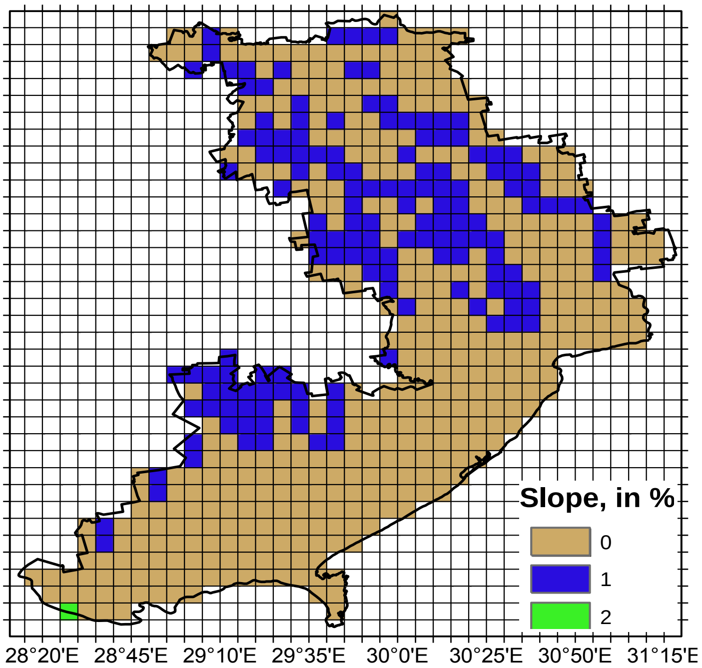


Figure 3.10. Slope raster dataset for Odessa Oblast with resolution 05x05 min

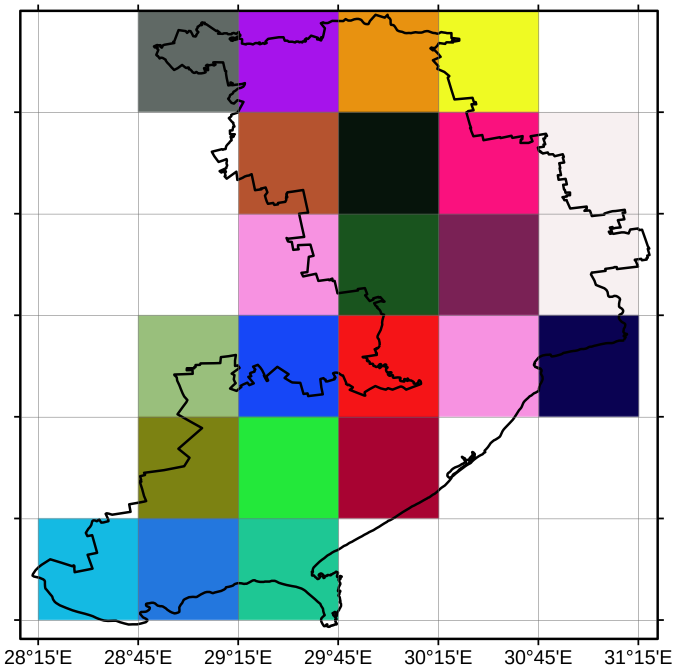


Figure 3.11. Country raster dataset for Odessa Oblast with resolution 30x30 min

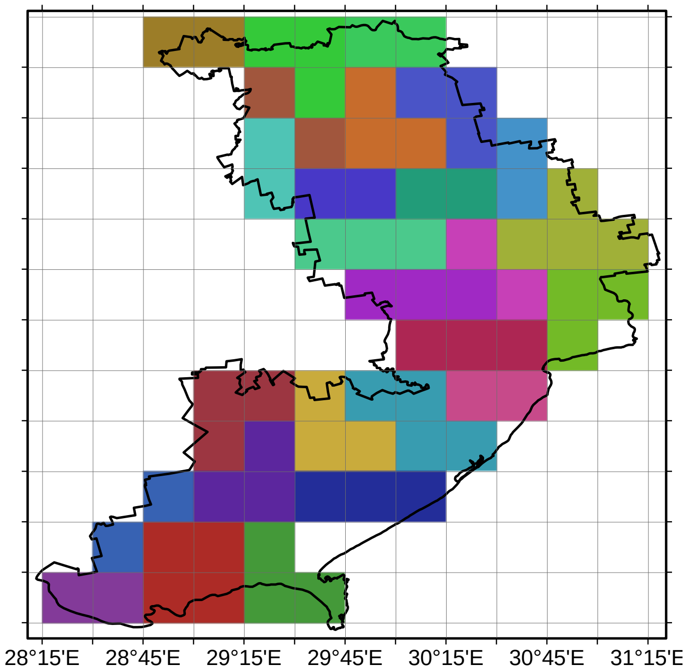


Figure 3.12. Country raster dataset for Odessa Oblast with resolution 15x15 min

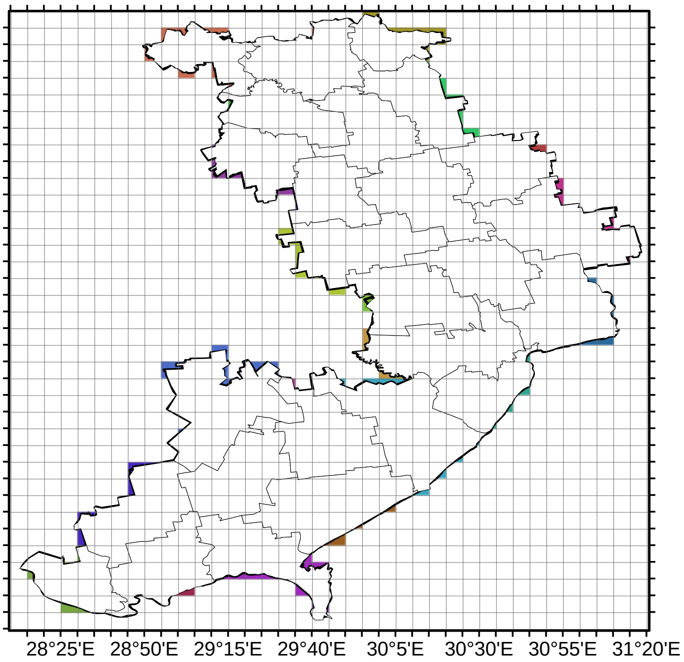


Figure 3.13. Country raster dataset for Odessa Oblast with resolution 05x05 min

As the source data for **land use raster dataset** we have used the data from the Institute of Soil Sciences and Agro-Chemistry named after O.N.Sokolovskiy about Ukrainian soils bonitet for different agricultural crops growing (Medvedev at al. 2002). Aim of soil bonitet is to establish relative value (suitability) of soils for crops growing – partial bonitet. Partial bonitet is calculated taking into account soils and climate characteristics with regard to the crops grown in Ukraine. Figures 3.14, 3.15, 3.16, 3.17 show the maps of partial bonitet of Odessa Oblast soils for winter wheat, sunflower, spring barley and maize. Based on those maps rasters of landuse had been produced for all the crops modelled the example of which is presented on figure 3.18.

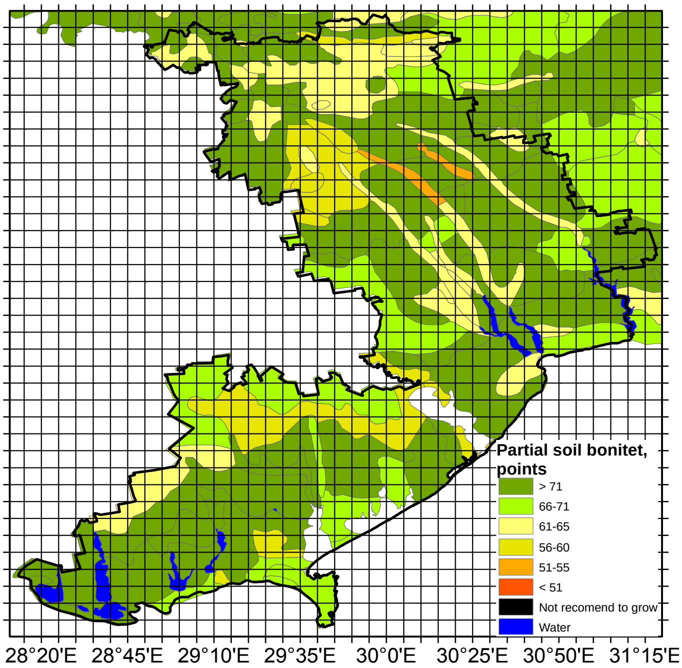


Figure 3.14. Partial soil bonitet (points) for winter wheat, Odessa Oblast

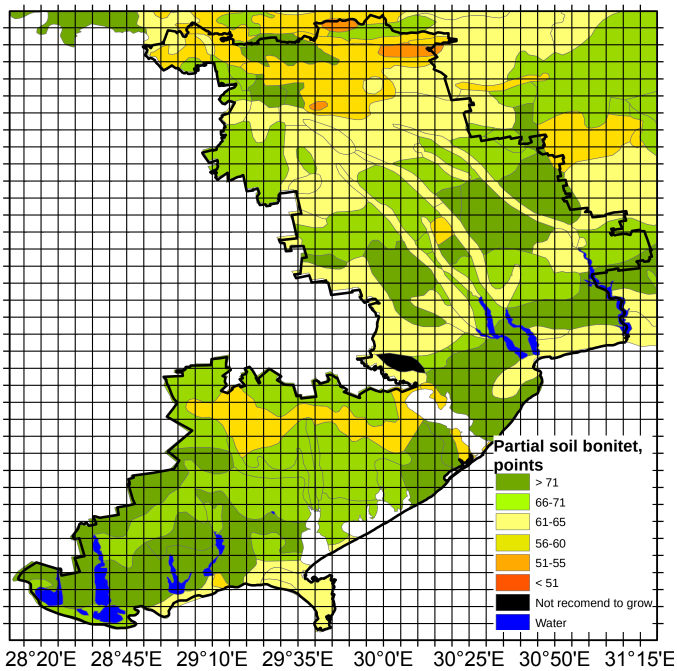


Figure 3.15. Partial soil bonitet (points) for sunflower, Odessa Oblast

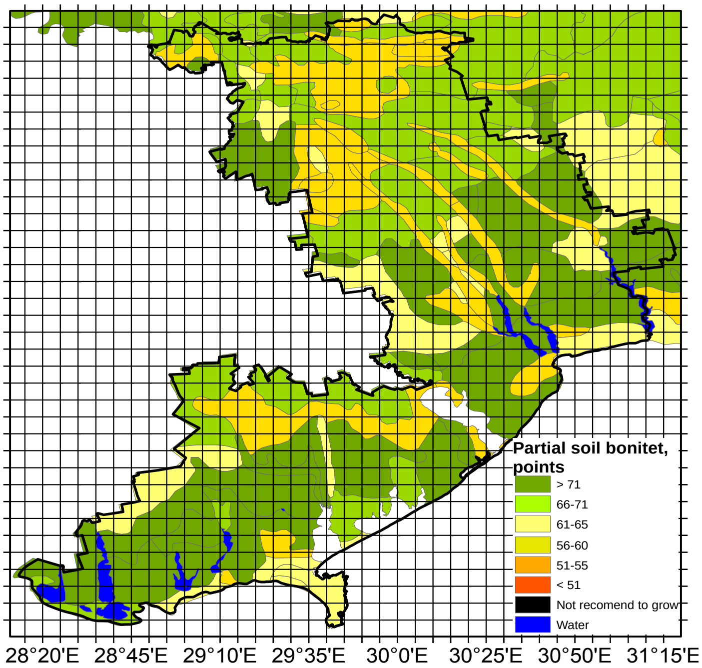


Figure 3.16. Partial soil bonitet (points) for spring barley, Odessa Oblast

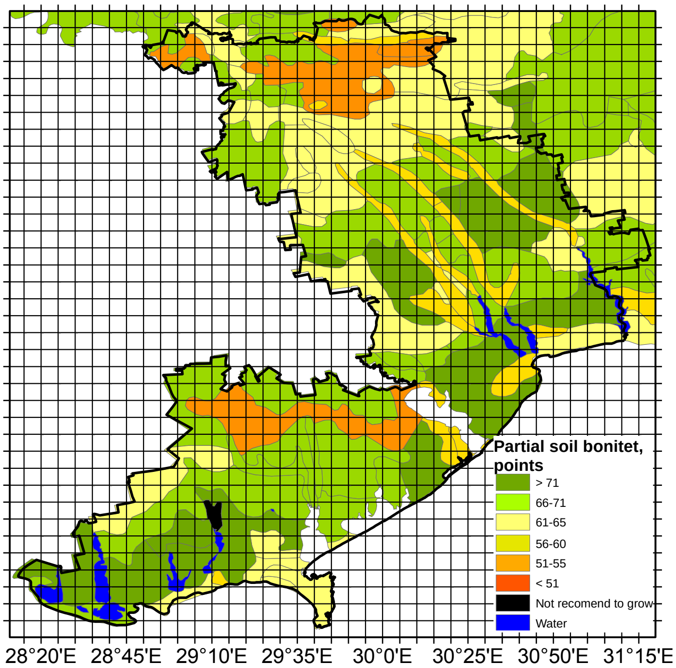


Figure 3.17. Partial soil bonitet (points) for maize, Odessa Oblast

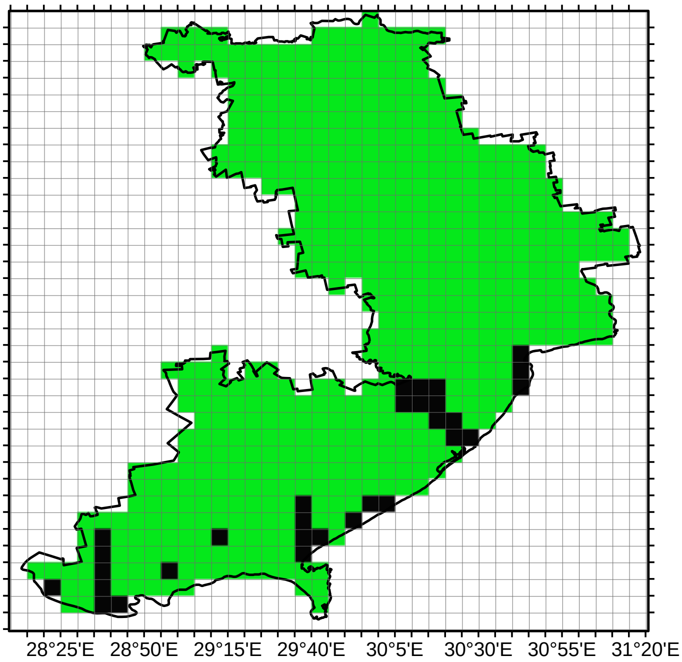


Figure 3.18. Land use raster dataset for winter wheat, Odessa Oblast, resolution of 5x5 min (all cells have code=1 - existence of the crop under rainfed conditions)

Soil raster dataset contains code numbers of the soil files in each grid cell. The soil 0.5 by 0.5 degree grid and soil parameters files required for simulations are obtained from ISRIC-WISE (ISRIC 2006; Batjes 2006). The ISRIC-WISE dataset contains a database with derived soil properties for 106 soil units: soil drainage class, organic carbon content, total nitrogen, C/N ratio, pH, base saturation, aluminium saturation, calcium carbonate content, gypsum content, exchangeable sodium percentage (ESP), electrical conductivity, particle size distribution (content of sand; silt and clay), content of coarse fragments, bulk density, and available water capacity etc. Linkage of the spatial (raster) data to the derived soil data and to the EPIC soil files will be through the grid cell identifier (Suid) of raster file (figure 3.19). Each soil code corresponds to one soil text file, which contains the soil parameters. An example of the EPIC soil file is on figure 3.20. The format of the soil files is shown in the EPIC User Manual (Shabliy at al. 1998). Coming out of source soil raster the rasters for each variant of spatial resolution were produced. Those are presented on figures 3.21, 3.22, 3.23.

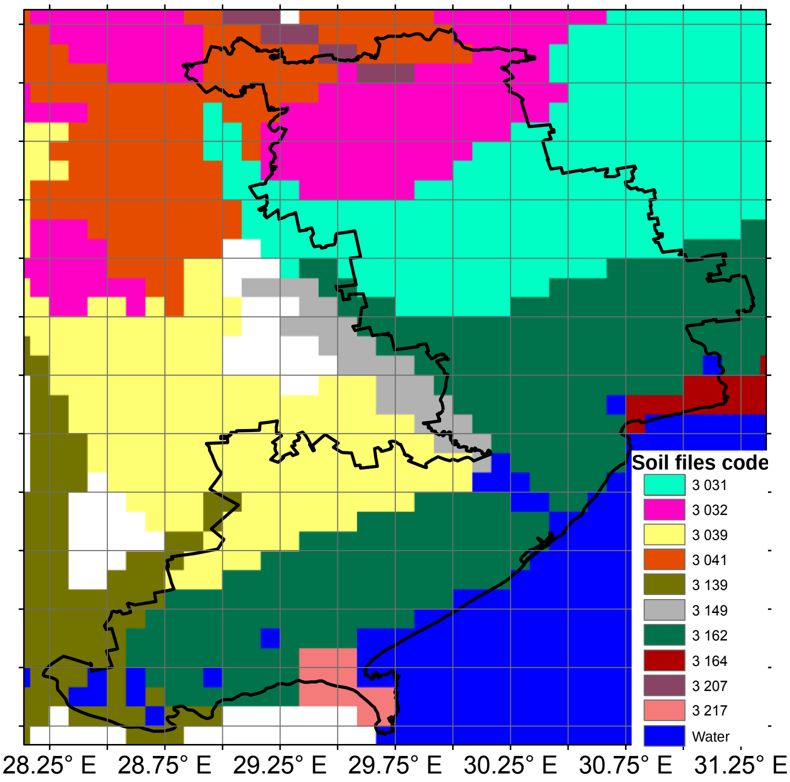


Figure 3.19. The ISRIC-WISE soil raster dataset for Odessa Oblast (Ukraine)

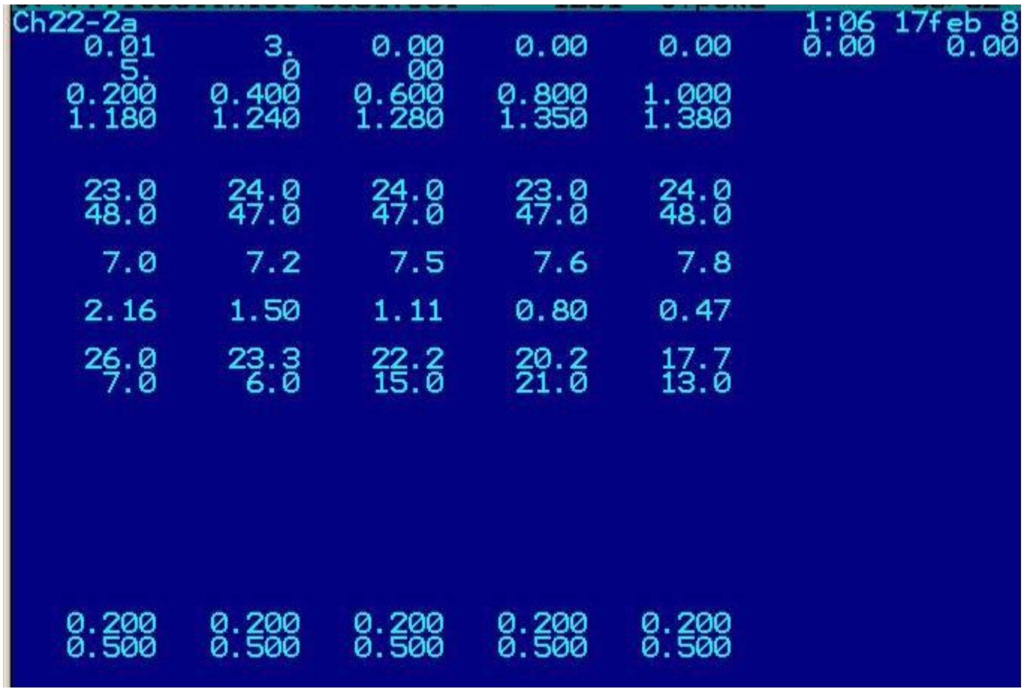


Figure 3.20. The content of the EPIC soil file 3031.sol

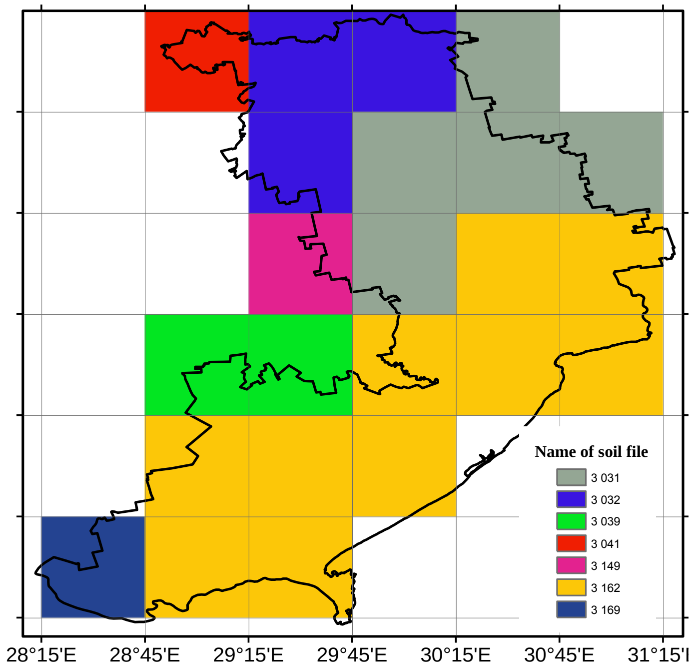


Figure 3.21. Soil raster dataset for Odessa Oblast with resolution 30x30 min

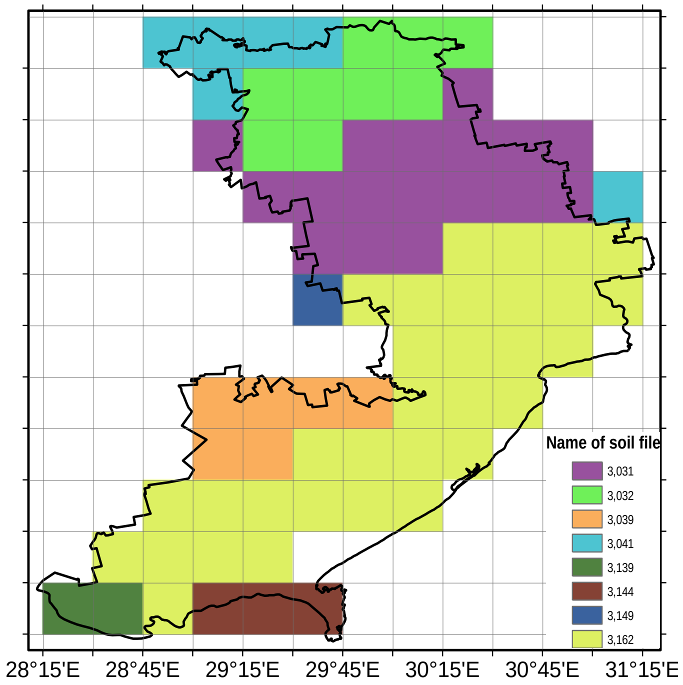


Figure 3.22. Soil raster dataset for Odessa Oblast with resolution 15x15 min

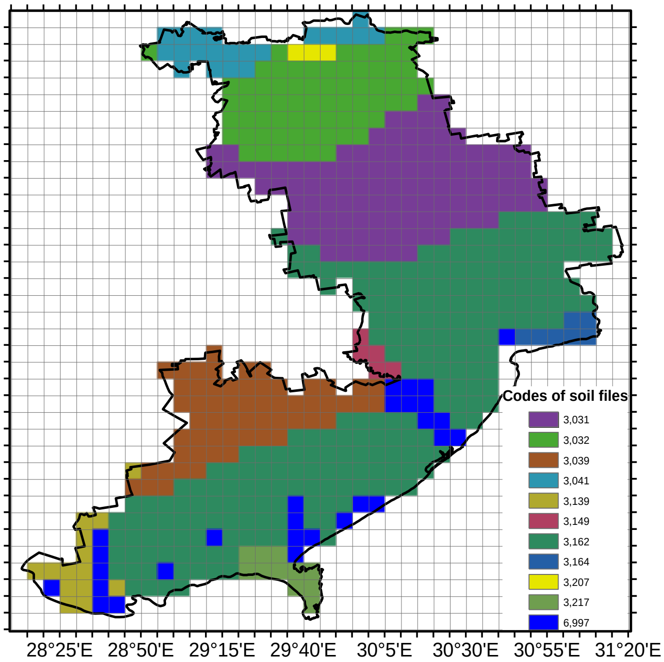


Figure 3.23. Soil raster dataset for Odessa Oblast with resolution 05x05 min

Climate raster dataset. Datasets for each spatial resolution are produced based on the gridded observational datasets of daily precipitation and temperature which have been developed on the basis of a European network of high-quality station series. The datasets cover the period from 1950 to 2010. They are made available on a 0.25 and 0.5 degree regular latitude–longitude grid. These datasets are made in the framework of the EU FP6 Integrated Project ENSEMBLES in format NetCDF. The description can be found in Haylock et al. (Haylock at al. 2008).

Actually the EPIC needs daily weather records: solar radiation, maximum temperature, minimum temperature, precipitation, relative humidity and wind speed (EPIC 2010), or EPIC can generate daily weather data using a stochastic weather generator.

For our purposes, out of the datasets (0.25) only those getting on the territory of Odessa Oblast were picked out, and using those climate raster datasets were produced for each respective spatial resolution - figures 3.24, 3.25, 3.26, and daily weather data files (*.dly) - figure 3.27.

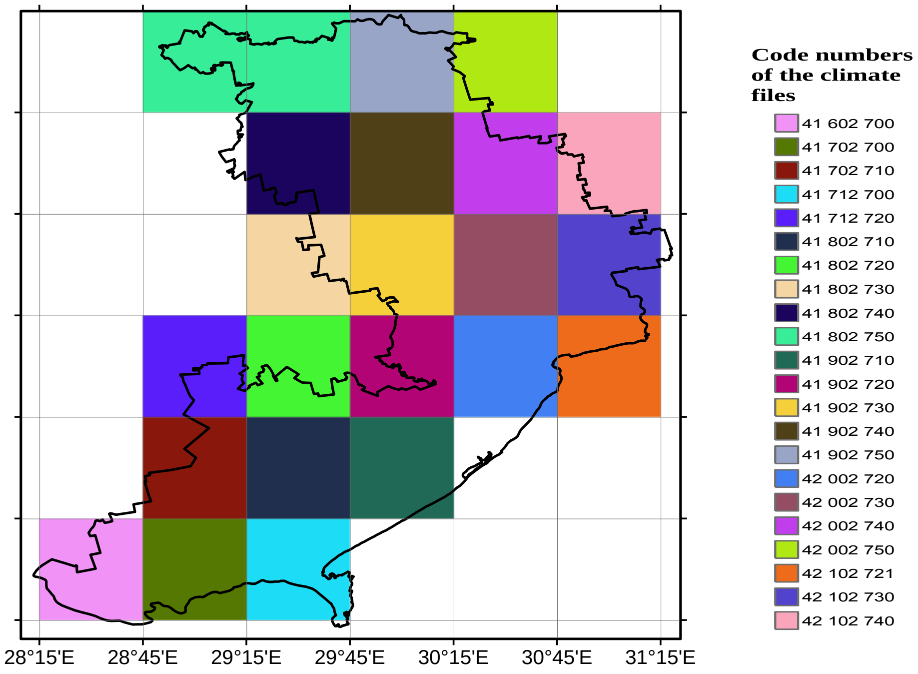


Figure 3.24. Climate raster dataset for Odessa Oblast with resolution 30x30 min

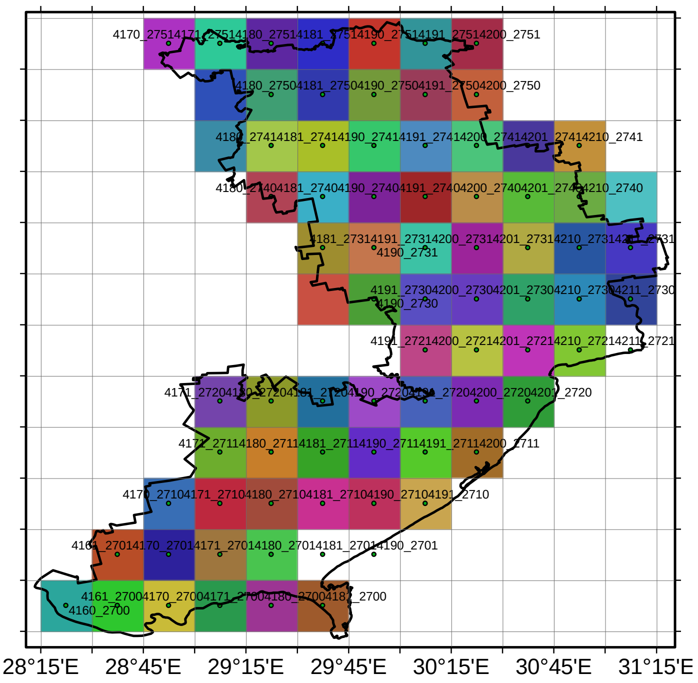


Figure 3.25. Climate raster dataset for Odessa Oblast with resolution 15x15 min

(The points numbers correspond to the daily weather data file names)

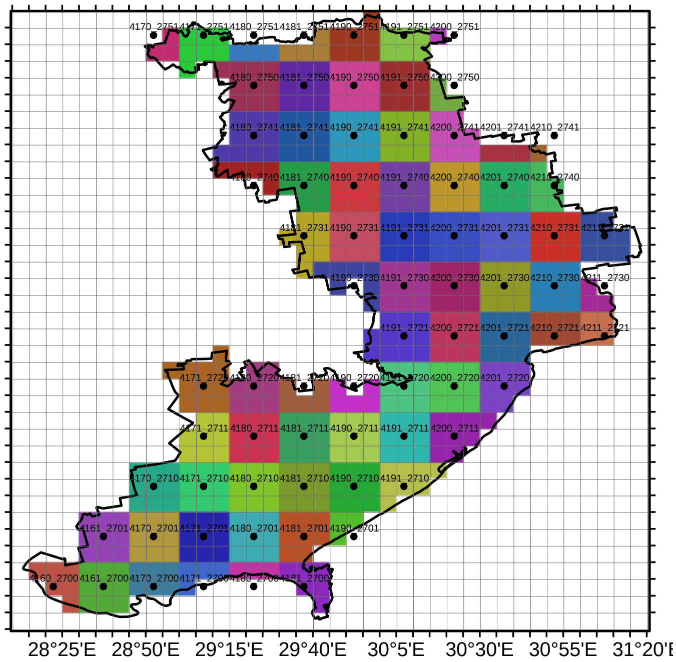
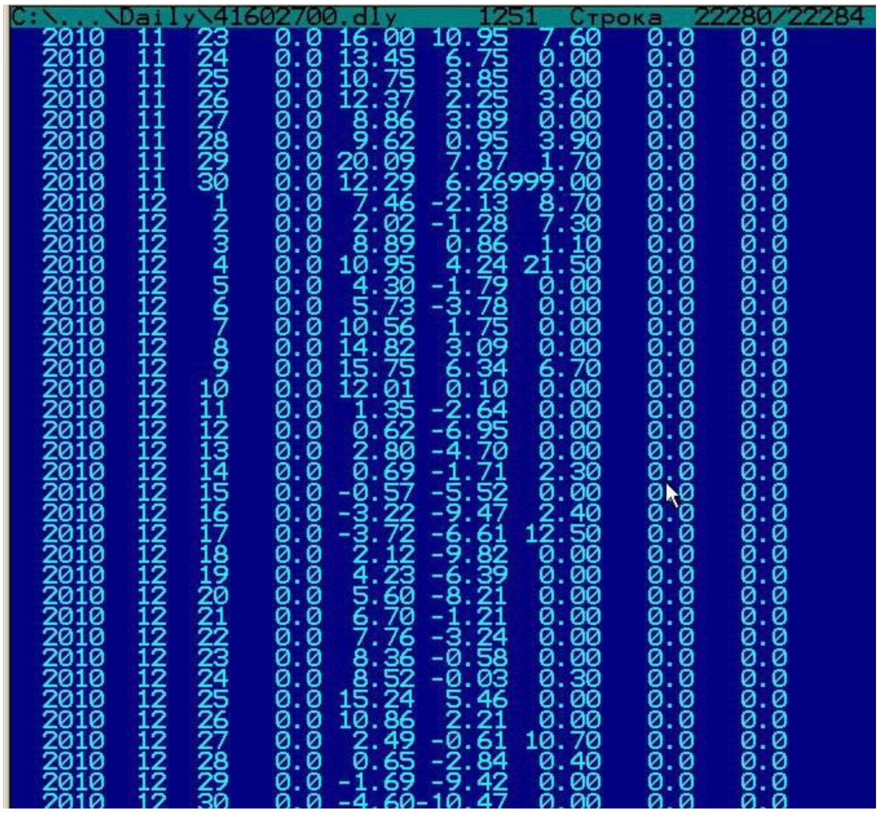


Figure 3.26. Climate raster dataset for Odessa Oblast with resolution 05x05 min (The points numbers correspond to the daily weather data file names)



```
C:\...\Daily\41602700.dly        1251  Строка   22280/22284
    2010   11   23     0.0 16.00 10.95  7.60    0.0    0.0
    2010   11   24     0.0 13.45  6.75  0.00    0.0    0.0
    2010   11   25     0.0 10.75  3.85  0.00    0.0    0.0
    2010   11   26     0.0 12.37  2.25  3.60    0.0    0.0
    2010   11   27     0.0  8.86  3.89  0.00    0.0    0.0
    2010   11   28     0.0  9.62  0.95  3.90    0.0    0.0
    2010   11   29     0.0 20.09  7.87  1.70    0.0    0.0
    2010   11   30     0.0 12.29  6.26999.00    0.0    0.0
    2010   12    1     0.0  7.46 -2.13  8.70    0.0    0.0
    2010   12    2     0.0  2.02 -1.28  7.30    0.0    0.0
    2010   12    3     0.0  8.89  0.86  1.10    0.0    0.0
    2010   12    4     0.0 10.95  4.24 21.50    0.0    0.0
    2010   12    5     0.0  4.30 -1.79  0.00    0.0    0.0
    2010   12    6     0.0  5.73 -3.78  0.00    0.0    0.0
    2010   12    7     0.0 10.56  1.75  0.00    0.0    0.0
    2010   12    8     0.0 14.82  3.09  0.00    0.0    0.0
    2010   12    9     0.0 15.75  6.34  6.70    0.0    0.0
    2010   12   10     0.0 12.01  0.10  0.00    0.0    0.0
    2010   12   11     0.0  1.35 -2.64  0.00    0.0    0.0
    2010   12   12     0.0  0.62 -6.95  0.00    0.0    0.0
    2010   12   13     0.0  2.80 -4.70  0.00    0.0    0.0
    2010   12   14     0.0  0.69 -1.71  2.30    0.0    0.0
    2010   12   15     0.0 -0.57 -5.52  0.00    0.0    0.0
    2010   12   16     0.0 -3.22 -9.47  2.40    0.0    0.0
    2010   12   17     0.0 -3.72 -6.61 12.50    0.0    0.0
    2010   12   18     0.0  2.12 -9.82  0.00    0.0    0.0
    2010   12   19     0.0  4.23 -6.39  0.00    0.0    0.0
    2010   12   20     0.0  5.60 -8.21  0.00    0.0    0.0
    2010   12   21     0.0  6.70 -1.21  0.00    0.0    0.0
    2010   12   22     0.0  7.76 -3.24  0.00    0.0    0.0
    2010   12   23     0.0  8.36 -0.58  0.00    0.0    0.0
    2010   12   24     0.0  8.52 -0.03  0.30    0.0    0.0
    2010   12   25     0.0 15.24  5.46  0.00    0.0    0.0
    2010   12   26     0.0 10.86  2.21  0.00    0.0    0.0
    2010   12   27     0.0  2.49 -0.61 10.70    0.0    0.0
    2010   12   28     0.0  0.65 -2.84  0.40    0.0    0.0
    2010   12   29     0.0 -1.69 -9.42  0.00    0.0    0.0
    2010   12   30     0.0 -4.60-10.47  0.00    0.0    0.0
```

Figure 3.27. The content of daily weather data file (41602700.dly)

Different irrigation depth has been used as **irrigation raster dataset** for different simulation scenarios and for different years. Information on levels of irrigation for different years has been obtained from Odessa Oblast Water Management Department, Ukraine (WATERMD 2008; WATERMD 2009).

To take into account the actual irrigated area in Odessa Oblast covered by calculation cells the information from Global Map of Irrigation Areas of FAO's AQUASTAT (version 4.0.1) has been used (AQUASTAT 2007) figure 3.28. This map includes sub-national irrigation statistics for most countries. The target year for the statistics is the year 2000 and refers for most countries to areas equipped for irrigation. The spatial resolution of the original map is 5 minutes.

Average fertilizer use for **fertilizer raster dataset** for calculating years was taken from the General Department of Statistics in Odessa Oblast, Ukraine (Statistics Committee of Ukraine (2010) a; Statistics Committee of Ukraine (2010) b). As examples, figure 3.29, 3.30, 3.31 present fertilizer raster dataset for calculation of yields for 2009.

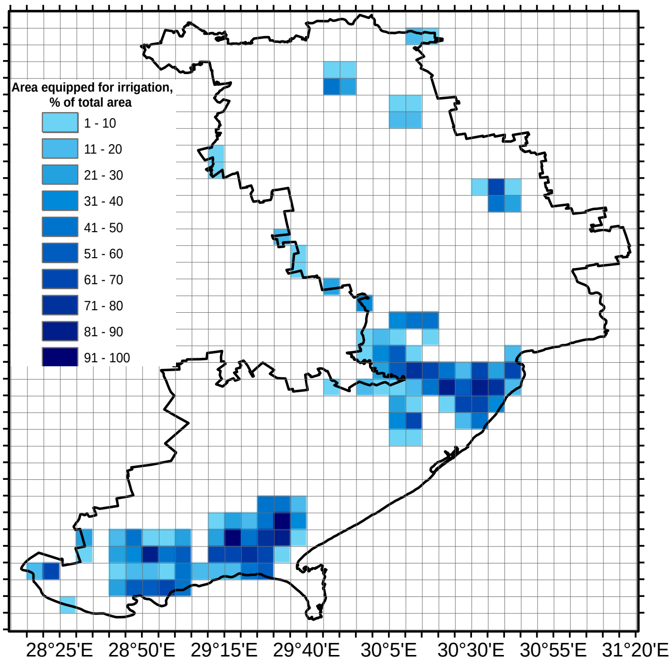


Figure 3.28. Map of Irrigation Areas (AQUASTAT) - area of Odessa Oblast equipped for irrigation expressed as percentage of total area

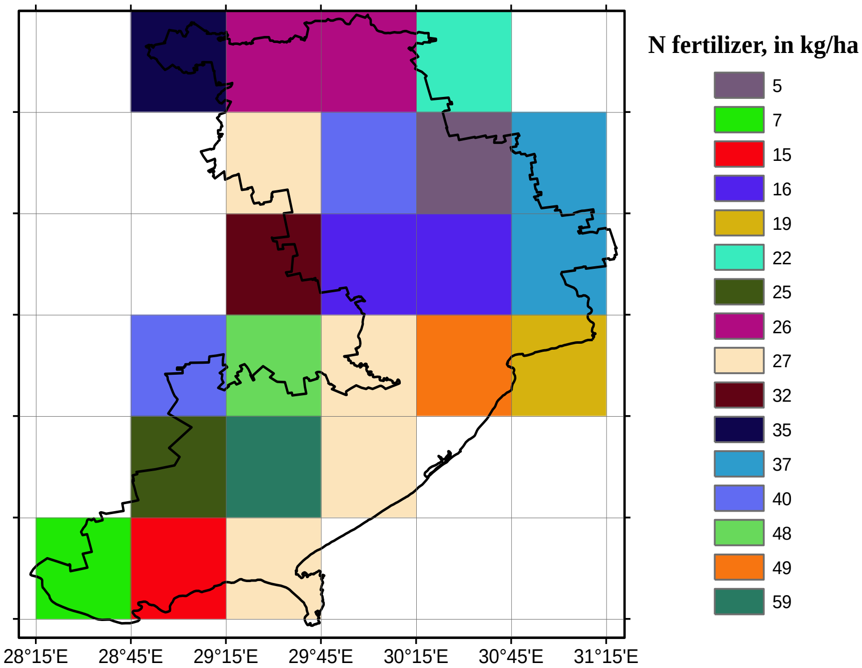


Figure 3.29. Fertilizer raster dataset for Odessa Oblast with resolution 30x30 min for 2009

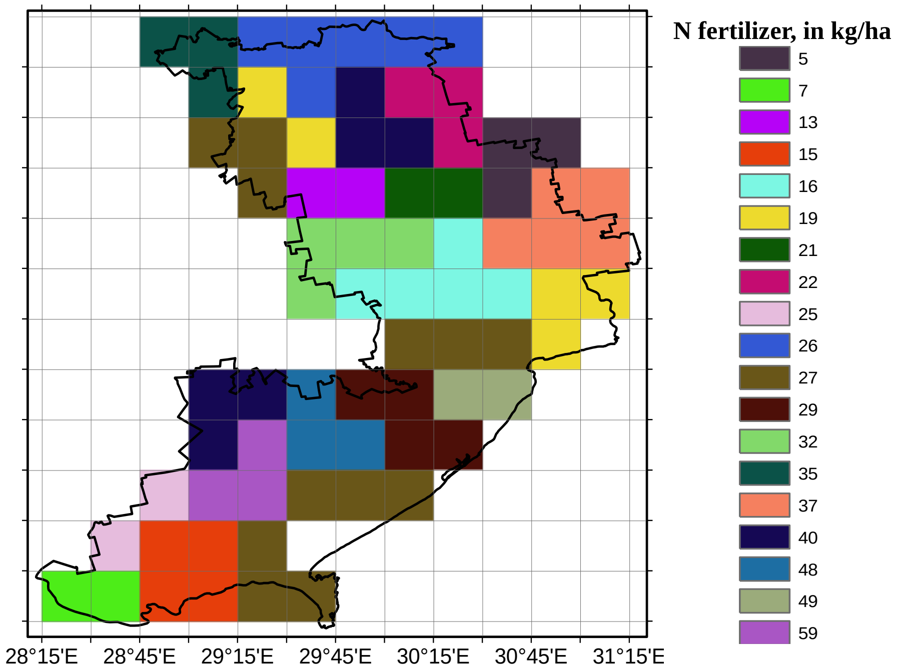


Figure 3.30. Fertilizer raster dataset for Odessa Oblast with resolution 15x15 min for 2009

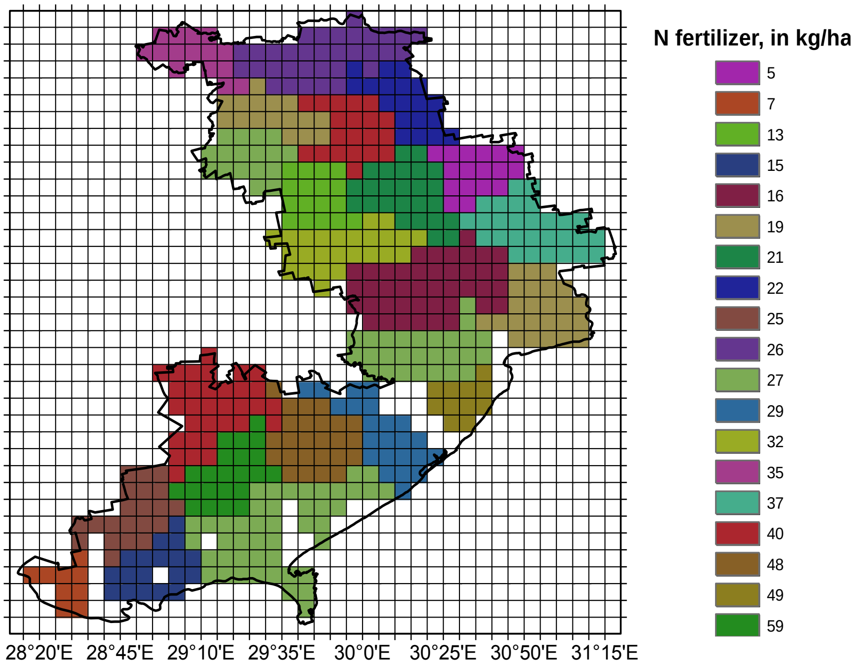


Figure 3.31. Fertilizer raster dataset for Odessa Oblast with resolution 05x05 min for 2009

Output data

Series of model experiments have been made for Odessa Oblast territory to calculate yields of winter wheat, sunflower, spring barley and maize using GEPIC model (version 1.0) working with ARCGIS 9.2 and biophysical module EPIC (version EPIC0509, 2005) for spatial resolution 30x30 min, 15x15 min and 5x5 min. Temporal resolution of the simulation: 4 years of calculation; calculation years – 2002, 2005, 2009.

Simulation results for four crops and four scenarios have been obtained for three years.

After the GEPIC advanced training workshop the same experiments have been repeated using the new knowledge and approaches to simulation.

Output rasters of yields for three spatial resolutions received before the GEPIC advanced training workshop are presented in Annexes 3A, 4A and 5A respectively.

Output rasters of yields for three spatial resolutions received after the GEPIC advanced training workshop are presented in Annexes 3B, 4B and 5B respectively.

Calculation of final rasters of yields taking into account actual sizes of irrigated areas was done with ARC GIS 9.2. according to Global Map of Irrigation Areas of FAO's AQUASTAT (version 4.0.1) (AQUASTAT 2007). The target year for the statistics is the year 2000 and refers for most countries to areas equipped for irrigation. Spatial resolution of the original map is 5 minutes.

Thus, calculation of final yield of each crop for each cell of Odessa Oblast has been done using the following formula:

Final yield without input of fertilizers =

I=0;F=0*(per cent of non-irrigated territory according to AQUASTAT) + I=MAX;F=0*(per cent of irrigated territory according to AQUASTAT), and

Final yield with input of fertilizers =

I=0;F=MAX*(per cent of non-irrigated territory according to AQUASTAT) + I=MAX;F=MAX*(per cent of irrigated territory according to AQUASTAT),

Where:

I=0;F=0 – yield under no irrigation and no fertilizers

I=MAX;F=0 – yield with irrigation and no fertilizers;

I=0;F=MAX – yield under no irrigation and with input of fertilizers;

I=MAX;F=MAX – yield with irrigation and input of fertilizers.

Final rasters of yields for three spatial resolution received before the GEPIC advanced training workshop are also presented in the abovementioned Annexes.

1.2.3.2 For the Entire Ukrainian Territory (Final Study)

Input data

For model experiments National statistical data about fertilizers input (N, P, K) and irrigation levels have been used, as well as information about irrigated and upland areas according to MIRCA 2000 (MIRCA2000). Crop rotation has not been taken into account.

Model experiments have been carried out for the following four scenarios:

- No irrigation and no input of fertilizers;
- No irrigation, but with input of fertilizers;
- With irrigation, but no fertilizers;
- With both irrigation and input of fertilizers.

The following input data for spatial resolution 15x15 min have been prepared for modelling of Ukrainian territory.

The GTOPO30 - global DEM from the U.S. Geological Survey's EROS Data Center in Sioux Falls (GTOPO30 1996) has been used as source data for **DEM (Digital elevation model) raster dataset** for Ukraine (figure 3.32). Elevations in GTOPO30 are regularly spaced at 30-arc seconds (approximately 1 kilometre or 0.00833 degrees). GTOPO30 was developed to meet the needs of the geospatial data user community for regional and continental scale topographic data. GTOPO30 is a global data set covering the full extent of latitude from 90 degrees south to 90 degrees north, and the full extent of longitude from 180 degrees west to 180 degrees east. The horizontal coordinate system is WGS84. The vertical units represent elevation in meters above mean sea level. The elevation values range from -407 to 8,752 meters.

Based on the GTOPO30 raster DEM (figure 3.33) for spatial resolution 15x15 min was produced.

As the source data for **Slope raster dataset** the 1-km resolution HYDRO1K digital raster slope map was used, which defined the maximum change in the elevations between each cell and its eight neighbours GTOPO30 (GTOPO30 1996) (figure 3.34). The slope is expressed in integer degrees of slope between 0 and 90. On its basis the slope raster for spatial resolution 15x15 min was produced - figure 3.35.

As the source for **Country raster dataset** vector layer of Ukrainian Oblasts was used, approximated for spatial resolution 15x15 min - figure 3.36.

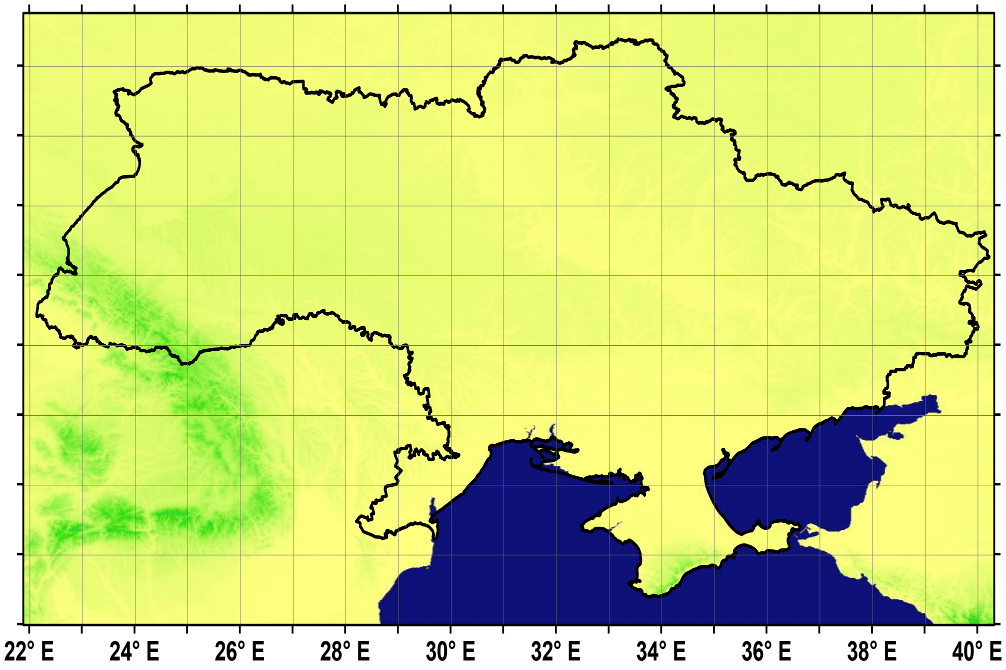


Figure 3.32. Digital elevation model GTOPO30 for Ukraine at spatial resolution 30-arc seconds

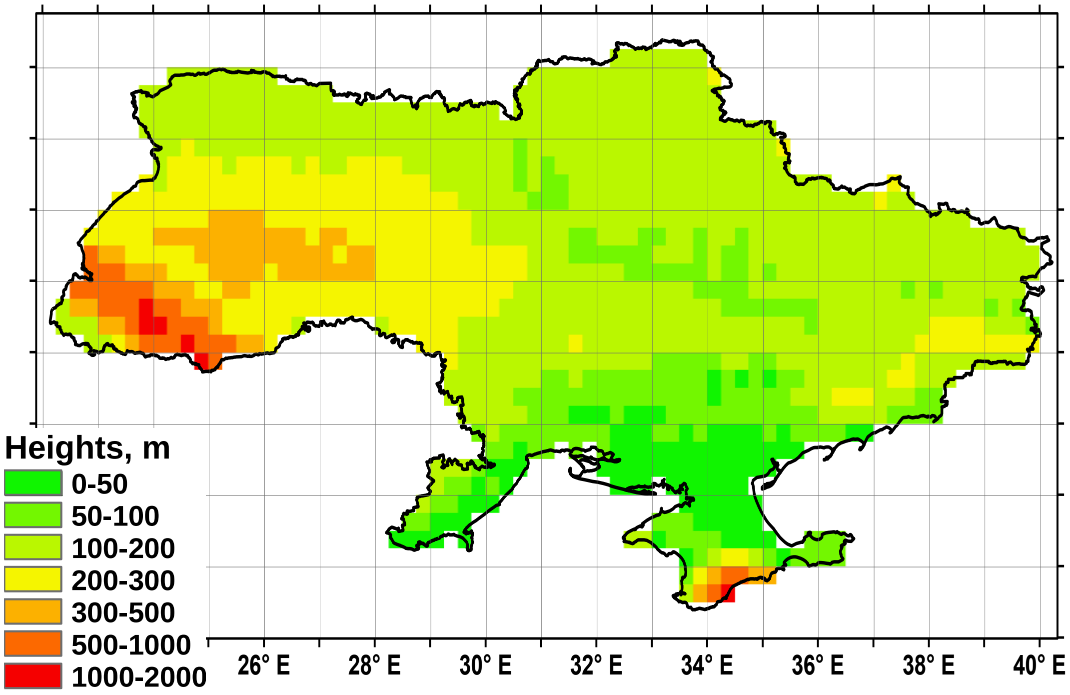


Figure 3.33. DEM raster dataset for Ukraine at spatial resolution 15x15 minutes

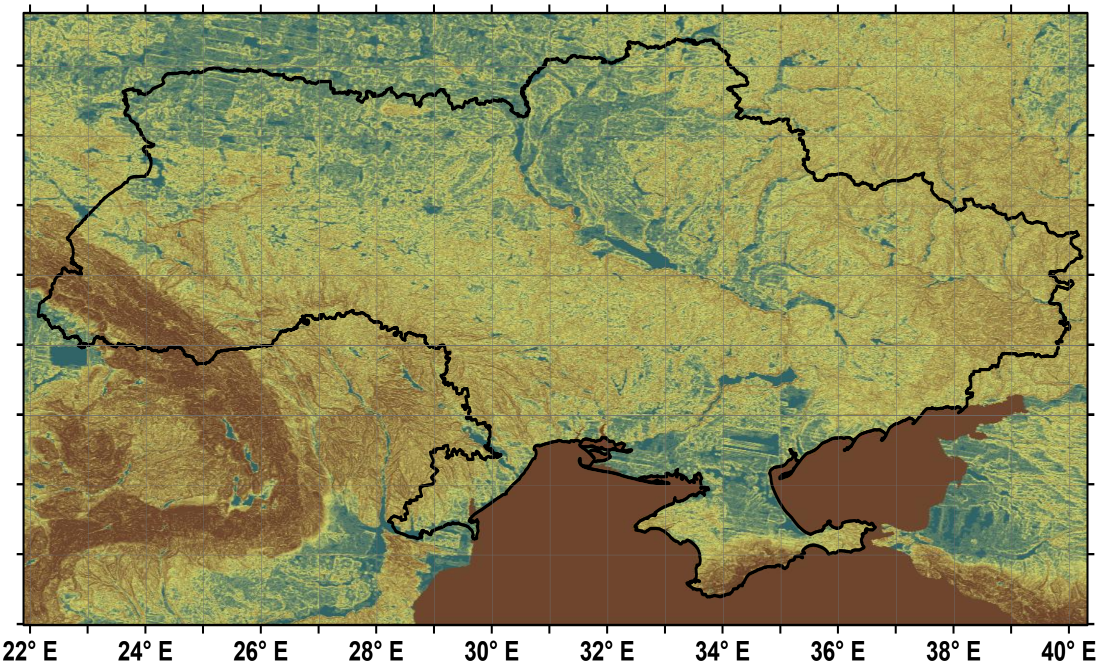


Figure 3.34. The 1-km resolution HYDRO1K digital raster slope map for Ukraine

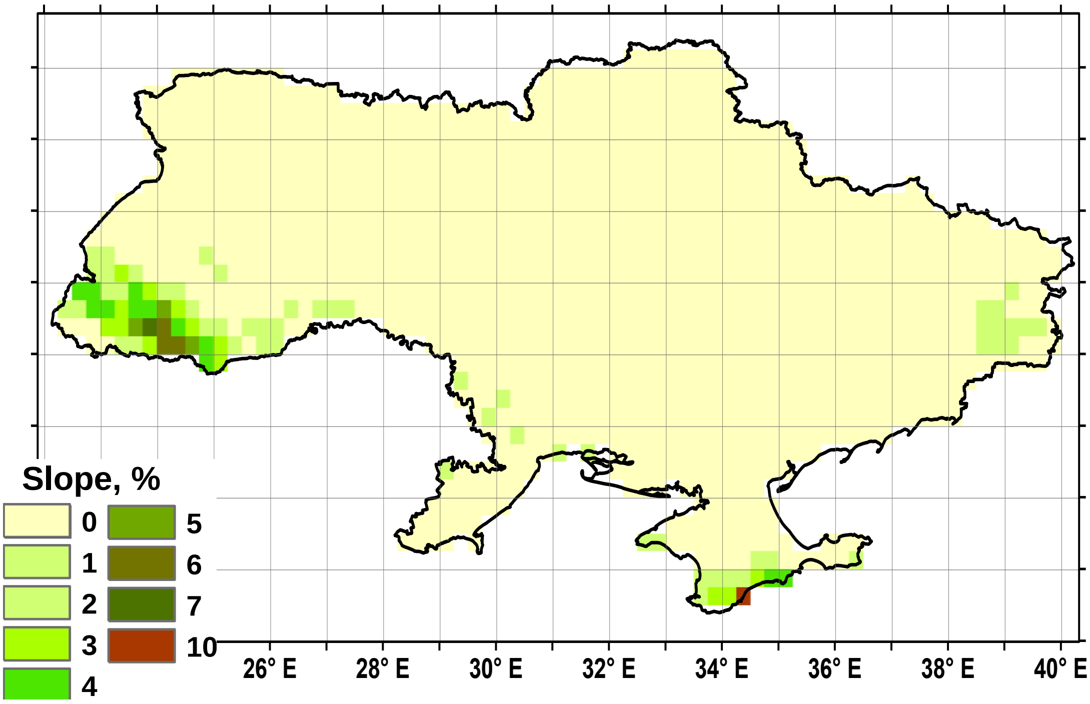


Figure 3.35. Slope raster dataset for Ukraine at spatial resolution 15x15 minutes

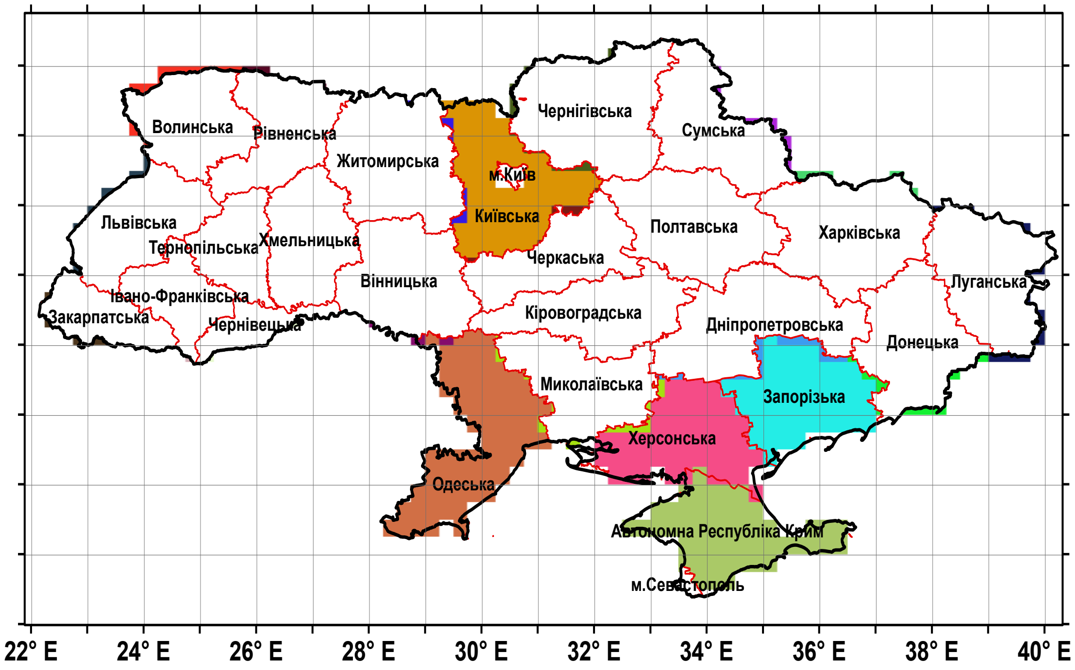


Figure 3.36. Country raster dataset for Ukraine at spatial resolution 15x15 minutes

The GEPIC model is used to simulate the annual irrigation depth. Unfortunately, spatial maps of annual irrigation depth have not been available on the national scale. As the irrigation raster dataset for different simulation scenarios and for different years we have used raster with maximal irrigation depth -188 mm for 2000-2008 and 194 mm for 2009-2010 calculated based on the information about the levels of irrigation in different years from Water Management Department of Ukraine (WATERMD 2008; WATERMD 2009; State Agency of Water Management of Ukraine 2010). When modelling, the EPIC put in the required quantity of water and the values 188 and 194 were maximal annual irrigation depths per unit of area. In experiments for 2009-2010 to assess the influence of water and fertilizers input on the four mentioned crops' yields the irrigation depth 268 mm has been set and the amount of fertilizers input applied in 1990.

To take into account the actual area of crops at irrigated and upland conditions we used the information from Global data set of monthly irrigated and rainfed crop areas around the year 2000 (MIRCA2000). These datasets represent annual harvested areas grids of 26 irrigated and rainfed crops in 5 arc-minute grid cell resolution around the year 2000.

Those data were taken as the source data to produce **land use raster datasets**. Based on the MIRCA2000 data the landuse raster datasets were produced for each calculated crops for irrigated and rainfed conditions. As examples, the raster datasets for sunflower are presented on figures 3.37, 3.38.

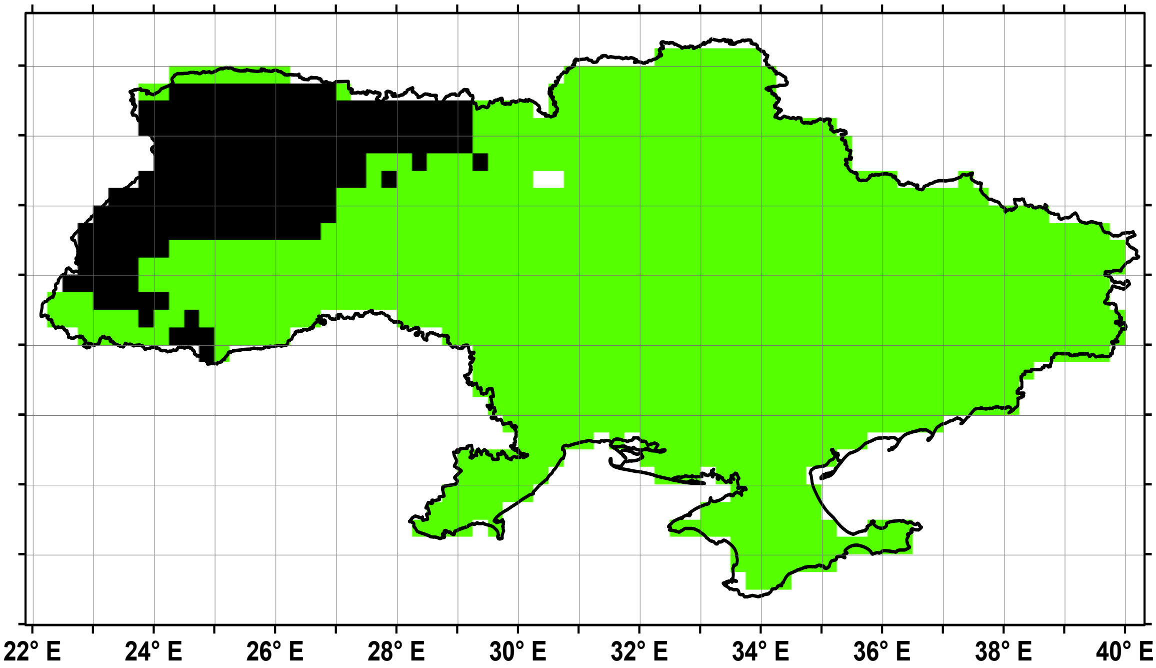


Figure 3.37. Land use raster dataset for sunflower at spatial resolution 15x15 minutes under rainfed conditions (green cells –cultivation area)

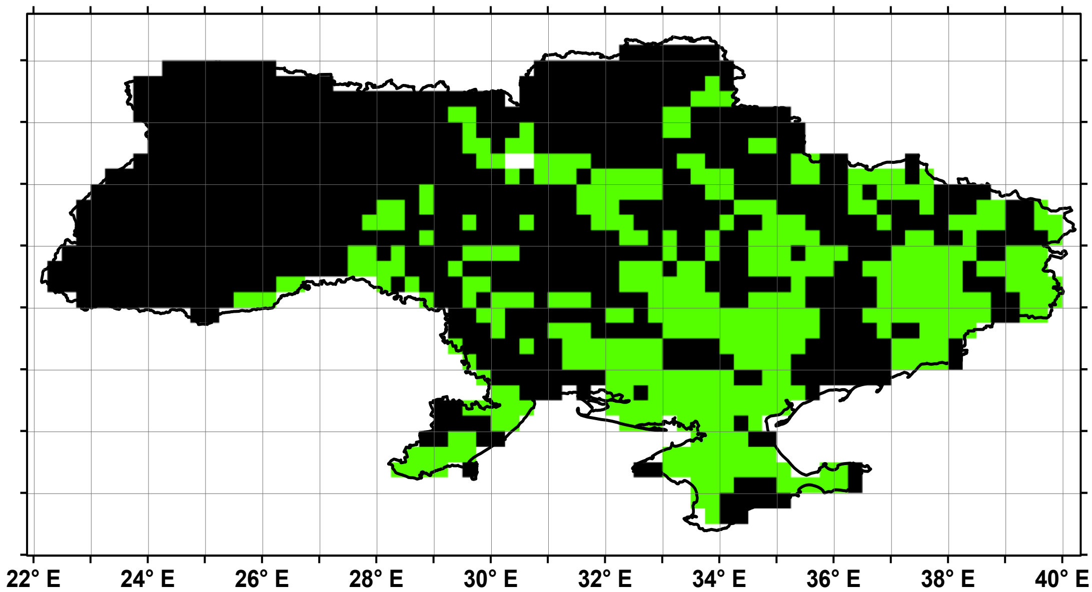


Figure 3.38. Land use raster dataset for sunflower at spatial resolution 15x15 minutes under irrigated conditions (green cells – cultivation area)

Soil raster dataset contains code numbers of the soil text files in each grid cell. The soil 5x5 min grid and soil parameters files are obtained from ISRIC-WISE (ISRIC 2006; Batjes 2006). The ISRIC-WISE dataset contains the database with derived soil properties for the 106 soil units: soil drainage class, organic carbon content, total nitrogen, C/N ratio, pH, base saturation, aluminium saturation, calcium carbonate content, gypsum content, exchangeable sodium percentage (ESP), electrical conductivity, particle size distribution (content of sand; silt and clay), content of coarse fragments, bulk density, and available water capacity etc. Linkage of the spatial (raster) dataset and to the EPIC soil files (text) is existing through the grid cell identifier (Suid) of the raster dataset. From ISRIC-WISE dataset 33 soil types were selected for Ukraine area (figure 3.39). Each soil code of the soil raster dataset corresponds to the unique soil text file which contains the soil parameters. An example of the EPIC soil file is presented on figure 3.40. The format of the soil files is described in the EPIC User Manual (EPIC 2010).

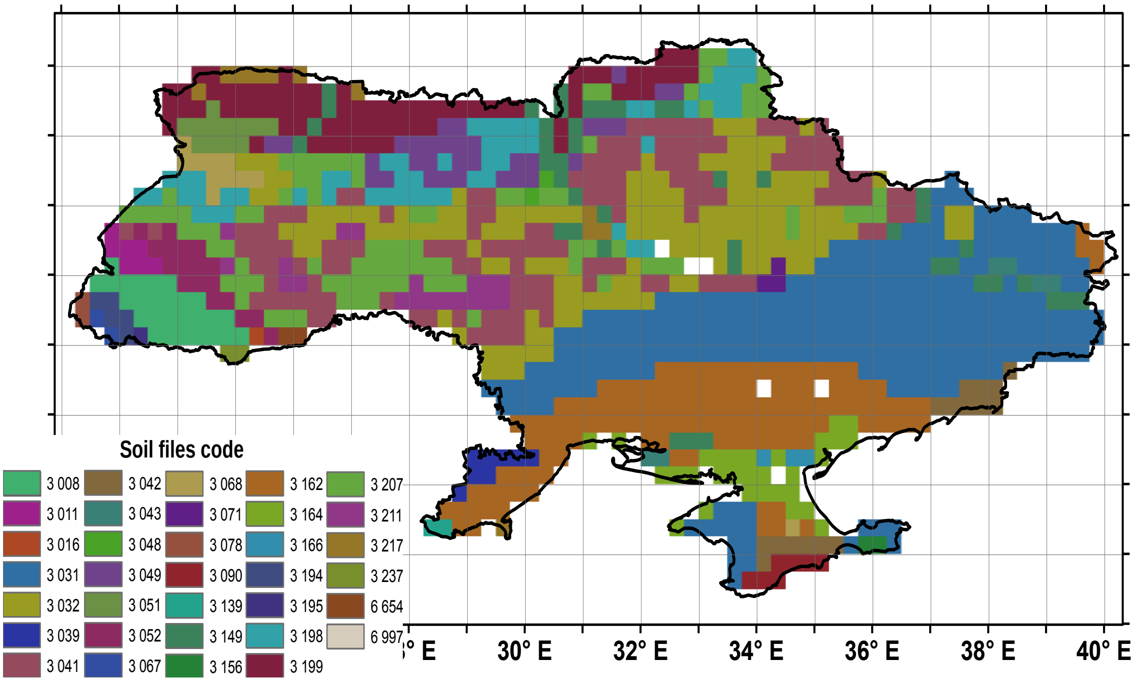
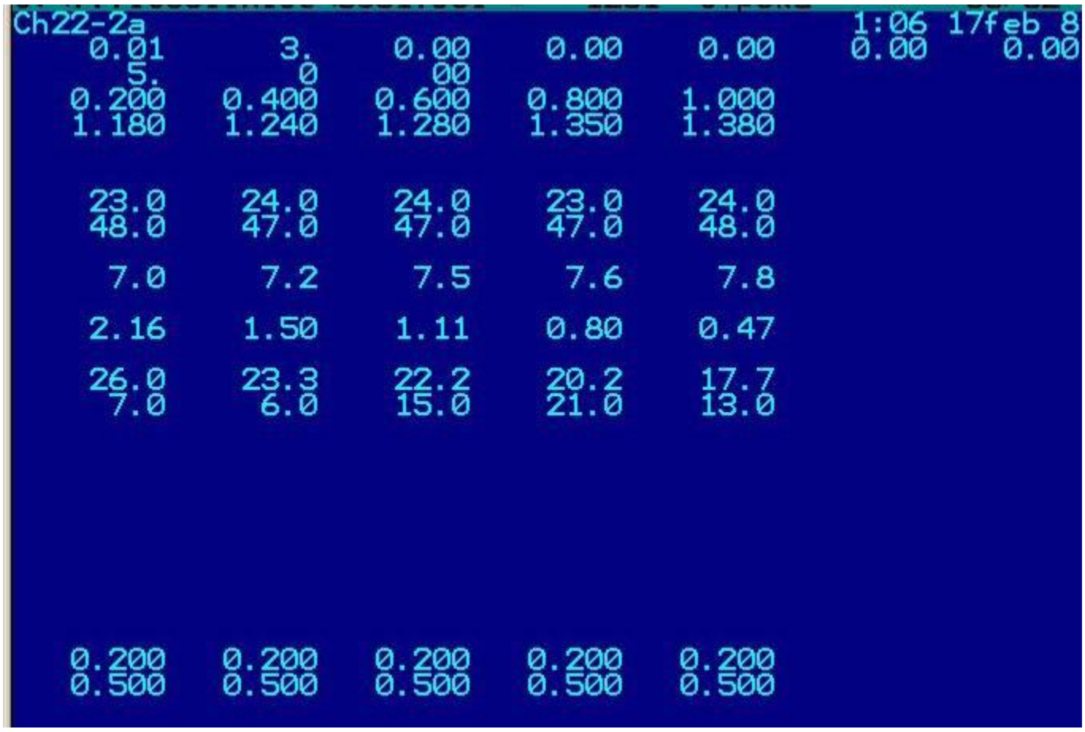


Figure 3.39. The ISRIC-WISE soil raster dataset for Ukraine at spatial resolution 15x15 minutes



```
Ch22-2a                                                    1:06  17feb 8
   0.01        3.     0.00      0.00      0.00         0.00       0.00
     5.         0       00
  0.200     0.400    0.600     0.800     1.000
  1.180     1.240    1.280     1.350     1.380

   23.0      24.0     24.0      23.0      24.0
   48.0      47.0     47.0      47.0      48.0
    7.0       7.2      7.5       7.6       7.8
   2.16      1.50     1.11      0.80      0.47
   26.0      23.3     22.2      20.2      17.7
    7.0       6.0     15.0      21.0      13.0




  0.200     0.200    0.200     0.200     0.200
  0.500     0.500    0.500     0.500     0.500
```

Figure 3.40. The content of the EPIC soil file - 3031.sol

Climate raster dataset datasets were produced based on the gridded observational datasets of daily precipitation and temperature which have been developed on the basis of a European network of high-quality station series. These datasets cover the period from 1950 to 2010. They are made available on a 0.25 and 0.5 degree regular latitude–longitude grid. The datasets are made in the framework of the EU FP6 Integrated Project ENSEMBLES in format NetCDF (Haylock at al. 2008).

Actually the EPIC needs in the daily weather records: solar radiation, maximum temperature, minimum temperature, precipitation, relative humidity, and wind speed (EPIC 2010), or EPIC can generate daily weather data using the stochastic weather generator.

For this case-study from the ENSEMBLES climate datasets the data were selected which were getting on the territory of Ukraine, and using those climate raster dataset were produced for spatial resolution 15x15 minutes - figure 3.41 and 1260 daily weather data files (*.dly) for the period 1990-2010 (figure 3.42, as example).

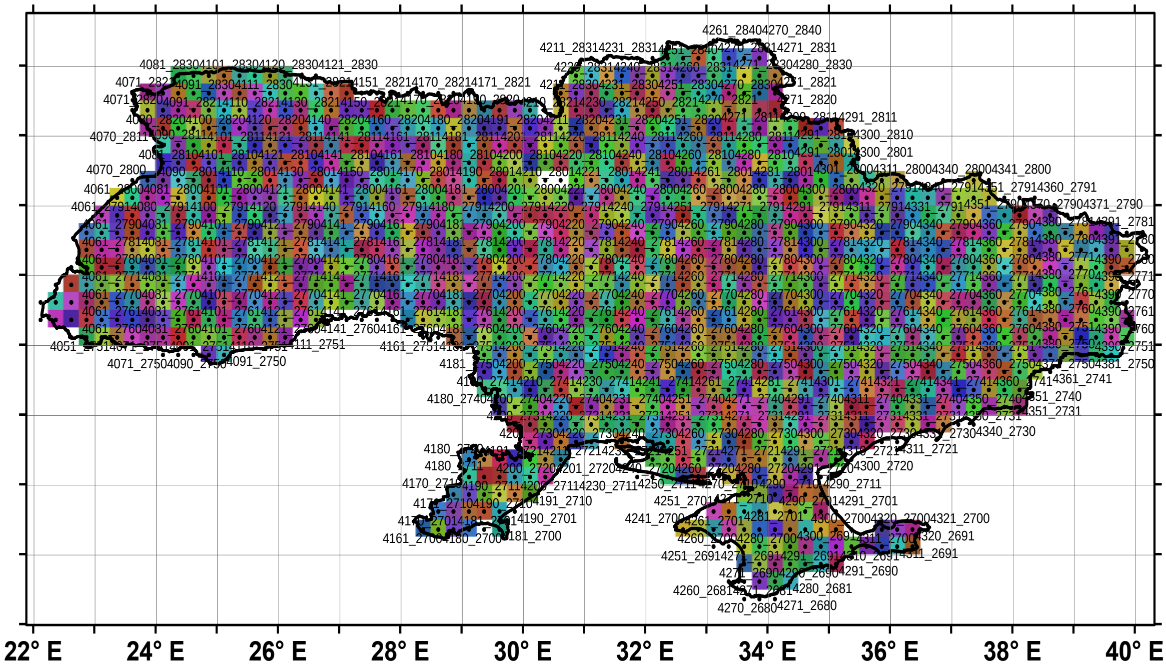
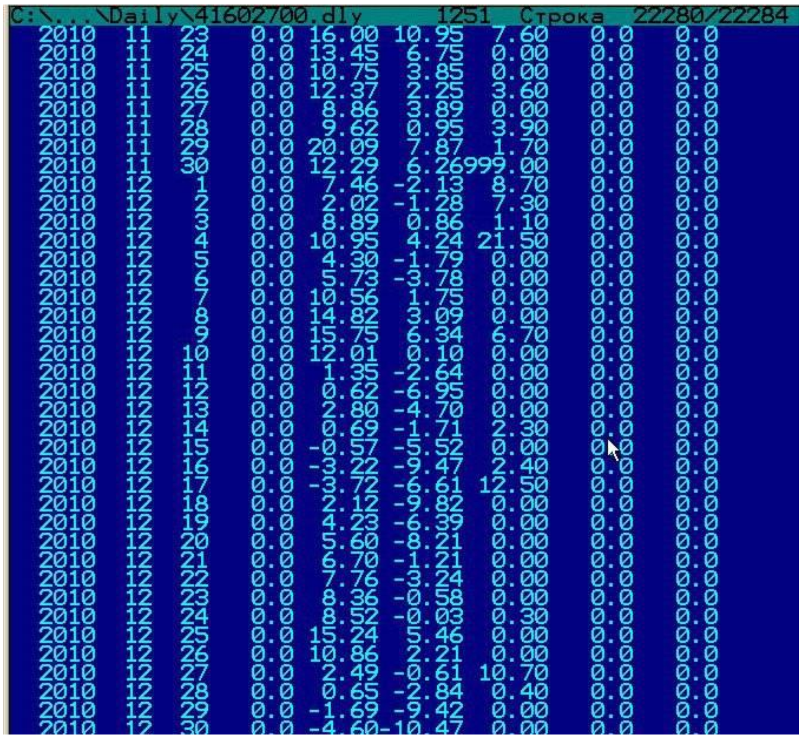


Figure 3.41. Climate raster dataset for Ukraine at spatial resolution 15x15 minutes (The points' numbers correspond to the daily weather data files)



C:\...\Daily\41602700.dly 1251 Строка 22280/22284

2010	11	23	0.0	16.00	10.95	7.60	0.0	0.0
2010	11	24	0.0	13.45	6.75	0.00	0.0	0.0
2010	11	25	0.0	10.75	3.85	0.00	0.0	0.0
2010	11	26	0.0	12.37	2.25	3.60	0.0	0.0
2010	11	27	0.0	8.86	3.89	0.00	0.0	0.0
2010	11	28	0.0	9.62	0.95	3.90	0.0	0.0
2010	11	29	0.0	20.09	7.87	1.70	0.0	0.0
2010	11	30	0.0	12.29	6.26	999.00	0.0	0.0
2010	12	1	0.0	7.46	-2.13	8.70	0.0	0.0
2010	12	2	0.0	2.02	-1.28	7.30	0.0	0.0
2010	12	3	0.0	8.89	0.86	1.10	0.0	0.0
2010	12	4	0.0	10.95	4.24	21.50	0.0	0.0
2010	12	5	0.0	4.30	-1.79	0.00	0.0	0.0
2010	12	6	0.0	5.73	-3.78	0.00	0.0	0.0
2010	12	7	0.0	10.56	1.75	0.00	0.0	0.0
2010	12	8	0.0	14.82	3.09	0.00	0.0	0.0
2010	12	9	0.0	15.75	6.34	6.70	0.0	0.0
2010	12	10	0.0	12.01	0.10	0.00	0.0	0.0
2010	12	11	0.0	1.35	-2.64	0.00	0.0	0.0
2010	12	12	0.0	0.62	-6.95	0.00	0.0	0.0
2010	12	13	0.0	2.80	-4.70	0.00	0.0	0.0
2010	12	14	0.0	0.69	-1.71	2.30	0.0	0.0
2010	12	15	0.0	-0.57	-5.52	0.00	0.0	0.0
2010	12	16	0.0	-3.22	-9.47	2.40	0.0	0.0
2010	12	17	0.0	-3.72	-6.61	12.50	0.0	0.0
2010	12	18	0.0	2.12	-9.82	0.00	0.0	0.0
2010	12	19	0.0	4.23	-6.39	0.00	0.0	0.0
2010	12	20	0.0	5.60	-8.21	0.00	0.0	0.0
2010	12	21	0.0	6.70	-1.21	0.00	0.0	0.0
2010	12	22	0.0	7.76	-3.24	0.00	0.0	0.0
2010	12	23	0.0	8.36	-0.58	0.00	0.0	0.0
2010	12	24	0.0	8.52	-0.03	0.30	0.0	0.0
2010	12	25	0.0	15.24	5.46	0.00	0.0	0.0
2010	12	26	0.0	10.86	2.21	0.00	0.0	0.0
2010	12	27	0.0	2.49	-0.61	10.70	0.0	0.0
2010	12	28	0.0	0.65	-2.84	0.40	0.0	0.0
2010	12	29	0.0	-1.69	-9.42	0.00	0.0	0.0
2010	12	30	0.0	-4.60	-10.47	0.00	0.0	0.0

Figure 3.42. Content of daily weather data file

Applied amounts of fertilizers were taken from the State Statistics Committee of Ukraine (State Statistics Committee of Ukraine 2010 a; State Statistics Committee of Ukraine 2010 b). Based on those data **fertilizer raster datasets** for each crop and each calculated year were produced (figure 3.43, as example).

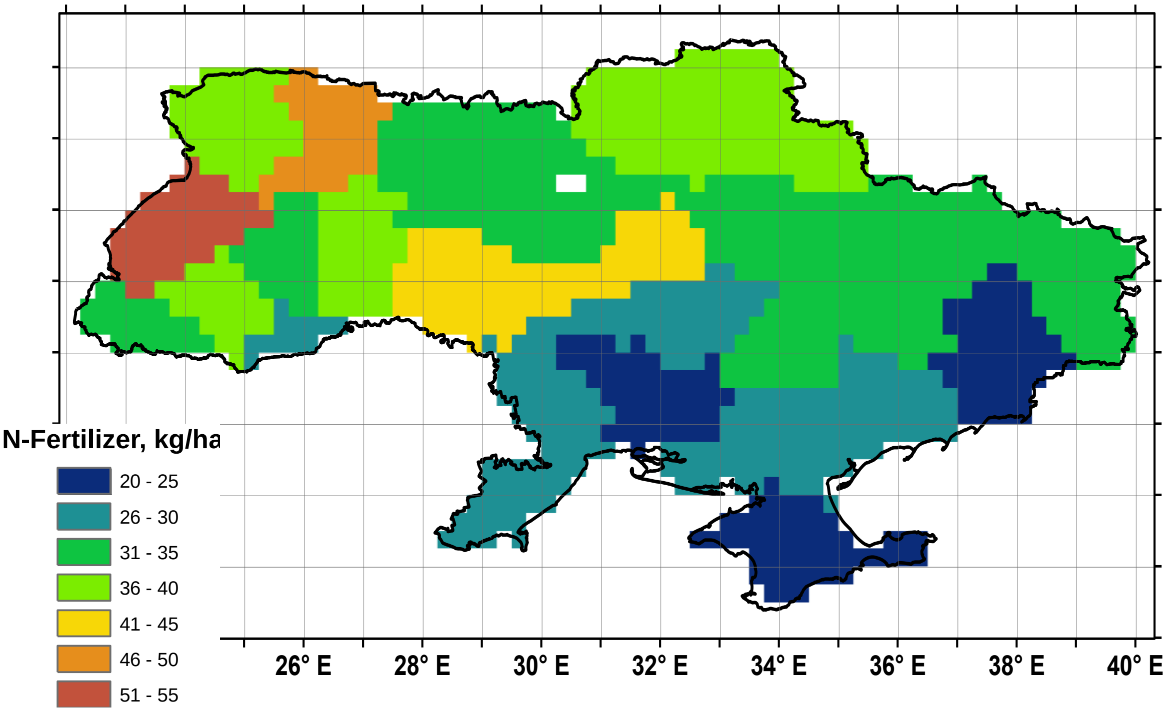


Figure 3.43. N-Fertilizer raster dataset for Ukraine at spatial resolution 15x15 minutes for winter wheat fields in 2005

Output data

Series of model experiments have been made for the territory of Ukraine to calculate yields (Yd) and evapotranspiration (ET) using the GEPIC model (version 1.0) with ARCGIS 9.2 and biophysical module EPIC (version EPIC0509, 2005) for spatial resolution 15x15 min, which made 1260 calculation cells. Temporal resolution of the simulation: 11 years; calculation years: 2000-2010.

Also, a series of experiments for the years 2009-2010 were made to assess the influence of amounts of water and fertilizers input on the yields of the four mentioned crops. For this purpose and for the climate conditions of 2009 and 2010 the depths of irrigation and fertilizers inputs were set as of 1990, i.e. before the demise of the USSR.

Calculation of final rasters of yields and evapotranspiration was done with ARC GIS 9.2. according to statistical data about irrigation and fertilizers input.

To calculate final yield of each crop the following formulas were used in each cell:

Final yield = I=0;F=0*(share of non-irrigated territory)*(share of non-fertilized territory) + I=MAX;F=0*(share of irrigated territory)*(share of non-fertilized territory) + I=0;F=MAX*(share of non-irrigated territory)*(share of fertilized territory) + I=MAX;F=MAX*(share of irrigated territory)*(share of fertilized territory),

Where:

I=0;F=0 - yield under no irrigation and no fertilizers;

I=MAX;F=0 – yield with irrigation and no fertilizers;

I=0;F=MAX – yield under no irrigation and with input of fertilizers;

I=MAX;F=MAX – yield with irrigation and input of fertilizers.

Final rasters of yields of the crops and evapotranspiration are presented in Annexes 6 and 7, respectively.

1.2.3.3 Discarding of Simulation Data

To evaluate the model performance the coefficient of determination (R^2) was used – measure of dispersion of dependent variable deviations from its mean value. In particular case R^2 is the second degree of correlation coefficient between dependent variable and its forecasted values (Statistics committee of Ukraine 2010 b).

Formula for determination coefficient calculation is the following:

$$R^2 \equiv 1 - \frac{\sum_i (y_i - f_i)^2}{\sum_i (y_i - \bar{y})^2},$$

where y_i – observed value of dependent variable, f_i – value of dependent variable forecasted from equation of regression, $\hat{y}$ – arithmetic average of dependent variable. Qualitative assessment was given to correlation ratio indices of two datasets according to Chaddock scale (Statistics committee of Ukraine 2010 b):

Quantitative Measure of Correlation Ratio	Qualitative Characteristics of Correlation Ratio
0,1-0,3	Weak
0,3-0,5	Moderate

0,5-0,7	Noticeable
0,7-0,9	High
0,9-0,99	Very high

Using the calculated by the model yield values, ARCGIS 9.2. function «zonal statistics» was applied to calculate average values for Oblasts. Beside average value, the «zonal statistics» function calculates a set of average statistical parameters for each Oblast: standard deviation, minimal and maximal values, sample size etc.

This selection was used for discarding of unreliable data from the set of analyzed determination coefficients, which are introducing significant errors into the main sequence.

Standard deviation (σ) was used as the criteria for discarding. The formula for the standard deviation, calculated on the entire population (the "N" method), is:

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2};$$

where:

x_i — i-th element of sample;

n — size of sample;

$\bar{x}$ — arithmetic average of sample.

Three variants of discarding have been used to analyze statistical dependence:

1 – without discarding of insignificant values;

2 – with discarding of insignificant values, P=99.73 %;

3 – with discarding of insignificant values, P=95.45 %.

Under the first variant all the values of determination coefficients were analyzed without discarding. Criterion of discarding in the second variant was the «three sigmas rule» - when separate values of yield missed the interval:

$|\bar{x}$-3σ; $\bar{x}$+3σ|;

Criterion of discarding in the third variant was the «two sigmas rule » - when separate values of yield missed the interval:

$|\bar{x}$-2; $\bar{x}$+2σ|.

Confidence level of determination coefficients for different degrees of freedom (sample sizes) were determined in accordance with (Fisher and Frank 1963).

1.3 Results and Discussion

1.3.1 Yields simulation for Odessa oblast (Pilot area)

1.3.1.1 Winter Wheat

To simulate the yields of winter wheat in Odessa Oblast three experiments were performed:

- Experiment № 1. - Automatic;
- Experiment № 2. – Auto-manual;
- Experiment № 3. - Manual;

After the GEPIC advanced training in EAWAG (June, 2011), additional experiment № 3a was performed to simulate winter wheat yields, being the improved experiment №3.

Results of comparison of model experiment outputs with statistical data are presented in Tables 4.1, 2 of Annex 1 and 8.1 of Annex 8.

Analyses of the data from Table 4.1 have shown that practically all the results of experiment №1 for the years 2002, 2005 and 2009 were unsatisfactory (Annexes 3.C, 4.C, 5.C, 8), as correlation with statistical data was very low or insignificant. At that, while for spatial resolution 30x30 min with all years in some cases (mainly taking into account irrigated areas according to AQUASTAT) determination coefficients 0,23 and below were received, for the resolutions 15x15 and 5x5 min. the same coefficients of determinations were observed only for the year 2009. This could be explained by the fact that we used the crops statistics on the Raions of Odessa Oblast, the sizes of which are the most suitable for approximation with 30x30 min grid.

Table 4.1. Values of Determination Coefficient R^2 for Simulated in Four Experiments Values of Winter Wheat Yields and Statistical Data for 2002, 2005 and 2009 for Odessa Oblast

Experiment	Scale	2002				2005				2009				Note
		F=0, I=0	F=0, I=M	F=M, I=0	F=M, I=M	F=0, I=0	F=0, I=M	F=M, I=0	F=M, I=M	F=0, I=0	F=0, I=M	F=M, I=0	F=M, I=M	
№1	30x30	0.00	0.32/0.01	0.04	0.30/0.33	0.14	0.08/0.22	0.14	0.16/0.24	0.15	0.00/0.11	0.16	0.01/0.12	1
	15x15	0.04	0.03/0.18	0.10	0.02/0.05	0.03	0.03/0.07	0.04	0.07/0.08	0.23	0.02/0.11	0,24	0.07/0.11	1
	5x5	0.03	/0.01	0.09	/0.04	0.02	0.04/0.04	0.02	0.07/0.05	0.19	0.02/0.05	0.21	0.06/0.05	1
№2	30x30	0.28	0.02/0.29	0.35	0.07/0.36	0.18	0.11/0.20	0.16	0.10/0.20	-	-	-	-	1
	15x15	0.24	0.01/0.23	0.26	0.02/0.25	0.04	0.06/0.05	0.04	0.07/0.05	-	-	-	-	1
	5x5	0.30	0.08/0.30	0.31	0.04/0.32	0.02	0.01/0.03	0.03	0.06/0.04	-	-	-	-	1
№3	30x30	0.28	0.02/0.28	0.30	0.02/0.31	0.18	0.11/0.20	0.17	0.11/0.20	-	-	-	-	1
	15x15	0.26	0.07/0.25	0.26	0.06/0.25	0.28	0.02/0.04	0.03	0.04/0.04	-	-	-	-	1
	5x5	0.30	0.08/0.31	0.32	0.10/0.32	0.02	0.01/0.03	0.02	0.03/0.04	0.09	0.17/0.10	0.09	0.18/0.10	1
№3a	30x30	-	-	0.36	0.02	-	-	0.23	0.24	-	-	0.07	0.06	
	15x15	-	-	0.05/0.44	0.05/0.45	-	-	0.04/0.07	0.04/0.07	-	-	0.04/0.36	0.04/0.36	2
	5x5	-	-	0.17/0.22	0.16/0.52	-	-	0.00/0.21	0.00/0.28	-	-	0.12/0.46	0.14/0.65	2

Notes:

1 – Determination coefficients for conditions – «irrigation for all the territory» / «irrigation according to AQUASTAT»;

2 – Determination coefficients for comparison - «cell with cell» / «zonal statistics results»;

* - F=0 –no fertilizers; I=0 – no irrigation; F=M – fertilizers applied; I=M - irrigation;

** - significant determination coefficients for grid 05x05 min exceed 0,07 - at P=0,95 and exceed 0,10 at P=0,99;

*** - significant determination coefficients for grid 15x15 min exceed 0,20 - at P=0,95 and exceed 0,30 at P=0,99;

**** - significant determination coefficients for grid 30x30 min exceed 0,34 - at P=0,95 and exceed 0,47 at P=0,99.

Results of experiment №2 improved significantly compared to experiment № 1 for all spatial resolutions for the year 2002 only. For spatial resolution 5x5 min at number of calculation cells 531 the time of calculation for 4 years was about 15 min. For spatial resolution 30x30 min for the years 2002 and 2005 determination coefficients up to 0,10-0,36 were obtained. For the 15x15 and 5x5 min resolutions an improvement was pointed out only for the year 2002 – 0,23-0,31.

The results received in experiment №3 improved insignificantly (or stayed at the same level) compared to experiment № 2 only for 2002. For 2005 no improvement of results (linear correlation between calculated and statistical yields) was observed. The reason could lie in the source data on climate or low-quality statistics on yields in 2005 (with evident yield errors).

Maximal determination coefficients, which we managed to receive in the first three experiments on winter wheat, were 0.31, 0.26, 0.32 for spatial resolutions 30x30, 15x15 and 05x05 min, respectively. These values are in the category ‘weak’ or ‘moderate’ dependence according to Chaddock scale (Sizova 2005).

When performing experiments, we used a significant part of time to find errors in source data and modelling parameters, which have lead to such poor results.

Analysis of results received in three first experiments enabled us to reveal the following regularities common for all spatial resolutions:

- The use of undersized value of carbon dioxide concentration in atmosphere decreased yields insignificantly and in some cases caused zero values of yields in the cells (EPIC 2010).
- The HI (harvest index) value introduced by developers of the model for winter wheat, 0.45, for Odessa Oblast happened to be overestimated and after a number of experiments was replaced with 0.35.
- By now we did not find Ukrainian analogues of pesticides and herbicides which have been introduced by model developers on default. Use of the default pesticides and herbicides result at significant, sometimes up to 50 %, decrease in calculated yields, that is why we stopped using pesticides for calculations in the framework of this case-study.
- Attempts have been made to improve the results of simulation by fitting the sizes of stress factors on fertilizers and required moisture, specified in the managing file EPICCONT.DAT. However, that gave no significant improvement.

Regularities received from the results of three first experiments for each spatial resolution separately are given below.

1. In experiments with spatial resolution 30x30 min maximal value of determination coefficient was received in experiment №2 for 2002 taking into account per cent of irrigated acreage according AQUASTAT and automatic application of fertilizers - 0,36. From the results of simulation for this resolution the following regularities were observed:

    - When simulating in the regime Automatic crop calendar the determination coefficients 0 to 0,32 were received, i.e. from absence to moderate constraint force (Annex 3C). Results of calculation for 2005 have shown weak constraint force between calculated and statistical values of yields (Annex 3C, Figures 3C.4, 3C.5, 3C.6 etc.).
    - Use of Fixed crop calendar (experiments 2 and 3) for winter wheat increased significantly the values of determination coefficients for 2002 under no irrigation (Annex 3C, Figures 3C.1, 3C.2, 3C.3, 3C.22, 3C.23, 3C.24) compared with experiment № 1.
    - Also, coefficient of determination increased in almost all the experiments for calculations using AQUASTAT (Annex 3C, Figures 3C.12, 3C.13, 3C.33, 3C.37, etc.).

2. Maximal value of determination coefficient for spatial resolution 15x15 min was received in experiment №2 for 2002 under no irrigation and automatic input of fertilizers and no fertilizers - 0,26 (Annex 4C, Figures 4C.3, 4C.23). The result close to the above was also received for 2002 in experiment №3 under the same conditions. Comparing results of the experiments for spatial resolution 15x15 min we revealed the following:

    - The value of determination coefficient with irrigation is close to zero, which is explained with the fact that irrigation is used in reality for a restricted part of Odessa Oblast. Use of the AQUASTAT data enabled us to increase the determination coefficient significantly, from zero value to 0,23-0,25 (Annex 4C, Figures 4C.12, 4C.13, etc.).
    - Significant increase of determination coefficient (R^2) can be observed in experiments №2 and №3 (from 0,03 to 0,26) compared to experiment №1 for 2002, and practical absence of correlation connections for 2005 (under all conditions the values of R^2 were below 0,1 (Annex 4C). Possible reasons could be errors in climatic data or statistical data for 2005.
    - Results of calculations in the regime Automatic crop calendar prevented us from

recommending its further use as the schedule of tillage and sowing does not take into account natural peculiarities of the region. At that, it has been revealed that automatic input of fertilizers and automatic irrigation influence negatively simulation results. Among drawbacks of this regime is also relatively long time of calculation compared to Fixed crop calendar.

3. Analysis of results received from experiments №1-3 for spatial resolution 5x5 min has revealed the following regularities (Annex 5C).

- When simulating in the regime Automatic crop calendar (experiment № 1) the determination coefficients 0,01-0,02 were received (Annex 5C, Figures 5C.1, 5C.4, 5C.11 etc.), except for simulation for 2009 (Figure 5C.7) under no irrigation – fertilizers/no fertilizers conditions. This, and also significant time consumption for calculations served as the ground to stop using this regime.
- Use of Fixed crop calendar (experiments 2 and 3) for winter wheat increased significantly the values of determination coefficients (Annex 5C, Figures 5C.2, 5C.3, 5C.21 etc.) for 2002 and 2009 (for non-irrigated variants) (from zero values to 0,30) and did not tell on the results of simulation for 2005. The reason, as it has been mentioned above, could possibly be in source data on climate or low-quality crops statistics for 2005.
- Taking into account of per cent of irrigated acreage according to AQUASTAT has also resulted at making crop values more precise for each calculation cell. As well as increase of determination coefficients' values (Annex 5C, Figures 5C.12, 5C.13 etc.) (from 0,08 to 0,31).
- While for 2005 simulation results stayed consistently unsatisfactory, no explanation has been found at the moment for low determination coefficients in calculations for 2002 on irrigated variant (Annex 5C, Figures 5C.32, 5C.33, 5C.34)and for 2009 (Annex 5C, Figures 5C.8, 5C.31).
- Different influence of changes in fertilizers and irrigation depth on values of yields has been revealed:
  - Increase of yield 1.3-44.9 % at automatic irrigation compared with upland conditions;
  - Increase of yield 0-3.7 % at automatic input of fertilizers compared to calculation with no fertilizers.

Due to this, the use of non-automatic regime of fertilizers input in experiment №3 has insignificantly increased the values of determination coefficients compared to experiment 2, or left them at the same level.

As it has been pointed out above, an additional experiment № 3a for winter wheat was made after the GEPIC advanced training in EAWAG. In this experiment all improvements and approaches to simulation received during the training have been taken into account.

The results of experiment №3a are presented in the following annexes: for spatial resolution 30x30 min - in Annexes 3.B, 3.D; for spatial resolution 15x15 min in Annexes 4.B, 4.D; for spatial resolution 5x5 min in Annexes 5.B, 5.D.

Two approaches have been used in analyses of the results from the experiment 3a:

a) assessment of determination coefficient between the simulated yields and statistical data for all calculation cells;

b) calculation of determination coefficients on the results of zonal statistics for 26 Raions of Odessa Oblast in ARC GIS 9.2. For spatial resolution 30x30 min zonal statistics has not been performed.

Subsequent consideration has shown that for analysis, both for Odessa Oblast and for the entire Ukraine, it was better to use the results of zonal statistics.

Experiment № 3a in simulation of winter wheat yields for 2002, 2005 and 2009 has given determination coefficients (at P=95%) within the limits: – 0,21-0,65 for spatial resolution 5x5 min; 0,07-0,45 - for spatial resolution 15x15 min; –0,02-0,36 - for spatial resolution 30x30 min (Annexes 8).

Maximal determination coefficients were received for 2009 for spatial resolution 5x5 min – 0,65 (P=99%). It should be mentioned that the reason of this could be the most complete statistical information on fertilizers for that year.

Taking into account of per cent of irrigated acreage according to AQUASTAT has also contributed to more precise calculation of yields.

1.3.1.2 Maize

Two experiments have been made to simulate maize yields in Odessa Oblast:

- Experiment № 6 - Manual;
- Experiment № 6a – Manual, taking into account approaches learned at the GEPIC advanced training in EAWAG (June 2011).

Comparison of results of maize crops simulation in two model experiments and the corresponding statistical data are presented in Tables 4.2., 2 of Annex 1 and 8.4 of Annex 8.

Analysis of results presented in Table 4.2 has shown that practically all the calculations in experiment № 6 carried out before the GEPIC advanced training in EAWAG have given unsatisfactory results at all spatial resolutions (Annex 3C, 4C, 5C), though the non-automatic variant of fertilizers input and irrigation has been used, and the tillage and sowing management files have been developed for this crop for the local agro-climatic conditions.

Experiment № 6 a made after the GEPIC advanced training in EAWAG has given improved results.

Comparison of average simulated yields values calculated by zonal statistics, with the statistical data has shown that the best correspondence was received for spatial resolution 5x5 min in 2002 under no irrigation. For spatial resolution 15x15 min maximal determination coefficient was received for 2009 taking into account the irrigated acreage according to AQUASTAT (Annex 8).

Taking into consideration the per cent of irrigated acreage according to AQUASTAT almost always enabled us calculate maize yields 1-40 % more precisely except for the year 2002.

Table 4.2. Values of Determination Coefficient R^2 for the Simulated in Two Experiments Values of Maize Yields and Statistical Data for 2002, 2005 and 2009 for Odessa Oblast

Experiment	Scale	2002				2005				2009				Note
		F=0, I=0	F=0, I=M	F=M, I=0	F=M, I=M	F=0, I=0	F=0, I=M	F=M, I=0	F=M, I=M	F=0, I=0	F=0, I=M	F=M, I=0	F=M, I=M	
№6	30x30	0.03	-	0.03	-	0.36	-	0.36	-	-	-	-	-	
	15x15	0.00	-	0.00	-	0.03	-	0.03	-	-	-	-	-	
	5x5	0.03	-	0.03	-	0.06	-	0.06	-	-	-	-	-	
№6a	30x30	-	-	0.03	0.07	-	-	0.06	0.04	-	-	0.55	0.67	
	15x15	-	-	0.01/0.16	0.01/0.17	-	-	0.00/0.07	0.00/0.01	-	-	0.01/0.27	0.00/0.33	2
	5x5	-	-	0.01/0.46	0.00/0.35	-	-	0.00/0.10	0.00/0.12	-	-	0.00/0.21	0.01/0.34	2

Notes:

2 – Determination coefficients for comparison - «cell with cell» / «zonal statistics results»;

* - F=0 –no fertilizers; I=0 – no irrigation; F=M – fertilizers applied; I=M - irrigation;

** - significant determination coefficients for grid 05x05 min exceeds 0,07 - at P=0,95 and exceeds 0,10 at P=0,99;

*** - significant determination coefficients for grid 15x15 min exceeds 0,20 - at P=0,95 and exceeds 0,30 at P=0,99;

**** - significant determination coefficients for grid 30x30 min exceeds 0,34 - at P=0,95 and exceed 0,47 at P=0,99.

1.3.1.3 Spring Barley

Two experiments have been made to simulate spring barley yields in Odessa Oblast:

- Experiment № 5 - Manual;
- Experiment № 5a –Manual, taking into account approaches learned at the GEPIC advanced training in EAWAG (June 2011).

Comparison of results of spring barley crops simulation in two model experiments and the corresponding statistical data are presented in Tables 4.3., 2 of Annex 1 and 8.3 of Annex 8.

Analysis of results presented in Table 4.3 has shown that, the same sa for maize, all the calculations in experiment № 5 carried out before the GEPIC advanced training in EAWAG have given unsatisfactory results at all spatial resolutions (Annex 3C, 4C, 5C) with determination coefficients from 0,04 to 0,21 (2005, resolution 30 min).

Experiment № 5a performed after the GEPIC advanced training in EAWAG has given improved results. From the comparison of yields calculated with zonal statistics with the data of official statistics of yields the determination coefficients within the range 0,18-0,54 were received.

Comparison of average simulated yields values calculated with zonal statistics with the statistical data has shown that the best correspondence was received for spatial resolution 5x5 min in 2009 – R^2 up to 0,54 (P=99%) taking into account the irrigated acreage according to AQUASTAT. For spatial resolution 15x15 min maximal determination coefficient was for 2002 – 0,29 (P=95%) taking into account and not taking into account irrigated acreage according to AQUASTAT (Annexes 8). For spatial resolution 30x30 min simulating spring barley yields for all three years – 2002, 2005 and 2009 – we received determination coefficients within the limits 0,29-0,49 with maximal coefficient in 2005 (P=99%) taking into account the irrigated acreage according to AQUASTAT (Annexes 8).

Taking into consideration the per cent of irrigated acreage according to AQUASTAT always enabled us to receive 1-40 % more precise values of spring barley yields.

Table 4.3. Values of Determination Coefficient R^2 for the Simulated in Two Experiments Values of Spring Barley Yields and Statistical Data for 2002, 2005 and 2009 for Odessa Oblast

Experiment	Scale	2002				2005				2009				Note
		F=0, I=0	F=0, I=M	F=M, I=0	F=M, I=M	F=0, I=0	F=0, I=M	F=M, I=0	F=M, I=M	F=0, I=0	F=0, I=M	F=M, I=0	F=M, I=M	
№5	30x30	0.04	-	0.04	-	0.16	-	0.21	-	-	-	-	-	
	15x15	0.04	-	0.04	-	0.10	-	0.11	-	-	-	-	-	
	5x5	0.04	-	0.04	-	0.16	-	0.18	-	-	-	-	-	
№5a	30x30	-	-	0.2873	0.31	-	-	0.48	0.49	-	-	0.35	0.36	
	15x15	-	-	0.04/0.29	0.04/0.28	-	-	0.06/0.26	0.06/0.26	-	-	0.00/0.18	0.00/0.18	2
	5x5	-	-	0.04/0.26	0.06/0.42	-	-	0.02/0.29	0.02/0.35	-	-	0.01/0.33	0.04/0.54	2

Notes:

2 – Determination coefficients for comparison - «cell with cell» / «zonal statistics results»;

F=0 –no fertilizers; I=0 – no irrigation; F=M – fertilizers applied; I=M - irrigation.

* - significant determination coefficients for grid 05x05 min exceeds 0,07 - at P=0,95 and exceeds 0,10 at P=0,99;

** - significant determination coefficients for grid 15x15 min exceeds 0,20 - at P=0,95 and exceeds 0,30 at P=0,99;

*** - significant determination coefficients for grid 30x30 min exceeds 0,34 - at P=0,95 and exceeds 0,47 at P=0,99.

1.3.1.4 Sunflower

Two experiments have been made to simulate sunflower yields in Odessa Oblast:

- Experiment № 4 - Manual;
- Experiment № 4a –Manual, taking into account approaches learned at the GEPIC advanced training in EAWAG (June 2011).

Comparison of results of sunflower crops simulation in two model experiments № 4 and 4 a and the corresponding statistical data are presented in Tables 4.4., 2 of Annex 1 and 8.2 of Annex 8.

Analysis of results presented in Table 4.4 has shown that practically all the calculations in experiment № 4 carried out before the GEPIC advanced training in EAWAG have given unsatisfactory results at all spatial resolutions (Annex 3C, 4C, 5C).

Experiment № 4 a made after the GEPIC advanced training in EAWAG has given somewhat improved results. However, in general the results received in this experiment for all years: 2002, 2005 and 2009 stayed unsatisfactory for two spatial resolutions: 15x15 and 30x30 min.

Comparison of average simulated yields values calculated with zonal statistics with the statistical data for spatial resolution 5x5 min has given the best correspondence for the year 2009 – R^2 up to 0,61 (P=99%) taking into account the irrigated acreage according to AQUASTAT (Annexes 8).

Taking into consideration the per cent of irrigated acreage according to AQUASTAT gave more precise calculated values of sunflower yields almost in all cases.

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Table 4.4. Values of Determination Coefficient R^2 for the Simulated in Two Experiments Values of Sunflower Yields and Statistical Data for 2002, 2005 and 2009 for Odessa Oblast

Experiment	Scale	2002				2005				2009				Note
		F=0, I=0	F=0, I=M	F=M, I=0	F=M, I=M	F=0, I=0	F=0, I=M	F=M, I=0	F=M, I=M	F=0, I=0	F=0, I=M	F=M, I=0	F=M, I=M	
№4	30x30	0.03	-	0.03	-	0.03	-	0.31	-	-	-	-	-	
	15x15	0.11	-	0.11	-	0.26	-	0.25	-	-	-	-	-	
	5x5	0.07	-	0.07	-	0.24	-	0.26	-	-	-	-	-	
№4a	30x30	-	-	0,02	0.03	-	-	0.29	0.29	-	-	0.07	0.08	
	15x15	-	-	0.30/0.30	0.29/0.31	-	-	0.02/0.02	0.02/0.02	-	-	0.00/0.14	0.00/0.11	2
	5x5	-	-	0.04/0.21	0.04/0.19	-	-	0.02/0.12	0.0./0.31	-	-	0.05/0.24	0.05/0.61	2

Notes:

2 – Determination coefficients for comparison - «cell with cell» / «zonal statistics results»;

F=0 –no fertilizers; I=0 – no irrigation; F=M – fertilizers applied; I=M - irrigation.

* - significant determination coefficients for grid 05x05 min exceeds 0,07 - at P=0,95 and exceeds 0,10 at P=0,99;

** - significant determination coefficients for grid 15x15 min exceeds 0,20 - at P=0,95 and exceeds 0,30 at P=0,99;

*** - significant determination coefficients for grid 30x30 min exceeds 0,34 - at P=0,95 and exceeds 0,47 at P=0,99.

1.3.2 Simulation of yields for Ukraine (whole territory)

Model experiments have been performed for the whole territory of Ukraine to calculate yields (Yd) and evapotranspiration (ET) for winter wheat, maize, spring barley and sunflower for the period 2000-2010. To make the calculations we have used the experience of work with GEPIC gained during the trainings in Bucharest and Dubendorf, as well as during pilot study for Odessa Oblast. Parameters of GEPIC simulation for the territory of Ukraine are presented in Annex 2. Results of model experiments for the whole Ukraine are presented in Annex 6A. To assess simulation quality comparison has been made between simulated yield values averaged for 25 Oblasts and statistical data. Detailed results of the assessment for four crops are presented in Annexes 6B, 10 and Table 4.5.

Table 4.5. Values of determination coefficient R^2 between simulated and averaged for Oblasts yields of winter wheat, spring barley, maize and sunflower and the respective statistical data of 2000-2010 for the territory of Ukraine

Year	Winter Wheat			Spring Barley			Maize			Sunflower		
000	.16	.15	.03	.01	.01	.01	.18**	.44**	.77**	.00	.00	.00
001	.45**	.45**	.46**	.29*	.18*	.13*	.29**	.51**	.60**	.01	.00	.12
002	.23**	.31**	.45**	.12*	.29**	.38**	.19**	.25**	.38**	.01	.00	.08
003	.03	.05	.49**	.00	.05	.31**	.00	.02	.12	.00	.01	.06
004	.01	.01	.01	.00	.00	.00	.02	.00	.01	.01	.00	.01
005	.01	.01	.04	.02	.02	.03	.01	.01	.21*	.08	.12*	.43**
006	.13	.13*	.15*	.11	.11*	.27**	.19**	.24**	.64**	.00	.09	.00
007	.23**	.40**	.57**	.75**	.78**	.85**	.50**	.64**	.63**	.17*	.25*	.23*
008	.36**	.36**	.39**	.06	.00	.00	.10	.27**	.53**	.00	.03	.03
009	.21**	.21**	.43**	.43**	.11	.23*	.21**	.51**	.54**	.00	.00	.00
010	.13*	.20*	.25*	.37**	.43**	.56**	.33**	.44**	.55**	.00	.00	.00
000-2010	.26**	.28**	.36**	.13**	.22**	.40**	.21**	.37**	.52**	.02**	.06**	.13**

Notes:

1 – All data

2 – With rejection of "bad" values (three-sigma rule, P=0.99)

3 – With rejection of "bad" values (two-sigma rule, P=0,95)

* - R^2 values, significant with P=0,95;

** - R^2 values, significant with P=0,99

Analysis of results from the Table 4.5 has shown that the range of determination coefficient between simulation results and statistical data varied from 0 to 0,85. To assess influence of fertilizers and irrigation depth on yields variants for the years 2009 and 2010 have been calculated, in which input of fertilizers and water was taken as of 1990, i.e. the input values of fertilizers and irrigation were the highest for the past 21 years.

Then analysis and comparison of yields simulation results are presented for each studied crop: winter wheat, spring barley, maize and sunflower.

1.3.2.1 Winter wheat

The range of determination coefficients received from experiments with winter wheat (Table 4.5 and Annex 9) was from 0.01 to 0.57. These values correspond to the categories 'weak', 'moderate' or 'noticeable' dependence according to Chaddock scale (Sizova 2005). An example of simulation results (A) and correlation relationship between simulated winter wheat yields and statistical data (B) for 25 Oblasts of Ukraine is shown on Figure 4.1.

Analysis of comparison between winter wheat yields simulation (Annex 6a) and statistical data for the territory of Ukraine has shown the following:

Only the determination coefficient for 2007 (P=95%) was within the range of significant dependence (0.5-0.7).

Determination coefficients for the years 2001, 2002, 2003, 2008, 2009, 2010, period 2000-2010 at P=95%, as well as for 2001, 2002, 2007, 2008, period 2000-2010 at P=99% are within the range of moderate dependence.

Within the range of weak dependence, its absence or insignificance were determination coefficients for 2000, 2004, 2005, 2006 at P=95% and for 2000, 2003, 2004, 2005, 2006, 2009 and 2010 at P=99%. The reason might be in source data on climate or low quality statistics on the yields in those years.

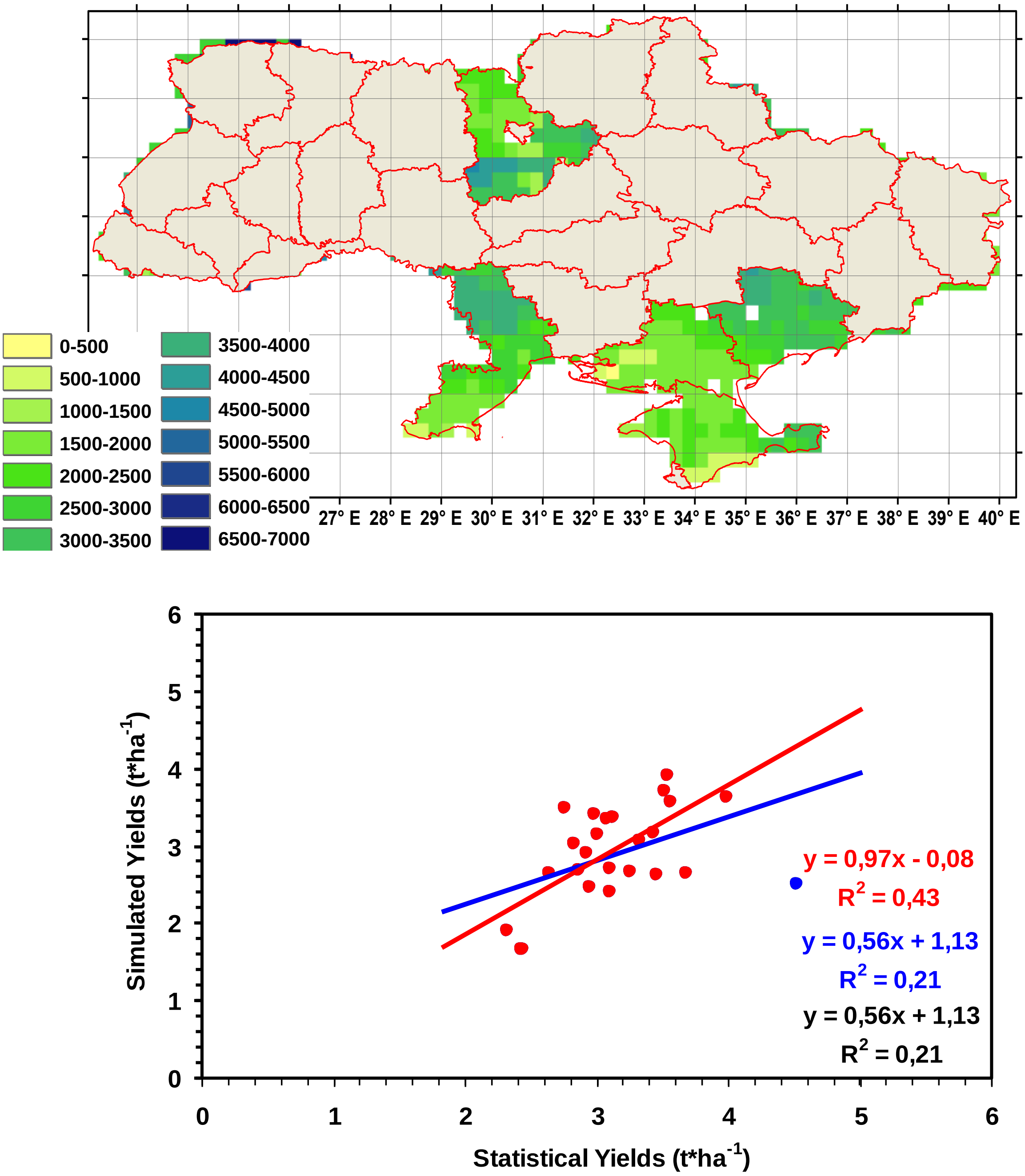


Figure 4.1. Winter wheat yields (kg/ha) simulation results (A) and comparison of simulated and statistical winter wheat yields (t/ha) in 2009 in Ukraine (B). ● – all data; ● – with rejection of values according three –sigma rule (P=99.73 %); ● – with rejection of values according of two-sigma rule (P=95.45 %).

The use of irrigation depth as of 1990 to calculate winter wheat yields in 2009-2010 has shown that without input of fertilizers no increase of yields is observed. So, we can conclude that irrigation depth 194 mm is sufficient for winter wheat for practically the whole territory of Ukraine.

Input of fertilizers at the level of 1990 for the years 2009 and 2010 at simulation of winter wheat yields has given an ambiguous picture for the territory of Ukraine (Annex 10, Figures 10.1-10.4), namely:

1. Input of fertilizers on the level of 1990 with no irrigation has given significant increase of yields (up to 50 %) for 2009-2010 in the north-western Oblasts of Ukraine, but produced almost no effect in the central, southern and eastern Oblasts. This scheme corresponds well to the distribution of soils in Ukraine, where central, southern and eastern Oblasts have chernozems (black soils) and chestnut soils (see Figure 3.39) containing significant (high) quantity of nutrients.

2. Several calculation cells (8 in 2009 and 25 in 2010) have been pointed out in which yields decreased with input of fertilizers as of 1990. Probably for certain types of soils (Chernozems Luvic, Chernozems Haplic) and a number of climatic parameters (2009, 2010) that amount of fertilizers (> 130 kg/ha) produce suppressing influence on the growth of winter wheat without irrigation (Annex 10, Figures 10.1, 10.3).

3. Simulating yields with fertilizers and depth of irrigation as of 1990 we observed no suppression of winter wheat growth, instead there was 0 to 50% increase of yields all over the territory of Ukraine. At that, 50% increase of yields was observed for the chernozem and chestnut soils where no increase happened without irrigation (Annex 10, Figures 10.2, 10.4).

4. Different influences of changes in climatic parameters on the winter wheat yields have been revealed: increase of yields in 2009 was almost twice as big as in 2010, though the same input of fertilizers and irrigation depth was used for both years.

1.3.2.2 Maize

The range of determination coefficients received from the experiments with maize was 0.00-0.77 (see Table 4.5 and Annex 9), which corresponds to the categories ‘weak’, ‘moderate’ or ‘noticeable’ and ‘high’ dependence according to Chaddock scale (Sizova 2005).

An example of simulation results and correlation relationship between simulated maize yields and statistical data for 25 Oblasts of Ukraine is shown on Figure 4.2.

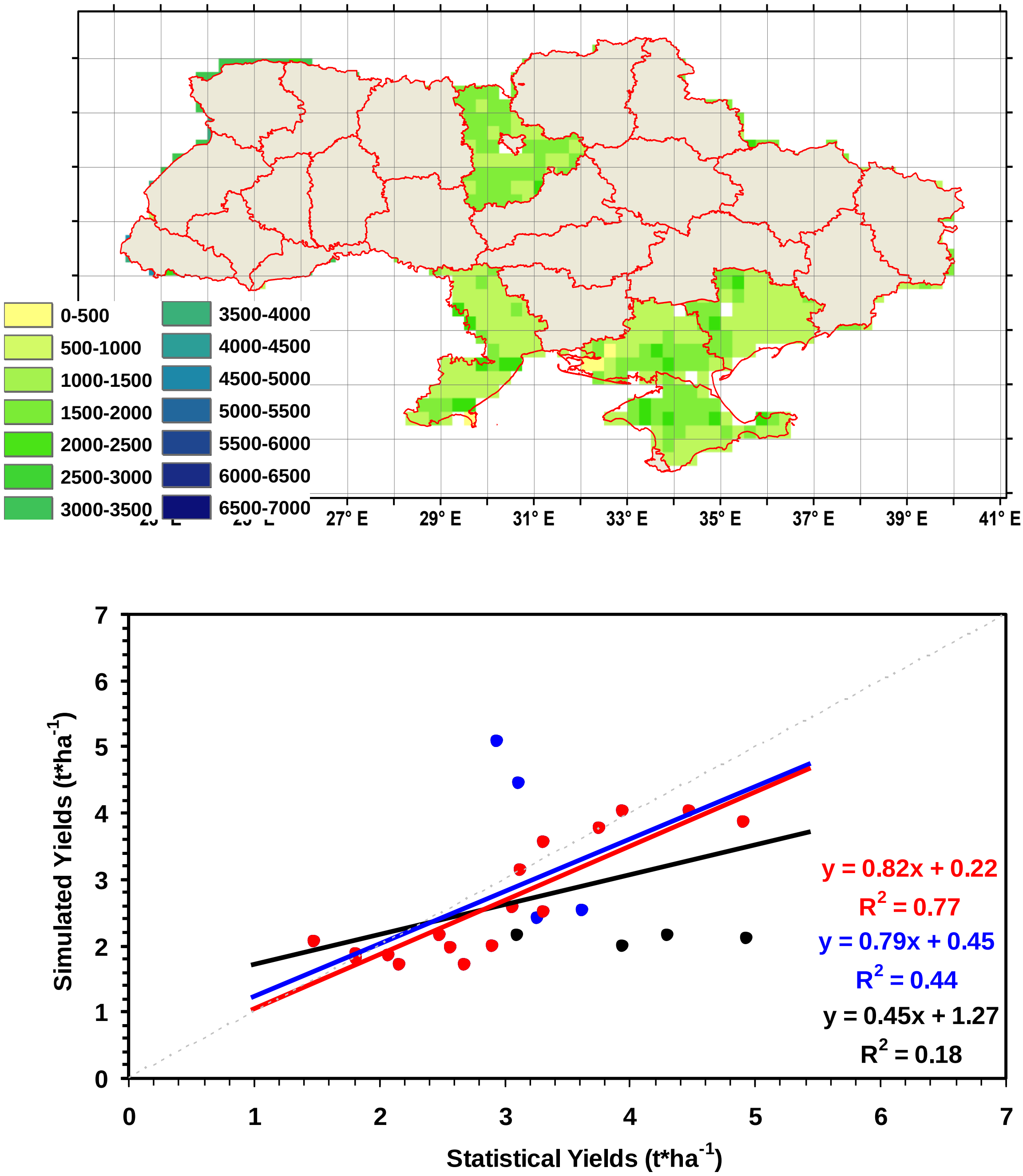


Figure 4.2. Maize wheat yields (kg/ha) simulation results (A) and comparison of simulated and statistical maize yields (t/ha) in 2000 in Ukraine (B). ● – all data; ● – with rejection of values according three–sigma rule (P=99.73 %); ● – with rejection of values according of two-sigma rule (P=95.45 %).

Analysis of comparison between maize yields simulation (Annex 6a) and statistical data for the territory of Ukraine has shown the following:

Determination coefficient for maize for 2000 (0.7–0.9) was within the range of high dependence at P=95%.

Determination coefficients for the years 2001, 2006, 2007, 2008, 2009 and 2010 of the period 2000-2010 for maize at P=95% and for 2001, 2007 and 2009 of the period 2000-2010 at P=99% were within the range of significant dependence (0.5-0.7).

Determination coefficients for the years 2002 and 2008 at P=95%, as well as for 2002 at P=99% are within the range of moderate dependence (0.3-0.5).

Within the range of weak dependence or its absence were determination coefficients for 2003, 2004, 2005, 2006 at P=95% and for 2003, 2004, 2005 at P=99%. The reason might be in source data on climate or low quality statistics on the yields in those years.

The use of irrigation depth as of 1990 to calculate maize yields in 2009-2010 has shown that without input of fertilizers no increase of yields is observed. So, we can conclude that irrigation depth 194 mm is sufficient, the same as for winter wheat, to grow maize practically for the conditions of the whole territory of Ukraine.

Input of fertilizers at the level of 1990 for the years 2009 and 2010 with no irrigation practically did not influence the size of maize yields during simulation: no increase of yields compared with simulation under conditions of 2009 and 2010 was observed; for significant number of calculation cells (5 %) decrease of yields (suppression of plants) was observed for eastern and northern Oblasts of Ukraine (Annex 10, Figures 10.5-10.7).

Decrease of maize yields with input of fertilizers as of 1990 when simulating the years 2009 and 2010was mainly observed for the soils Podzoluvisols Eutric and Chernozems Haplic. Different numbers of calculation cells with suppressed state of maize due to the influence of different sets of climatic parameters (2009, 2010) have been pointed out under practically the same input of fertilizers in those cells (Annex 10, Figures 10.5, 10.7).

Simulating yields with fertilizers and depth of irrigation as of 1990 we observed no suppression of maize growth, instead there was 0 to 20% increase of yields all over the territory of Ukraine (Annex 10, Figures 10.6, 10.8). Character of distribution of yields' increase values for 2009 and 2010 almost coincides, which proves significant dependence of maize yields growth on the types of soils.

1.3.2.3 Spring barley

The range of determination coefficients received from the experiments with spring barley was 0.00-0.85 (see Table 4.5 and Annex 9), which corresponds to the categories ‘weak’, ‘moderate’ or ‘noticeable’ and ‘high’ dependence according to Chaddock (Sizova 2005). An example of correlation relationship between simulated spring barley yields and statistical data for 25 Oblasts of Ukraine is shown on Figure 4.3.

Analysis of comparison between spring barley yields simulation (Annex 6a) and statistical data for the territory of Ukraine has shown the following:

Determination coefficient for spring barley for 2007 (0.7–0.9) was within the range of high dependence at P=95% and P=99%.

Determination coefficient for spring barley for 2010 (0.5–0.7) was within the range of noticeable dependence at P=95%.

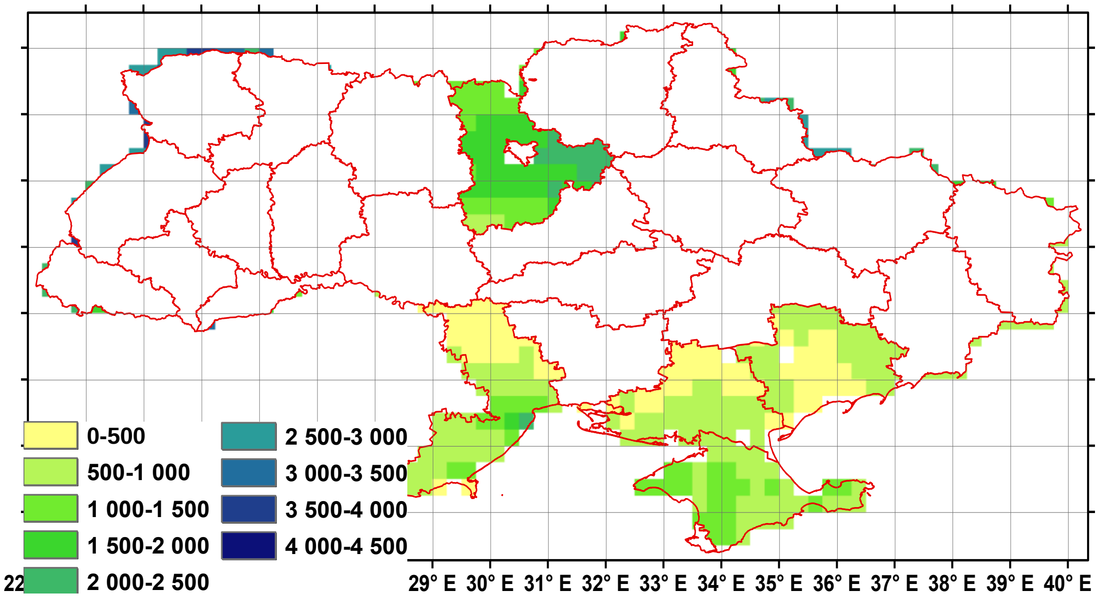
Determination coefficients for the years 2002, 2003 and 2006 of period 2000-2010 at P=95%, as well as for 2002, 2010 at P=99% are within the range of moderate dependence (0.3-0.5).

Within the range of weak dependence or its absence were determination coefficients for 2000, 2001, 2004, 2005, 2008 and 2009 at P=95% and for 2000, 2001, 2003, 2004, 2005, 2006, 2008, 2009 of period 2000-2010 at P=99%. We have to point out that GEPIC simulation results for spring barley were not very good. One of the reasons might be the unreliable source data on fertilizers input.

The use of irrigation depth as of 1990 to calculate spring barley yields in 2009-2010 has shown, similarly to winter wheat and maize, that without input of fertilizers no increase of yields is observed. So, the irrigation depth 194 mm is sufficient to grow spring barley practically for the conditions of the whole territory of Ukraine.

Input of fertilizers at the level of 1990 for the years 2009 and 2010 during simulation has given no increase in spring barley yields for most of Ukrainian areas – 80 and 86 %, respectively (Annex 10, Figures 10.9-10.11). Only north-western Oblasts demonstrated exceptions, as there yields grew in 2009, mainly about 10 %; for 2010 increase of yields was observed only for Carpathian regions.

With input of fertilizers at the level of 1990 and no irrigation for both years we also observed increased number of calculation cells with decreasing yields – 3 and 5 % for 2009 and 2010 respectively.



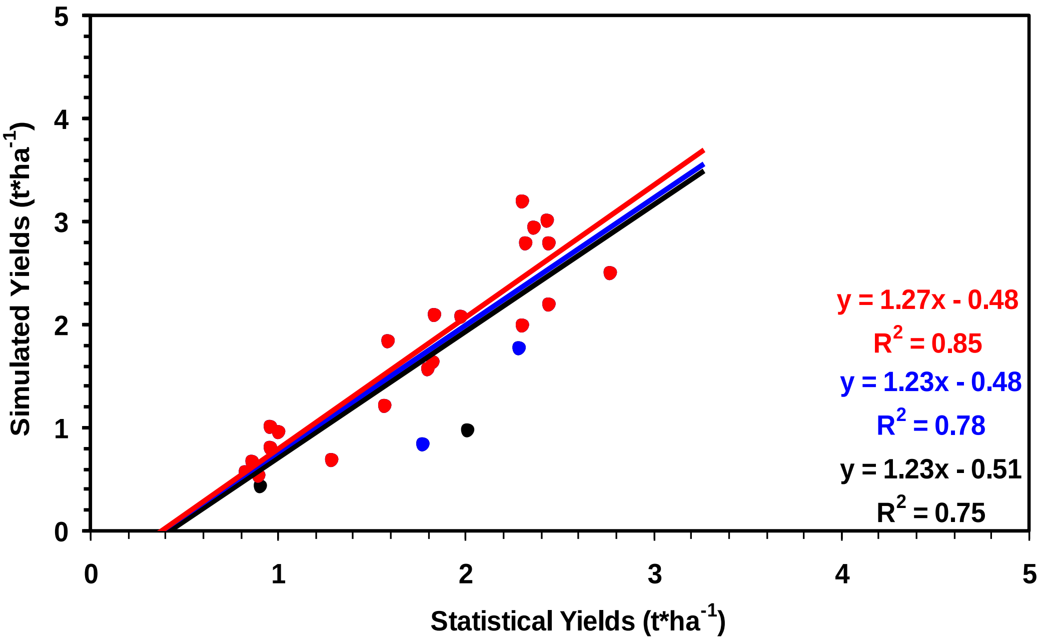


Figure 4.3. Spring barley yields (kg/ha) simulation results (A) and comparison of simulated and statistical spring barley yields (t/ha) in 2000 in Ukraine (B). ● – all data; ● – with rejection of values according three –sigma rule (P=99.73 %); ● – with rejection of values according of two-sigma rule (P=95.45 %).

Simulating yields with fertilizers and depth of irrigation as of 1990 we observed practically no suppression of spring barley growth, instead, there was 0 to 20% increase of yields, mainly for the north-western Oblasts of Ukraine (Annex 10, Figures 10.10, 10.12).

Number of calculation cells in which yields increased with input of fertilizers and irrigation depth on the level of the year 1990 for 2009 was 41 % higher of this number for 2010.

1.3.2.4 Sunflower

The range of determination coefficients received from the experiments with sunflower was 0.01-0.4 (Table 4.5 and Annex 9) which corresponds to the categories 'weak' and 'moderate' dependence according to Chaddock scale (Sizova 2005).

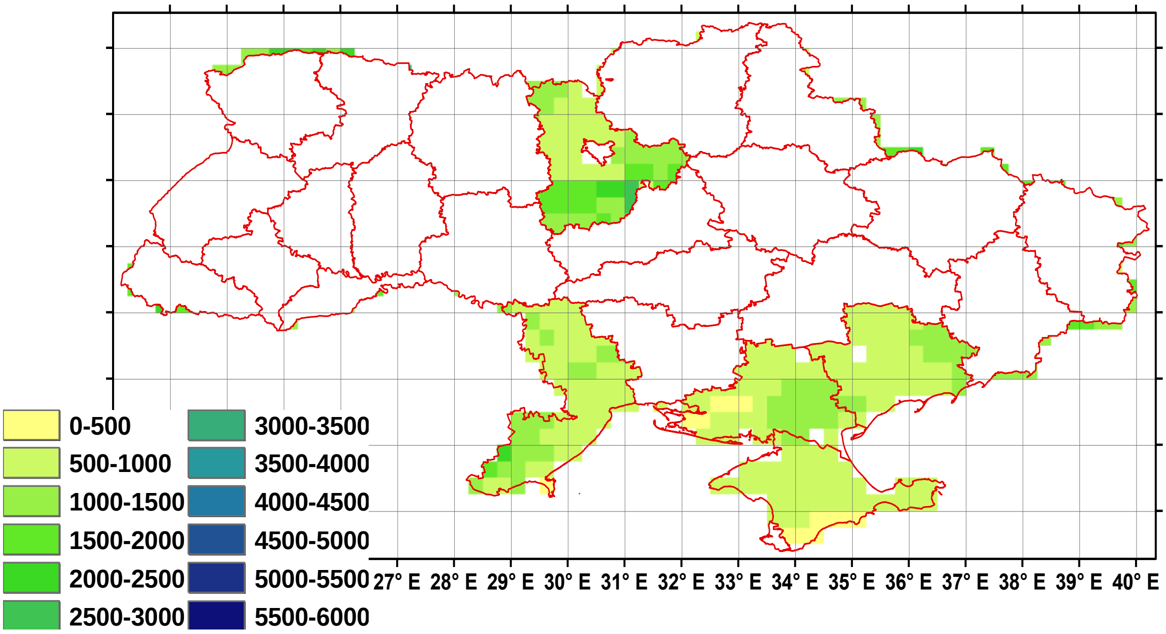
An example of correlation relationship between simulated sunflower yields and statistical data for 25 Oblasts of Ukraine is shown on Figure 4.4. Analysis of comparison between sunflower yields simulation (Annex 6a) and statistical data for the territory of Ukraine has shown the following:

- Two determination coefficients for the year 2005at P=95% and for 2007 at P=99% were within the range of moderate dependence (0.3-0.5).

- The calculations for the rest of years fell under the range of moderate dependence or its absence.

- The use of irrigation depth as of 1990 to calculate sunflower yields in 2009-2010 has shown, similarly to other crops, no increase of yields.

Input of fertilizers at the level of 1990 for the years 2009 and 2010 during simulation has given a patchy picture of yields increase distribution for the territory of Ukraine (Annex 10, Figures 10.13-10.15). In the black-soil central and eastern Oblasts of Ukraine the increase was generally 0-10 %; as for Ivano-Frankovsk, Chernovtsy, Khmelnitsk, Vinnitsa, Zhitomir, Kiev, Chernigov and Odessa Oblasts the significant portion of calculation cells has shown 30-50% increase and over. Simulating yields with input of fertilizers as of 1990, both with and without irrigation we observed practically no decrease in yields compared to 2009 and 2010. (Annex 10, Figures 10.13, 10.16). Increase of sunflower yields is observed all over the territory of Ukraine under input of fertilizers and irrigation depth as of 1990.



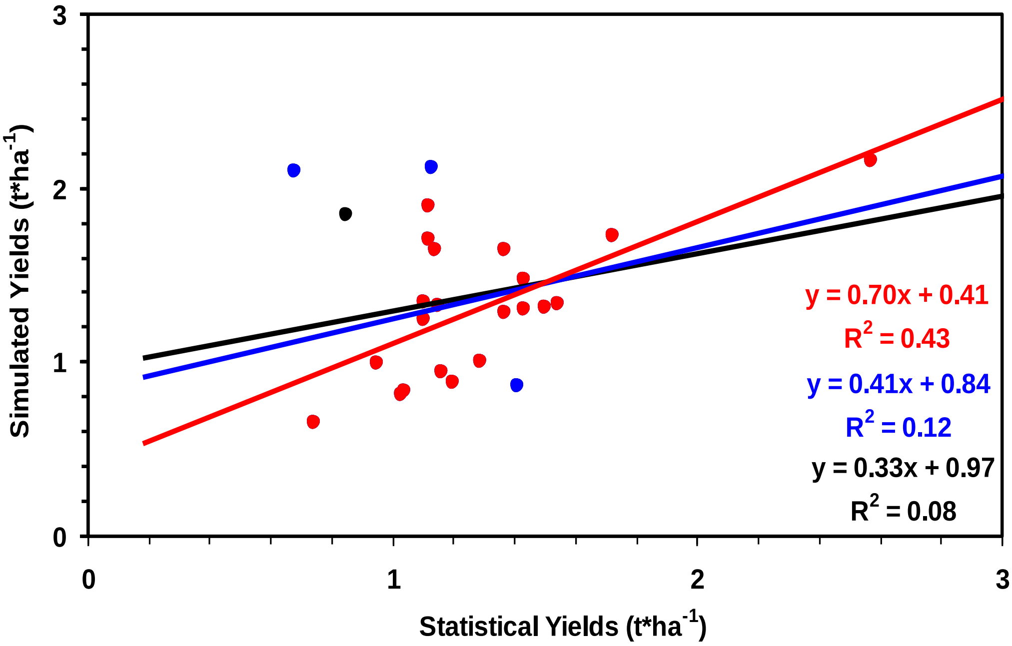


Figure 4.4. Spring sunflower yields (kg/ha) simulation results (A) and comparison of simulated and statistical sunflower yields (t/ha) in 2005 in Ukraine (B). ● – all data; ● – with rejection of values according three –sigma rule (P=99.73 %); ● – with rejection of values according of two-sigma rule (P=95.45 %).

However, the level of the increase is different for the different Ukrainian regions (Annex 10, Figures 10.14, 10.16). In the central, southern and eastern Oblasts of Ukraine the increase made generally 10 %, in the north-western Oblasts and the central part of Odessa Oblast – 10-50 and more percent. This scheme is characteristic of both 2009 and 2010.

1.3.2.5 Conclusions

The GEPIC model is very powerful and flexible instrument for simulation and forecasting of crops yields. Used for yields forecasting the model provides possibility to take into account external factors, first of all climate characteristics, soil properties, fertilizers and irrigation, as well as assess material inputs and economic expediency of growing this or that crop in different Oblasts of Ukraine.

The most successful were the results of model experiments for winter wheat and maize. Their use for practical purposes would, no doubt, provide significant benefit and result at economizing in agro-industrial branch of Ukrainian economy.

Unsatisfactory results of sunflower yield simulation could, to our mind, be explained by the facts that statistical data were not enough reliable and the required input parameters and coefficients for Ukraine and for this crop were lacking.

1.3.3 Evapotranspiration (ET)

The process of transpiration or evaporation of water by plants is very important for their life. As the result of transpiration plant supplies itself with water and minerals required for the normal life activities it its cells. Besides, it contributes to thermoregulation of plants. Leaf temperature is 4 - 10 °C below air temperature even at hottest weather.

Water transpiration with plants, and consequently, water movement along the stem is regulated by both internal physiological factors and external ones. There are two types of transpiration – stomata and cuticular. Stomata play the main role as transpiration regulators, as stomata transpiration exceeds the cuticular one many times.

Agronomic practice of Ukraine, as well as of other ex-USSR countries, uses the notion of transpiration coefficient, which implies weight of water quantity used by a plant during the entire time of its development to build a unit of dry weight (i.e. this is a quantity of grams of water consumed to accumulate one gram of dry matter). Values of transpiration coefficients for different crops approximately show the capability of plants to develop at conditions of different moisture content and vary from 230 to 1000. Transpiration coefficient of maize is 315-717, of wheat – 473-559, of barley 300-500 and of sunflower 450-630 mm.

The GEPIC model uses ET as the sum of evaporation and plant transpiration from the Earth's land surface to atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and waterbodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapour through stomata in its leaves.

Water shortage could greatly affect the total domestic grain production. The spatial distribution of annual water resources availability in Ukraine is uneven. However, water resources amount practically all over the Ukrainian territory is generally favourable for corn and technical crops growing.

Long term average annual precipitation in Ukraine varies from 620-660 mm in the north and north-western part of the plain zone to 450-500 mm in the steppe zone (Galuschenko 2001).

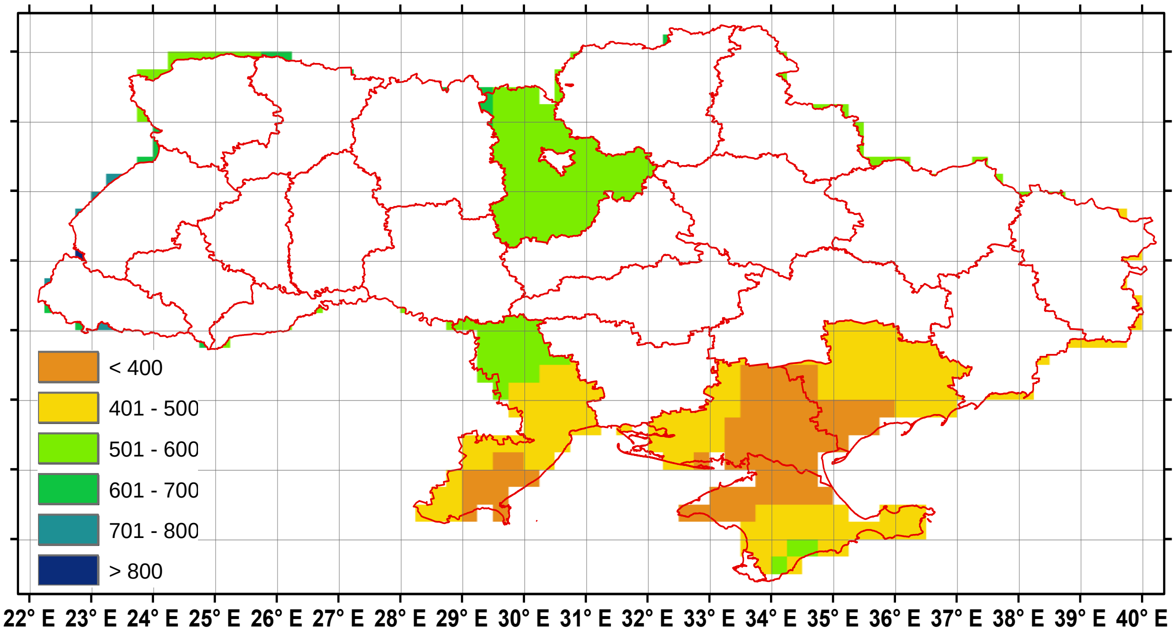


Figure 4.5. Average annual precipitation values distribution (mm) for the period 2000-2010 according to EU FP6 Integrated Project ENSEMBLES (Haylock 2008)

In the mountainous catchments in the Carpathians and the Crimea the distribution of atmospheric precipitation has vertical zonality. The biggest amount of precipitation equalling to 1500-1800 mm is registered in the upper reaches of the rivers Chornaya Tisza, Kosovskaya, Shopurka, Teresva, Tereblya and Rika the sources of which are located in the areas having elevation 1500-2000 m above sea level on Poloninskiy or Chernogorskiy Ridges (Galuschenko 2001). In the mountainous catchments of the Prut River basin the long term layer of precipitation makes 1000-1400 mm and in some of catchments on the right bank of the Dnister – 900-1500 mm. Within Volyn-Podolie Upland quantity of precipitation decreases to 700-800 mm. In the catchments of rivers in the Mountainous Crimea according to the data from some precipitation stations the precipitation makes 600-1000 mm.

Total evaporation from the surface of catchments in Ukraine, compared with precipitation and runoff, is distributed more evenly and varies within smaller limits. Its value depends on air temperature and humidity, as well as on moisture content in the area, which depends on precipitation depth. Evaporation values not only change in latitudinal direction but also decrease from west to east. On the plain territory of Ukraine annual evaporation from the land surface decreases from 500-530 mm in the north-western regions to 460-480 mm in the south-east. In the southern steppe areas of Ukraine the average long term evaporation makes 400-480 m (Galuschenko 2001). The highest evaporation value 650-700 mm is characteristic of the Zakarpatye Lowland. In this area the average rainfall equals to 800-850 mm and the long term air temperature - to 8.5-10.0°C. Though with elevation the rainfall increases to 1500-1800 mm, average long term air temperature goes down to 5.0-7.0°C, which causes evaporation decreasing down to 500-550 mm per year. In the river basins of Mountainous Crimea evaporation makes 500 mm per year.

The evapotranspiration (ET) calculated by GEPIC when simulating yields is an important indicator (Galuschenko 2001) of irrigation efficiency for growing crops and calculation of economic inputs required.

In the course of model experiments described in Chapter 4.2 evapotranspiration (ET, mm) values were calculated for winter wheat, maize, spring barley and sunflower for the territory of Ukraine and for each modelled year (Annex 7). Ranges of variation of growing season ET (mm) for the four crops are presented in Table 4.6.

1.3.3.1 Winter wheat

The results of ET simulation for winter wheat in 2000-2010 have shown that the highest ET values (370-440 mm) were observed in the western Oblasts of Ukraine (Volyn Oblast, Zakarpatye Oblast, Ivano-Frankovsk Oblast, Zhitomir Oblast, Lvov Oblast, Ternopol Oblast, Khmelnitsk Oblast and Chernovtsy Oblast) and the lowest values (287-338 mm) were characteristic of the southern and south-eastern Oblasts of Ukraine: The Crimea, Dnepropetrovsk Oblast, Donetsk Oblast, Zaporozhye Oblast, Lugansk Oblast, Nikolaev Oblast, Odessa Oblast and Kherson Oblast. An example of ET distribution at growing winter wheat is presented on Figure 4.6. ET distribution is in direct dependence on the distribution of precipitation values in the territory of Ukraine (Figure 4.5): correlation coefficient is equal to 0,96 (P=99%); distribution of mean calculated irrigation depths in the acreage under winter wheat for the period 2000-2010 (Figure 4.7) is in inverse dependence: on precipitation distribution (Figure 4.5) (correlation coefficient -0,68, P=99%); on the ET level (correlation coefficient -0,65, P=99%).

Table 4.6. Ranges of simulated ET values' variations (growing season ET in mm) for the territory of Ukraine, 2000-2010

Year	Winter Wheat		Maize		Spring Barley		Sunflower	
	Min	Max	Min	Max	Min	Max	Min	Max
2000	171	533	256	583	88	356	113	542
2001	171	533	256	583	88	356	115	541
2002	150	486	240	440	117	302	150	398
2003	67	436	118	465	102	284	137	435
2004	316	450	449	754	206	306	305	496
2005	328	463	262	449	193	302	247	447
2006	323	488	279	511	103	336	104	512
2007	203	451	182	509	112	320	150	479
2008	364	560	371	560	99	351	228	514
2009	140	523	204	485	119	341	153	464
2010	314	540	245	553	164	371	256	519

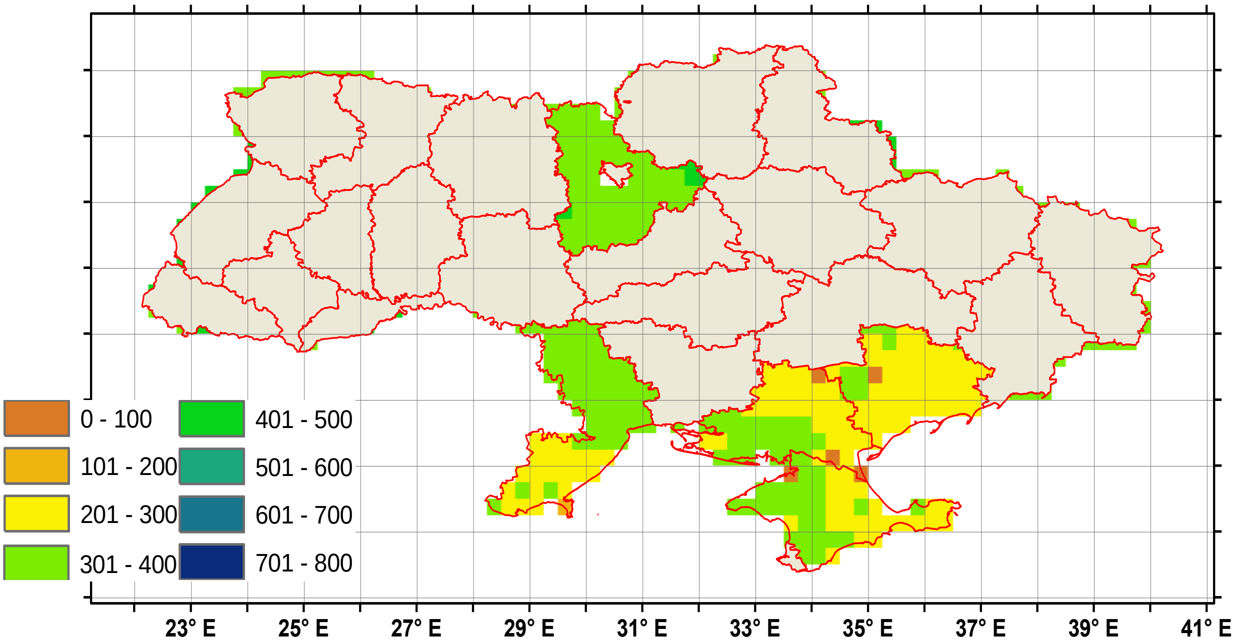


Figure 4.6. Simulated seasonal ET of winter wheat (mm) in Ukraine in 2002

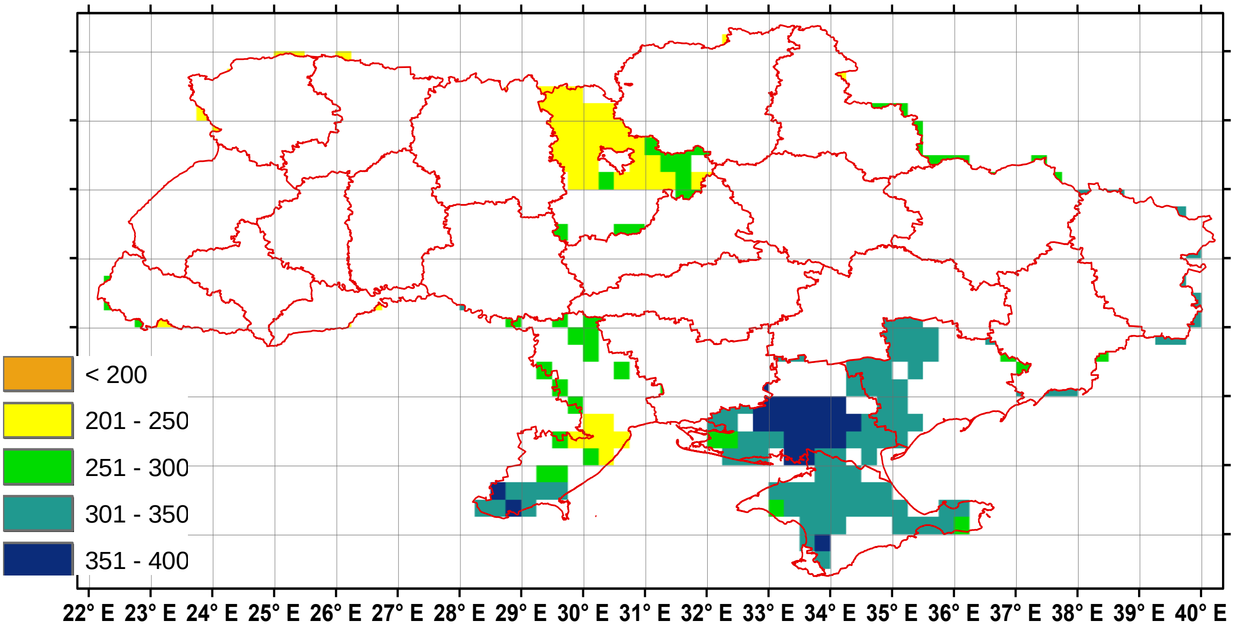


Figure 4.7. Distribution of irrigation mean values (mm) in the acreage under winter wheat for the period 2000-2010

Comparison of mean irrigation values distribution and winter wheat yields in the period 2000-2010 (Figures 4.7, 4.8, Table 4.7) shows that in general under the agricultural practice of winter wheat growing in Ukraine irrigation does not influence significantly the yield: correlation coefficient is equal to -0,30 (P=90%) and -0,38 (P=95%) for simulated and statistical yields respectively.

However, considering the regional peculiarities of climate in Ukraine and taking into account the results of model calculations of irrigation depth for winter wheat (Table 4.7) we have to point out that in the significant part of southern and eastern Oblasts increase in irrigation accompanied with increase of fertilizers input results at increase of yields up to 50 % (model experiments for 2009-2010 with fertilizers input and irrigation depth on the level of the year 1990 (Annex 10, Figures 10.2, 10.4).

Stable high yield of winter wheat mainly fall on fields in the central part of Ukraine, which are scarcely irrigated or rainfed, in the following Oblasts: Ternopol, Khmelnitsk, Vinnitsa, Kirovograd, Cherkassy, Poltava, south of Rovno Oblast, Volyn, Zhitomir, Kiev, Chernigov and Sumy Oblasts. Only small share of irrigated acreage also demonstrate stably high yields.

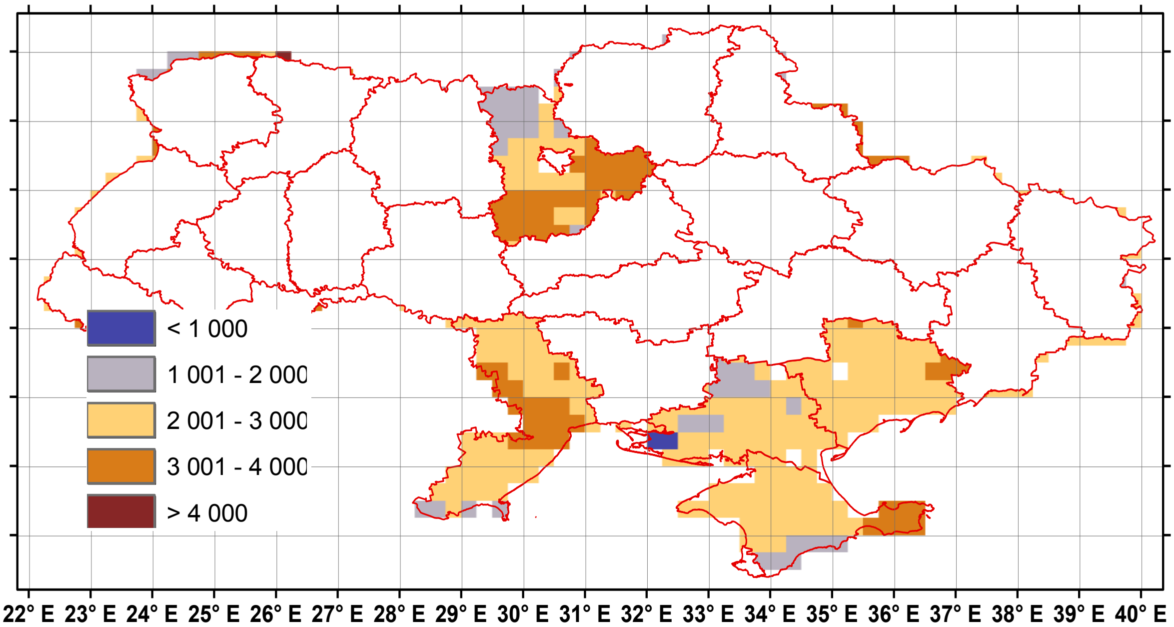


Figure 4.8. Distribution of winter wheat yields mean values (kg/Ha) in the period 2000-2010

Calculated and statistical values for winter wheat averaged for 11 years of simulation (2000-2010) are presented in Table 4.7.

Table 4.7. Averaged for Oblasts for the period 2000-2010 values of yields, ET and irrigation - calculated from simulation results and from statistical winter wheat yields

Oblast	A- Statistical yields, kg/Ha	B-Yields calculated from simulation results, kg/Ha	100*(B-A)/B), %	ET, mm	Irrigation depth, mm	Precipitation, mm
AR Crimea*	2212.7	2537.7	14.7	316.1	219.9	423.1
Vinnitsa	2991.8	2805.1	-6.2	364.0	122.8	566.9
Volyn	2666.4	2568.1	-3.7	375.4	127.6	598.0
Dnepropetrovsk	2902.7	2673.7	-7.9	332.1	174.2	463.0
Donetsk	2740.9	2843.7	3.8	337.8	262.3	490.0
Zhitomir	2478.2	2191.6	-11.6	374.6	106.8	627.2
Zakarpatye	2887.3	2678.9	-7.2	432.3	87.3	750.9
Zaporozhye	2640.9	2647.4	0.2	309.5	137.9	408.1
Ivano-Frankovsk	2557.3	2690.2	5.2	431.4	98.2	682.7
Kiev	3069.1	2645.6	-13.8	361.6	157.6	575.4
Kirovograd	2969.1	2755.0	-7.2	341.7	92.4	509.8
Lugansk	2400.9	2291.7	-4.5	327.4	195.2	485.0
Lvov	2608.2	2660.7	2.0	426.3	13.1	749.2
Nikolaev	2453.6	2456.7	0.1	324.9	168.5	461.1
Odessa	2555.5	2779.7	8.8	320.8	122.9	456.5
Poltava	2878.2	3193.7	11.0	359.5	92.2	560.1
Rovno	2692.7	2471.3	-8.2	371.5	92.0	619.0

Sumy	2582.7	2760.2	6.9	347.9	143.9	571.0
Ternopol	2568.2	3463.7	34.9	407.8	153.2	644.3
Kharkov	2876.4	2763.0	-3.9	340.9	121.2	525.4
Kherson	2352.7	2029.5	-13.7	287.2	246.4	376.4
Khmelnitsk	2644.5	2962.9	12.0	386.3	85.4	617.5
Cherkassy	3356.4	2730.0	-18.7	355.9	95.8	553.6
Chernigov	2490.9	2300.3	-7.7	343.1	182.7	589.1
Chernovtsy	2467.3	2643.7	7.2	383.8	152.5	604.0

*AR – Autonomous Republic

1.3.3.2 Maize

The results of ET simulation for maize 2000-2010 have shown that the highest ET values (379-422 mm) were observed in the western Oblasts of Ukraine (Volyn Oblast, Zakarpatye Oblast, Ivano-Frankovsk Oblast, Lvov Oblast, Ternopol Oblast, Khmelnitsk Oblast and Chernovtsy Oblast) and the lowest values (257-303 mm) were characteristic of the southern and south-eastern Oblasts of Ukraine: The Crimea, Dnepropetrovsk Oblast, Donetsk Oblast, Zaporozhye Oblast, Lugansk Oblast, Nikolaev Oblast, Odessa Oblast, Kharkov Oblast and Kherson Oblast.

An example of ET distribution at maize growing is presented on Figure 4.9.

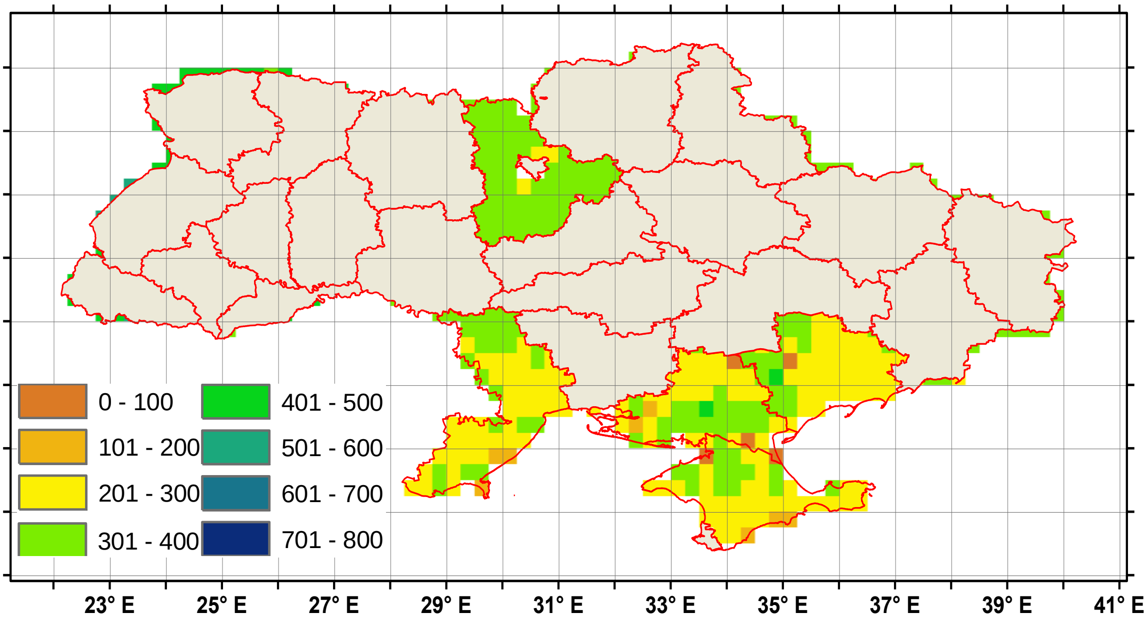


Figure 4.9. Simulated seasonal ET of maize (mm) in Ukraine in 2001

ET distribution for maize, as well as for winter wheat, is in direct dependence on the distribution of precipitation values in the territory of Ukraine (Figure 4.5): correlation coefficient is equal to 0,94 (P=99%); distribution of mean calculated irrigation depths in the acreage under maize for the period 2000-2010 (Figure 4.10) is in inverse dependence on precipitation distribution (Figure 4.5) (correlation coefficient -0,64, P=99%) and ET (correlation coefficient -0,63, P=99%).

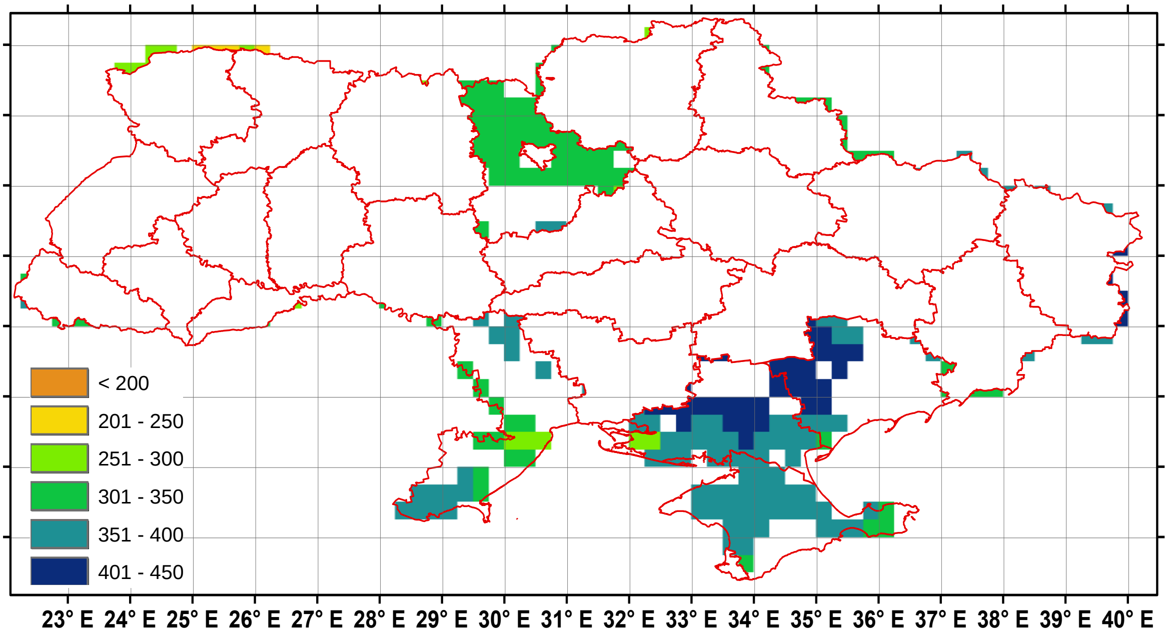


Figure 4.10. Distribution of irrigation mean values (mm) in the acreage under maize for the period 2000-2010

Comparison of mean irrigation values distribution and maize yields in the period 2000-2010 (Figures 4.10, 4.11, Table 4.8) shows that unlike winter wheat, precipitation and irrigation influence maize yields in Ukraine:

- correlation coefficient of irrigation depth and yield equals to -0,43 (P=95%) and -0,32 (P=90%) for simulated and statistical values of yields respectively;

- correlation coefficient of precipitation and yield is equal to 0,51 (P=95%) and 0,55 (P=90%) for simulated and statistical yields respectively.

Simulation of yields for the period 2009-2010 with input of fertilizers and irrigation depth as of 1990 has shown increase of maize yields all over the territory of Ukraine from 0 to 20 % (Annex 10, Figures 10.6, 10.8).

The highest mean values of maize yields fall on irrigated areas and the territories where rainfalls in vegetation period exceed 600 mm.

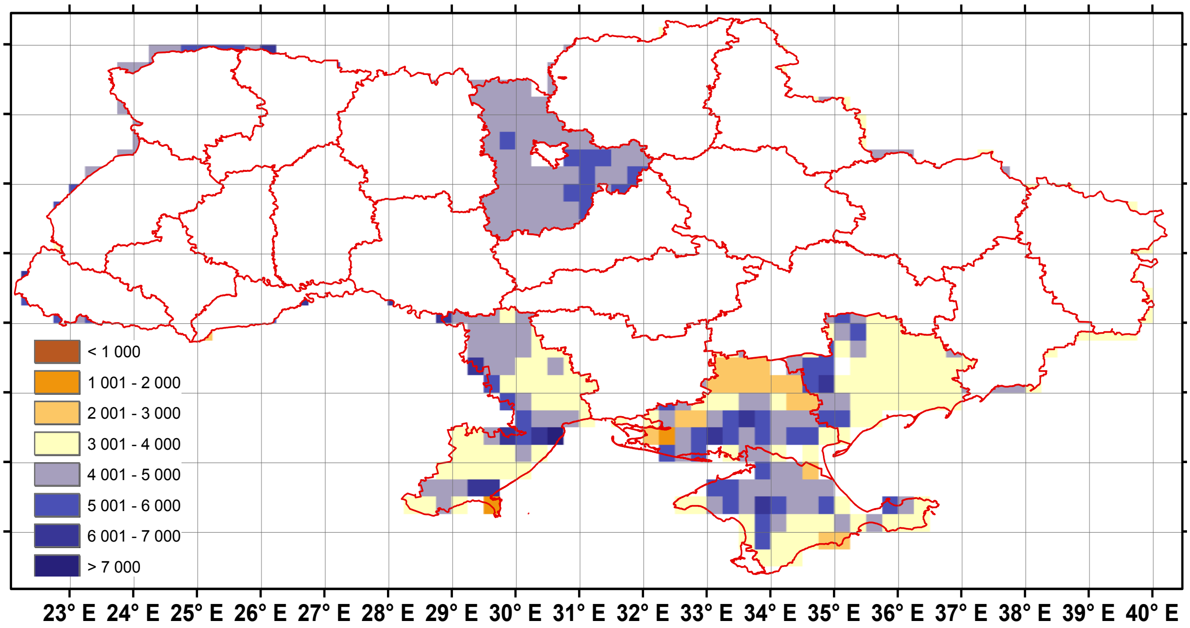


Figure 4.11. Distribution of maize yields mean values (kg/Ha) in the period 2000-2010

Calculated and statistical values for maize averaged for 11 years of simulation (2000-2010) are presented in Table 4.8.

Table 4.8. Averaged for Oblasts for the period 2000-2010 values of yields, ET and irrigation - calculated from simulation results and from statistical maize yields

Oblast	A- Statistical yields, kg/Ha	B-Yields calculated from simulation results, kg/Ha	100*(B-A)/B), %	ET, mm	Irrigation depth, mm	Precipitation, mm
AR Crimea	5120.9	4155.6	-18.9	256.3	252.8	423.1
Vinnitsa	4646.4	4994.7	7.5	363.1	148.9	566.9
Volyn	4601.8	4626.6	0.5	383.3	162.2	598.0
Dnepropetrovsk	3100.0	4129.2	33.2	297.9	236.1	463.0
Donetsk	2711.8	4146.6	52.9	291.3	320.1	490.0
Zhitomir	5197.3	4535.9	-12.7	364.2	189.8	627.2
Zakarpatye	4429.1	4249.5	-4.1	404.6	114.2	750.9
Zaporozhye	2228.2	3782.4	69.8	260.9	169.8	408.1
Ivano-Frankovsk	4092.7	4083.5	-0.2	405.8	143.3	682.7
Kiev	5273.6	4715.3	-10.6	342.9	214.3	575.4
Kirovograd	3880.9	4347.9	12.0	313.3	150.5	509.8
Lugansk	2275.5	3225.0	41.7	272.3	236.8	485.0
Lvov	4958.2	4594.7	-7.3	422.1	21.4	749.2
Nikolaev	2903.6	3912.2	34.7	284.1	223.4	461.1
Odessa	2746.4	4279.9	55.8	272.4	152.1	456.5
Poltava	4266.4	4728.0	10.8	331.0	122.2	560.1
Rovno	4302.7	4770.6	10.9	381.5	140.1	619.0

Sumy	3666.4	3925.7	7.1	321.8	186.0	571.0
Ternopol	4149.1	5385.9	29.8	418.3	179.0	644.3
Kharkov	3187.3	3893.5	22.2	303.0	159.2	525.4
Kherson	3959.1	3736.0	-5.6	257.9	280.8	376.4
Khmelnitsk	4779.1	5277.3	10.4	394.1	121.2	617.5
Cherkassy	5040.0	4604.1	-8.6	331.8	123.6	553.6
Chernigov	4636.4	4048.7	-12.7	319.7	258.2	589.1
Chernovtsy	4562.7	5121.4	12.2	379.0	196.4	604.0

1.3.3.3 Spring Barley

The results of ET simulation for spring barley in 2000-2010 have shown that the highest ET values (210-270 mm) in 2000-2010 were observed in the areas of Ukraine located within latitudinal interval 48-51,5ºN. At that, maximal values were pointed out for western regions: Volyn Oblast, Zakarpatye Oblast, Ivano-Frankovsk Oblast, Lvov Oblast, Ternopol Oblast and Khmelnitsk Oblast. The lowest ET values (160-200 mm) for the period 2000-2010 were characteristic of the southern Oblasts of Ukraine: The Crimea, Nikolaev Oblast, Odessa Oblast, Kharkov Oblast and Kherson Oblast. An example of ET distribution at growing spring barley is presented on Figure 4.12.

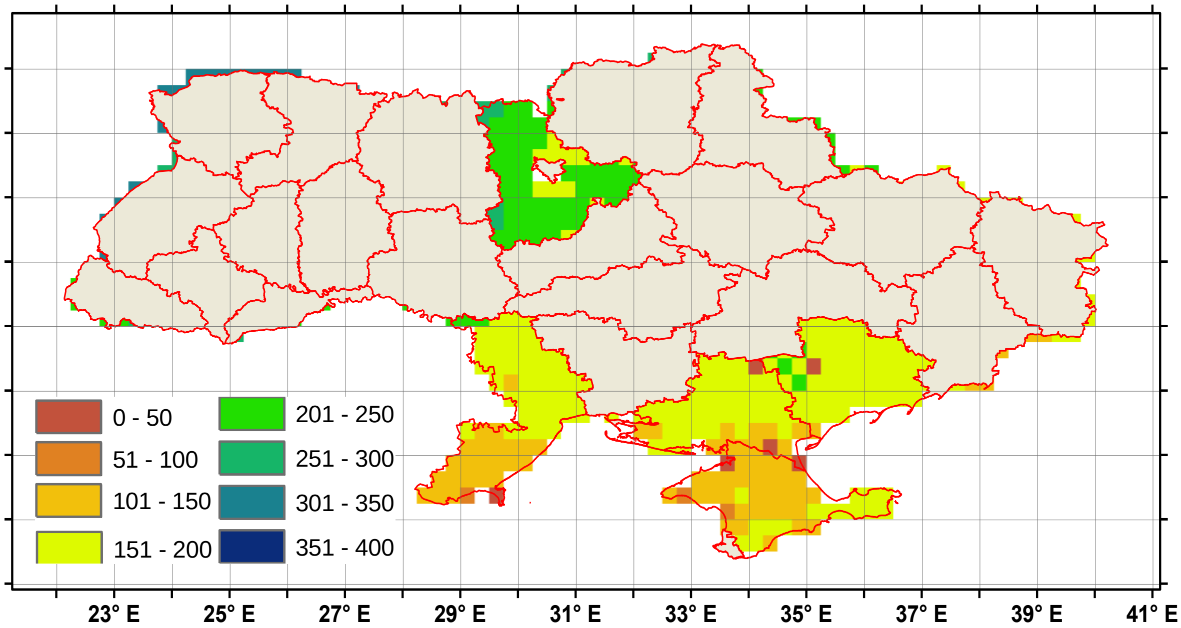


Figure 4.12. Simulated seasonal ET of spring barley (mm) in Ukraine in 2009

ET distribution is in direct dependence on the distribution of precipitation values in the territory of Ukraine (Figure 4.5): correlation coefficient is equal to 0,94 (P=99%); distribution of mean calculated irrigation depths in the acreage under spring barley for the period 2000-2010 (Figure 4.13) is in inverse dependence on precipitation distribution (Figure 4.15) (correlation coefficient -0,68, P=99%) and evapotranspiration (correlation coefficient -0,68, P=99%).

Good dependence of spring barley evapotranspiration on rainfall distribution is somewhat spoiled for the territories of Kiev Oblast, Chernigov Oblast and Sumy Oblast, where the ET values are lower than in the central Oblasts of Ukraine.

Mean irrigation values for the acreage under spring barley for the period 2000-2010 are presented on Figure 4.13.

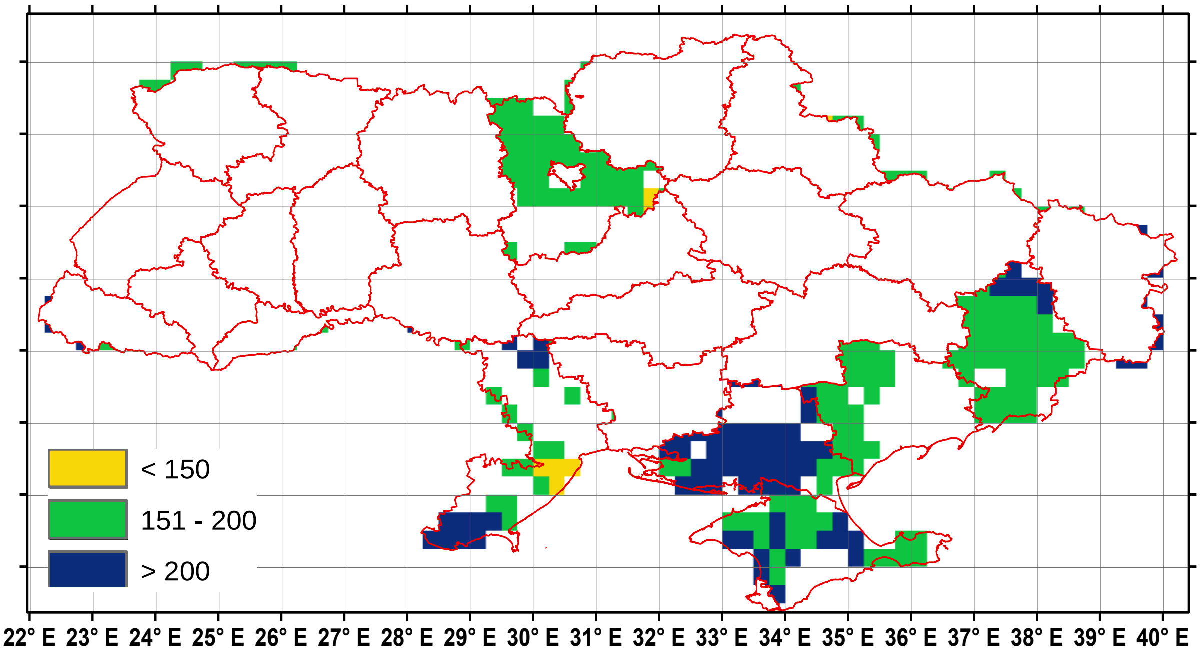


Figure 4.13. Distribution of irrigation mean values (mm) in the acreage under spring barley for the period 2000-2010

Comparison of mean irrigation values distribution and spring barley yields in the period 2000-2010 (Figures 4.13, 4.14, Table 4.9) gives negative correlation of these parameters: correlation coefficient is equal to -0,64 (P=99%) and -0,57 (P=99%) for simulated and statistical yields respectively.

Hence, in the territory of Ukraine irrigation does not produce significant influence on barley as it is a draught-resistant crop and rainfall gives enough water for its vegetation.

Simulation of yields for 2009-2010 with input of fertilizers and irrigation as of 1990 gives 0 – 20% increase of spring barley yields mainly for north-western Oblasts of Ukraine (Annex 10, Figures 10.10, 10.12).

The highest mean values of spring barley yields fall on irrigated areas and the territories where rainfalls in vegetation period exceed 600 mm, except for the northern regions (Volyn Oblast, Rovno Oblast, Zhitomir Oblast) and the northern parts of some Oblasts (Kiev, Chernigov and Sumy) where temperature conditions are less favourable for barley growing.

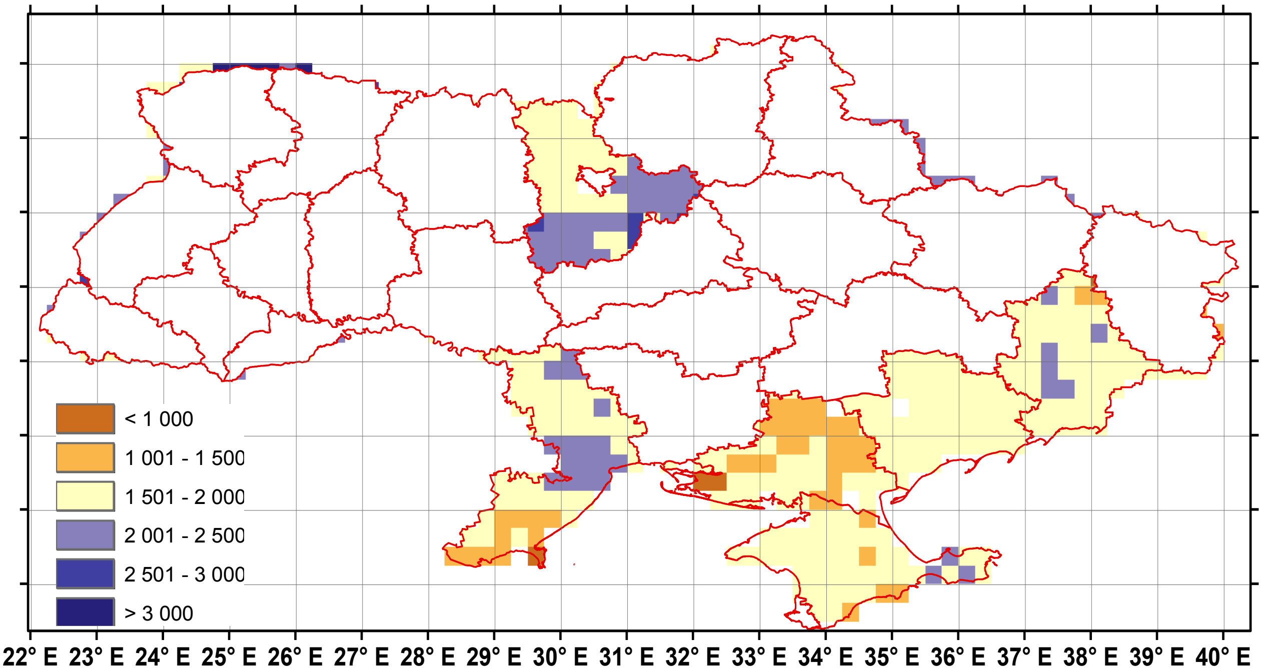


Figure 4.14. Distribution of spring barley yields mean values (kg/Ha) in the period 2000-2010

Calculated and statistical values for spring barley averaged for 11 years of simulation (2000-2010) are presented in Table 4.9.

Table 4.9. Averaged for Oblasts for the period 2000-2010 values of yields, ET and irrigation - calculated from simulation results and from statistical spring barley yields

Oblast	A- Statistical yields, kg/Ha	B-Yields calculated from simulation results, kg/Ha	100*(B-A)/B), %	ET, mm	Irrigation depth, mm	Precipitation, mm
AR Crimea	1968.2	1670.6	-15.1	176.4	136.3	423.1
Vinnitsa	2400.9	2225.2	-7.3	232.8	84.3	566.9
Volyn	2468.2	2208.5	-10.5	239.2	23.0	598.0
Dnepropetrovsk	2125.5	1842.4	-13.3	211.7	110.5	463.0
Donetsk	1843.6	1877.0	1.8	212.0	158.5	490.0
Zhitomir	2311.8	1998.6	-13.6	228.3	64.8	627.2
Zakarpatye	2658.2	2298.9	-13.5	258.5	69.0	750.9
Zaporozhye	1776.4	1712.0	-3.6	189.9	83.1	408.1
Ivano-Frankovsk	2506.4	2431.7	-3.0	266.0	12.1	682.7
Kiev	2858.2	2087.1	-27.0	226.0	120.4	575.4
Kirovograd	2282.7	2018.6	-11.6	214.8	73.8	509.8
Lugansk	1569.1	1602.9	2.2	201.9	125.7	485.0
Lvov	2358.2	2341.4	-0.7	264.2	9.8	749.2
Nikolaev	1984.5	1769.5	-10.8	197.9	112.5	461.1
Odessa	2229.1	1838.5	-17.5	190.3	82.0	456.5
Poltava	2356.4	2310.2	-2.0	235.7	57.9	560.1
Rovno	2445.5	2136.5	-12.6	234.3	12.0	619.0

Sumy	2220.0	2143.6	-3.4	226.2	90.8	571.0
Ternopol	2247.3	2683.4	19.4	258.0	80.6	644.3
Kharkov	2198.2	2003.4	-8.9	220.2	82.0	525.4
Kherson	1836.4	1385.5	-24.6	166.8	148.7	376.4
Khmelnitsk	2330.9	2359.3	1.2	240.7	52.3	617.5
Cherkassy	2710.9	2124.4	-21.6	223.4	61.8	553.6
Chernigov	2312.7	1920.2	-17.0	214.3	62.8	589.1
Chernovtsy	2188.2	2151.0	-1.7	231.5	120.5	604.0

1.3.3.4 Sunflower

The results of ET simulation for sunflower in 2000-2010 have shown that the highest ET values (300-420 mm) in 2000-2010 were observed in the western and northern areas of Ukraine: Vinnitsa Oblast, Volyn Oblast, Zhitomir Oblast, Zakarpatye Oblast, Ivano-Frankovsk Oblast, Kiev Oblast, Lvov Oblast, Poltava Oblast, Rovno Oblast, Sumy Oblast, Ternopol Oblast, Khmelnitsk Oblast, Cherkasy Oblast, Chernigov Oblast and Chernovtsy Oblast and the lowest ET values (297-265 mm) were characteristic of the southern and eastern regions of Ukraine: The Crimea, Dnepropetrovsk, Donetsk, Zaporozhye, Lugansk, Nikolaev, Odessa, Kharkov and Kherson Oblasts. An example of ET distribution at growing sunflower is presented on Figure 4.15.

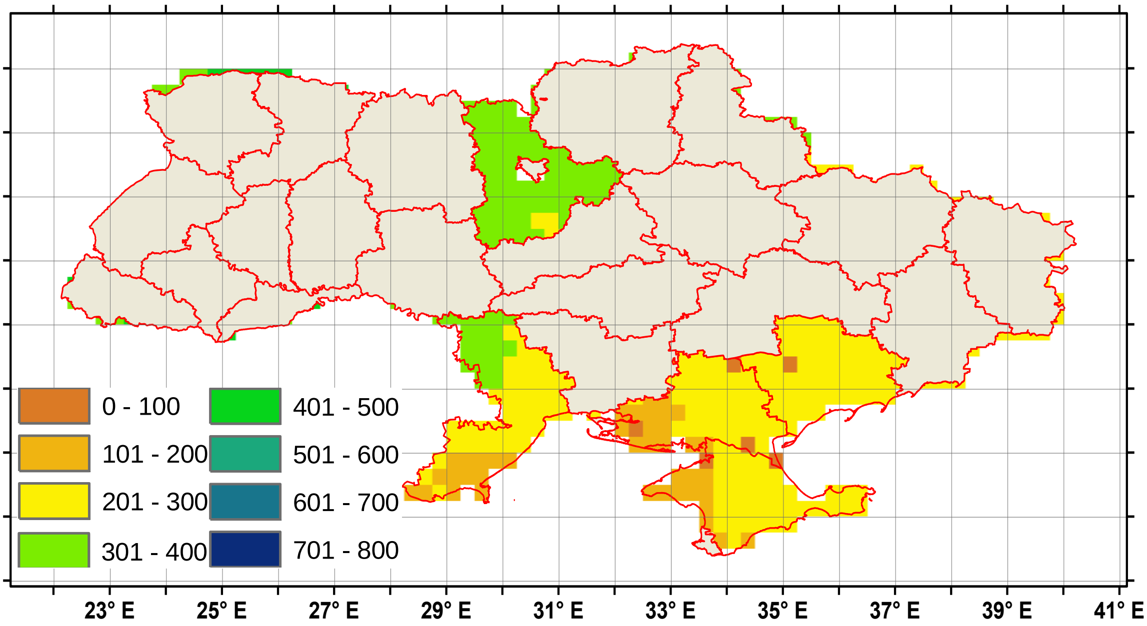


Figure 4.15. Simulated seasonal ET of sunflower (mm) in Ukraine in 2006

ET distribution for sunflower, as for winter wheat, is in direct dependence on the distribution of precipitation values in the territory of Ukraine (Figure 4.5): correlation coefficient is equal to 0,95 (P=99%); distribution of mean calculated irrigation depths in the acreage under sunflower for the period 2000-2010 (Figure 4.16) is in inverse dependence on precipitation distribution (Figure 4.5) (correlation coefficient -0,85, P=99%) and evapotranspiration (correlation coefficient -0,86, P=99%).

Good dependence of sunflower evapotranspiration on rainfall distribution is somewhat spoiled for the territories of Kiev Oblast, Chernigov Oblast and Sumy Oblast, where the ET values are lower than in the central Oblasts of Ukraine.

Mean irrigation values for the acreage under sunflower for the period 2000-2010 are presented on Figure 4.16.

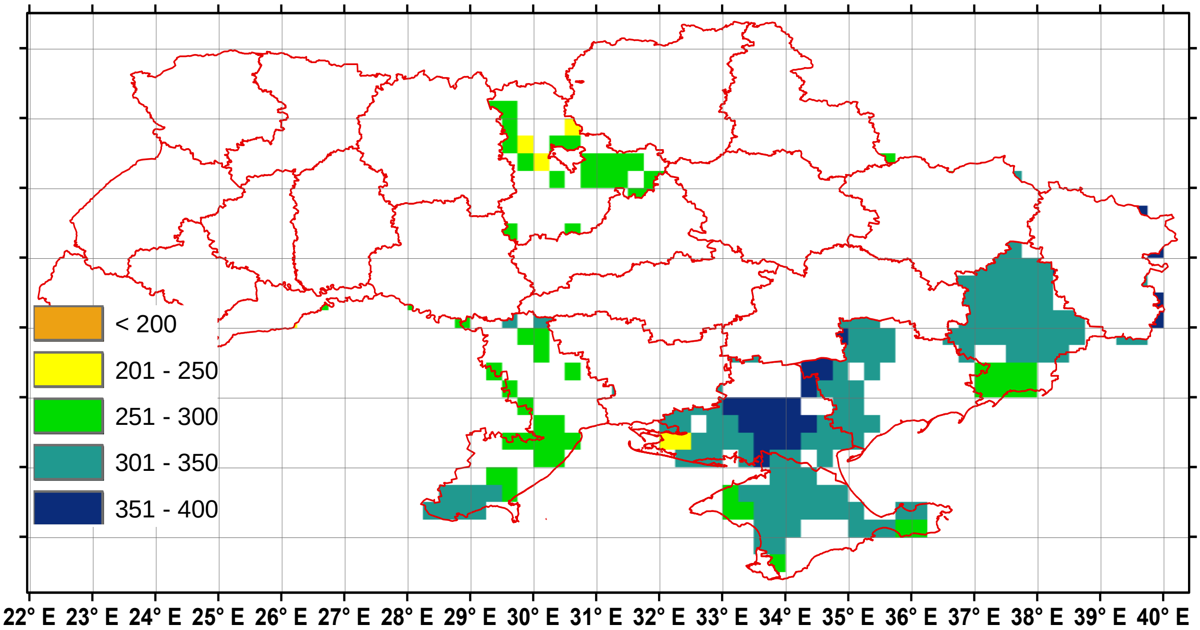


Figure 4.16. Distribution of irrigation mean values (mm) in the acreage under sunflower for the period 2000-2010

Comparison of mean irrigation values distribution and sunflower yields in the period 2000-2010 (Figures 4.16, 4.17, Table 4.10) has shown that in Ukraine both rainfall and irrigation are important for yields. At that, according to model calculations the dependence of sunflower yields on irrigation and precipitation appeared to be on the level of correlation coefficient -0,74; 0,69 (P=99 %), respectively, and according to statistical data on yields this connection was much weaker: -0,13; 0,21 respectively (insignificant coefficients).

Simulation of yields for 2009-2010 with input of fertilizers and irrigation as of 1990 gives increase of sunflower yield almost all over Ukraine. The level of this increase, as it has already been mentioned under 4.2.4., is different for the different regions of Ukraine (Annex 10, Figures 10.14, 10.16). For the central, southern and eastern Oblasts of Ukraine the increase was generally about 10 %, for the north-western Oblasts and the central part of Odessa Oblast – 10-50 % and more. This scheme was characteristic of both 2009 and 2010.

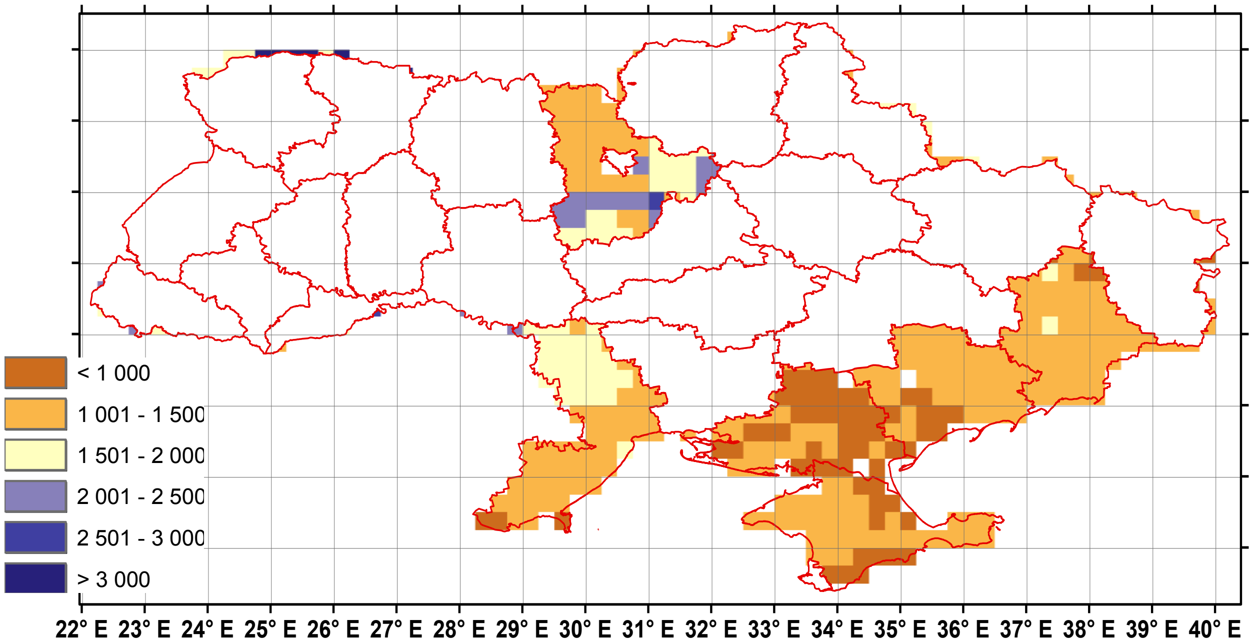


Figure 4.17. Distribution of sunflower yields mean values (kg/Ha) in the period 2000-2010

The highest mean values of sunflower yields, the same as spring barley, fall on the territories where rainfalls in vegetation period exceed 600 mm, except for the northern regions (Volyn Oblast, Rovno Oblast, Zhitomir Oblast) and the northern parts of some Oblasts (Kiev, Chernigov and Sumy) where temperature conditions are less favourable for sunflower growing. Besides, the five western Oblasts of Ukraine, enumerated in Table 4.10, where acreage under sunflower is insignificant, make an exception from this rule.

Calculated and statistical values for sunflower averaged for 11 years of simulation (2000-2010) are presented in Table 4.10.

Table 4.10. Averaged for Oblasts for the period 2000-2010 values of yields, ET and irrigation - calculated from simulation results and from statistical sunflower yields

Oblast	A- Statistical yields, kg/Ha	B-Yields calculated from simulation results, kg/Ha	100*(B-A)/B), %	ET, mm	Irrigation depth, mm	Precipitation, mm
AR Crimea	778.2	1077.9	38.5	210.0	216.3	423.1
Vinnitsa	1380.9	2085.9	51.1	334.2	110.8	566.9
Volyn	1205.5	2471.8	105.1	368.1	0.0	598.0
Dnepropetrovsk	1294.5	1350.4	4.3	264.6	194.4	463.0
Donetsk	1365.5	1370.2	0.3	259.0	276.0	490.0
Zhitomir	1130.0	1758.7	55.6	338.3	8.4	627.2
Zakarpatye	1150.0	1887.1	64.1	387.8	0.0	750.9
Zaporozhye	1204.5	1090.4	-9.5	225.5	141.1	408.1
Ivano-Frankovsk	1190.9	1994.7	67.5	402.4	0.0	682.7
Kiev	1441.8	1641.9	13.9	310.7	92.2	575.4
Kirovograd	1365.5	1751.6	28.3	293.5	108.3	509.8
Lugansk	1102.7	1055.8	-4.3	248.6	196.3	485.0
Lvov	1252.2	1789.6	42.9	420.5	0.0	749.2
Nikolaev	1118.2	1276.7	14.2	252.5	181.0	461.1
Odessa	1115.5	1374.1	23.2	243.4	127.3	456.5
Poltava	1573.6	1914.9	21.7	311.2	95.2	560.1
Rovno	1525.5	2854.5	87.1	383.7	0.0	619.0

Sumy	1146.4	1622.2	41.5	303.4	56.9	571.0
Ternopol	1092.7	2745.4	151.2	398.6	0.0	644.3
Kharkov	1416.4	1445.7	2.1	283.2	111.7	525.4
Kherson	860.9	891.0	3.5	197.9	240.5	376.4
Khmelnitsk	993.6	2414.6	143.0	368.0	0.0	617.5
Cherkassy	1566.4	1729.0	10.4	305.7	105.0	553.6
Chernigov	1106.4	1479.5	33.7	301.4	4.3	589.1
Chernovtsy	1162.7	2151.9	85.1	356.1	103.4	604.0

* - Oblasts, which have insignificant or no acreage under sunflower according to MIRCA2000

1.3.3.5 Conclusions

Evapotranspiration is very important for assessment of irrigation need and efficiency growing this or that crop. This parameter is especially effective to forecast economic input into crop growing under different climate conditions.

Model experiments using GEPIC for the territory of Ukraine for the period 2000-2010 have produced maps of ET distribution. Their analysis enabled us to conclude the following:

1. Significant interrelation is observed between the ET and atmospheric precipitation distribution over the territory of Ukraine.

2. Maximal ET values among the four crops considered applied to winter wheat (up to 440 mm), while minimal (up to 160 mm) applied to spring barley.

3. Model experiments have shown that input of fertilizers combined with irrigation on the level of the year 1990 could give significant (up to 50%) increase in yields of winter wheat, maize, barley and sunflower in Ukraine.

4. Spring barley and sunflower highest yields fall on the areas where precipitation exceeds 600 mm, except for the northern Oblasts of Ukraine.

5. Distribution of precipitation and irrigation in Ukraine influences yields of maize significantly: the highest mean values of maize yields fall on irrigated areas and the regions where precipitation during vegetation period exceeds 600 mm.

1.4 STATE AND PROSPECTS OF CROPS PRODUCTION AND EXPORTS IN UKRAINE

Historically, Ukraine is agricultural country. 60% of Ukrainian territory is occupied by unique soils - chernozems. At that, more than 40% of all agricultural products in Ukraine are grown without using pesticides, as the resultkrainian agricultural products are environmentally cleanest in Europe.

Portion of Ukrainian agriculture in the world volumes is shown in table 5.1. Ukraine produces 25% of sunflower oil in the world and occupies the 2nd place in the world for the production of sunflower oil.

Table 5.1. Portion of Ukrainian agriculture in the world volumes (Panorama of Ukraine Agrarian sector 2009)

Production	Indices, %
Grain	2,1
Sugar beet	5,9
Sunflower	18,3
Potato	6,2
Meat of all types (in slaughter weight)	0,7
Milk	1,7
Eggs	1,3

Ukraine is a leader in Europe on growing sugar beet, buckwheat and carrot and ranks second in Europe for the cultivation of wheat and tomato. Agricultural sector employs 28% of the total working population of Ukraine.

Climatic conditions in Ukraine are optimal for cultivation of winter and spring crops. Of the 60 million hectares of land about 42 million is arable land, which includes grain and technical crops, vegetables, orchards, vineyards, etc.

Since independence, Ukraine is constantly increasing exports of agricultural products produced. In 1998 its exports reached to the highest in the last 20 years amount of sugar, beef, sunflower seeds, and fish. Total value of agricultural exports was estimated at $ 1.898 billion. However, due to the protracted process in Ukraine the efficiency of agricultural productionand productivity in the agricultural sector has decreased, as many small farmers do not have enough money to buy new equipment and are using the old machines and technology with low productivity. The use of old machinery andtechnology leads to increased pollution and unsustainable use of land. Therefore, the present state of agriculture in Ukraine can be classified as unstable.

The absence of effective national strategy of agricultural development and the global financial crisis have led to the fact that the number of unprofitable enterprises currently stands at 87.4% of the total. Only the production of cereals, legumes and commercial crops such as sunflower is economically advantageous. All other crop and livestock sectors are currently unprofitable (Agriculture 2011). That is why the development of the production of grain crops, such as wheat, barley and corn; and technical, such as sunflower, are currently most important for the development of Ukrainian agrosector.

1.4.1 Production of main grain crops in Ukraine

Grain production in Ukraine, which is approaching pre-transition levels, is main background for the overall stabilization of agricultural output in Ukraine. Since the break-up of the Soviet Union in 1991, there has been a dramatic decline in the level of agriculture output in Ukraine (Figure 5.1). Annual grain production, which had been relatively stable at about 47 million tonnes in the period 1986–1990, halved to just 22–25 million tonnes during the period 2000–2004. Many agricultural producers were forced into subsistence farming due to the decreasing budget and financial resources for agricultural investments, hyperinflation (including rising input prices1), and the loss of traditional export markets in the Commonwealth of Independent States (CIS). More than fifteen years into the transition, the agricultural output level in Ukraine has gradually stabilized as macroeconomic conditions improved, capital investments picked up again, and a series of market reforms were implemented. During the period 2000–2006, annual grain production rose to 35–36 million tonnes. Nonetheless, total agricultural output remains below its pre-transition level as many structural constraints persist (EBRD 2010).

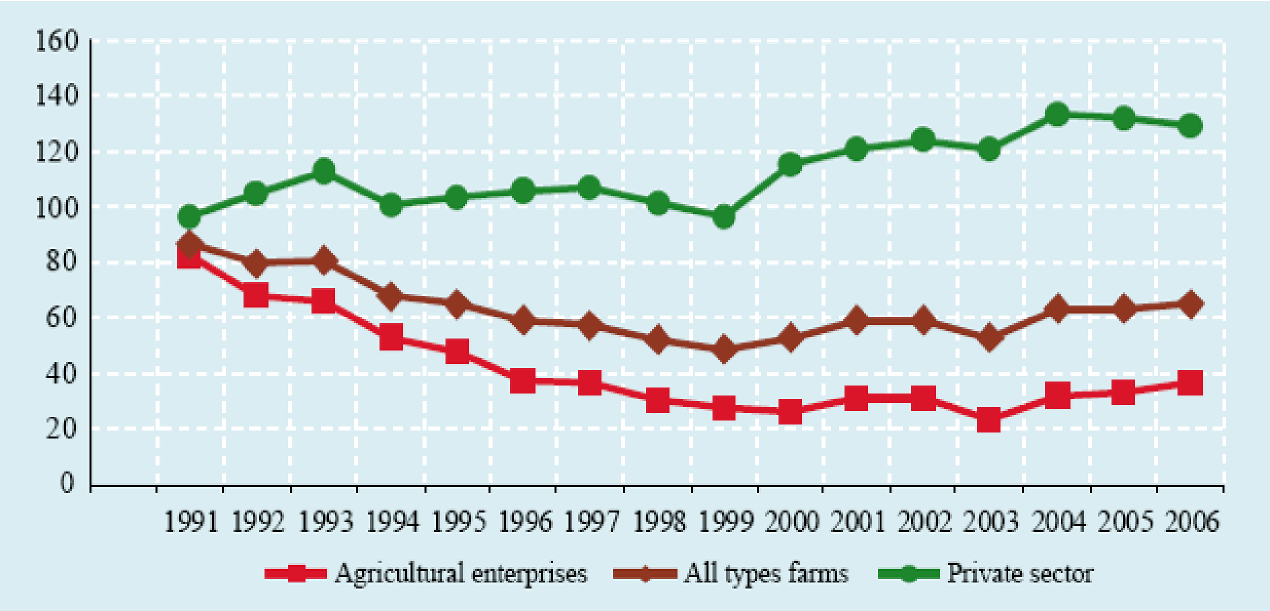


Figure 5.1. Trends in agricultural output (1990 = 100%) (%) (EBRD 2010).

The largest sown area and harvested area (grain and leguminous crops) was in 2008 and 2009 (Table 5.2). The lagest production and yield in Ukraine after break-up of the Soviet Union was in 2008. In 2008, rapeseed, wheat and maize showed the greatest increases in sown areas in response to high prices. The acreage expansion took place chiefly at the expense of barley and sugar beet (Table 5.2).

Table 5.2. Grain and leguminous crops 1990–2010 (EBRD 2010; Agriculture of Ukraine 2008; Agriculture of Ukraine 2009; Agriculture of Ukraine 2010).

Grain and leguminous crops	1990	1995	2000	2004	2005	2006	2007	2008	2009	2010
All sown area, thousands hectares	14583	14152	13646	15433	15005	14515	15115	15636	15837,3	15090
Production, thousands tons	51009	33929,8	24459	41808,8	38015,5	34258,3	29294,9	53290,1	46028,3	39270,9
Yield, centners per hectare of the harvested area	35,1	24,3	19,4	28,3	26,0	24,1	21,8	34,6	29,8	26,9
Harvested area, thousands hectares	14522,2	13962,5	12586,8	14776,0	14605,2	14191,6	13427,9	15380,7	15469,7	14575,7

Rapeseed has recently joined sunflower seed as a preferred crop (Figures 5.2). In 1990, only an estimated 90,000 ha of rapeseed were planted in Ukraine. The area under rapeseed started increasing in 2005 and reached 390,000 ha in 2006. Rapeseed now appears to be a strong choice in planting decisions due to strong demand from the countries of the European Union (EU). The area planted with rapeseed reached 1.4 million ha in 2008. The total area sown with oilseeds now exceeds 30% of Ukraine's arable area (EBRD 2010).

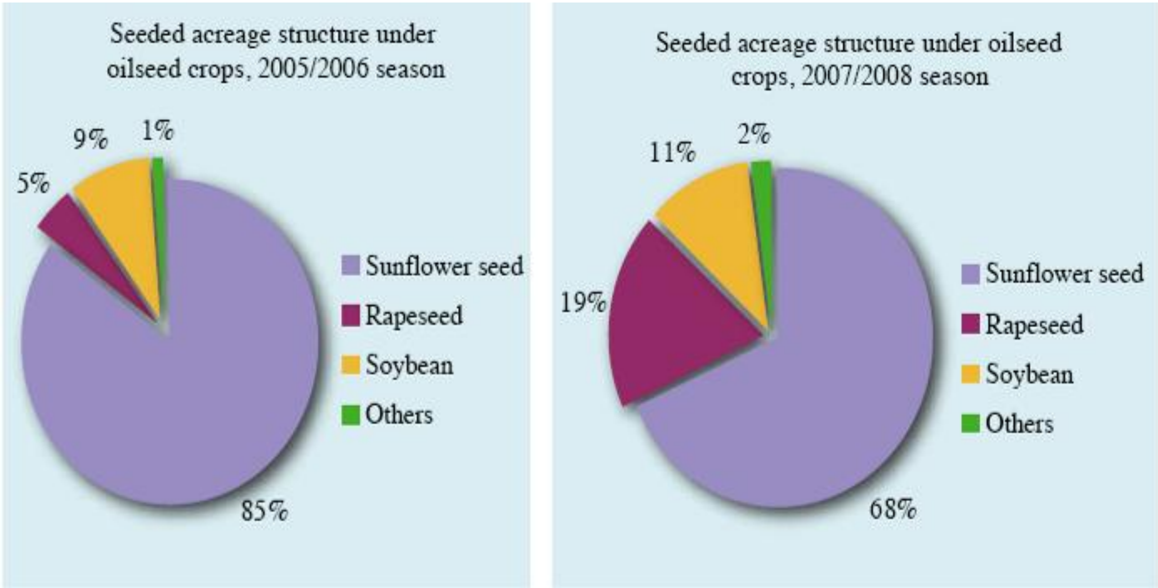
Cropping patterns in Ukraine seem to be strongly determined by crop margins. Technically, rapeseed is at present Ukraine's most profitable crop. In the period 2004–2007, its gross margins averaged USD 550/ha (for large-scale farms). The margins for other crops ranged between USD 56/ha (for rye) and USD 432/ha (for wheat). However, its margins are currently inflated due to relatively low input costs. The official estimates of sunflower seed profitability (measured as percentage of net income over total costs) averaged 54% from 2000 to 2007 and was a near-record 75% in 2007 as compared with much lower returns on grains and sugar beet (Figure 5.3). This was largely due to low input costs (Figures 5.4 and 5.5) and high sunflower seed prices (EBRD 2010).

Sown area under wheat was the biggest since 1995 in 2008 and occupied 6802 thousands hectares, under barley – the biggest sown area since 1990 in 2007 was 4417 thousands hectares, under maize for grain – since 1990 the biggest sown area in 2010 was 6.511 thousands hectares, under sunflower - since 1990 the biggest sown area also in 2010 was 4572 thousands hectares (Table 5.3).

Table 5.3. Structure of sown area under main agriculture crops, 1990–2010 ('000 ha) (Agriculture of Ukraine 2008; Agriculture of Ukraine 2009; Agriculture of Ukraine 2010).

Crops	Years									
	1990	1995	2000	2004	2005	2006	2007	2008	2009	2010
All sown area	32406	30963	27173	26752	26044	25928	26060	27133	26990	26952
Grain and leguminous crops:	14583	14152	13646	15433	15005	14515	15115	15636	15837	15090
winter grain	8614	6310	6324	6397	7289	5884	6725	8127	8308	7904
including										
wheat	7568	5324	5316	5139	6185	5089	5817	6802	6518	6137
rye	518	609	668	737	622	373	349	466	468	286
barley	528	377	340	521	482	422	559	859	1322	1481
spring grain and leguminous	5969	7842	7322	9036	7716	8631	8390	7509	7529	7186
including										
wheat	9	185	303	535	480	494	471	314	334	314
barley	2201	4130	3645	4157	4018	4883	4417	3360	3800	3024
oats	492	570	521	538	468	474	404	456	433	326
maize for grain	1234	1174	1364	2467	1711	1777	2087	2516	2149	2709
millet	205	167	437	434	141	136	122	153	119	95
buckwheat	350	459	574	439	426	398	352	302	273	225
rice	28	22	26	21	21	22	21	20	25	29
leguminous	1424	1103	408	387	422	406	438	263	371	429
of which										
pea	1287	996	307	270	326	339	362	206	286	305
vetch and vetch mixtures for grain	79	65	54	54	44	29	30	19	28	32
Industrial crops	3751	3748	4187	4971	5260	6105	5920	6778	6545	7296
including										
sugar beet (factory)	1607	1475	856	732	652	815	610	380	322	501
sunflower	1636	2020	2943	3521	3743	3964	3604	4306	4232	4572
soya	93	25	65	274	438	751	671	558	644	1076
rape	90	49	214	117	207	414	891	1412	1060	907
flax fibre	172	98	23	38	25	14	13	7	2	1
Potatoes, vegetables and cucurbitaceae	2073	2165	2277	2105	2041	2031	1997	1967	1950	1967

Crops	Years									
	1990	1995	2000	2004	2005	2006	2007	2008	2009	2010
crops										
including										
potatoes	1429	1532	1629	1556	1514	1464	1453	1413	1409	1408
vegetables grown in the open (without plants transplanted for seeds)	456	503	538	476	465	469	451	458	451	462
Fodder crops	11999	10898	7063	4243	3738	3277	3028	2752	2658	2599
including										
feed root crops (including sugarbeet for fodder)	624	480	285	299	294	277	275	259	247	244
maize for silage, green feed	4637	3475	1920	1015	774	675	629	518	485	473
annual grasses (including winter crops for green feed)	2583	2879	1765	990	891	717	614	567	585	583
perennial grasses sown in previous years	3986	3906	2985	1855	1702	1549	1459	1357	1289	1238
Area of pure fallow	1427	1570	3213	2330	2428	1866	1625	1413	1523	1465



Figures 5.2. Grains in productivity of rapeseed and other oilseeds, 2005–2008 (%) (EBRD 2010)

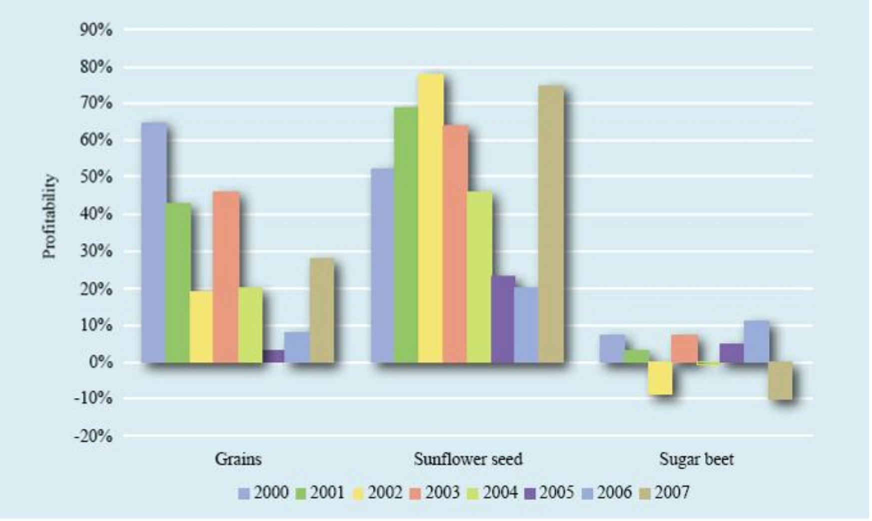


Figure 5.3. Profitability of grains, sunflower seed and sugar beet (%).Source: LMC International with data from the State Statistical Committee of Ukraine (EBRD 2010)

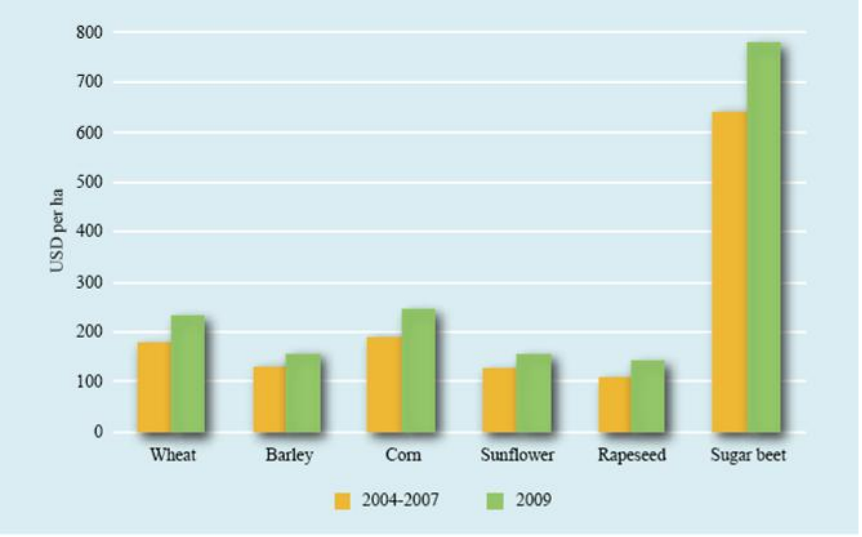


Figure 5.4. Direct crop input costs for large-scale agricultural enterprises (EBRD 2010)

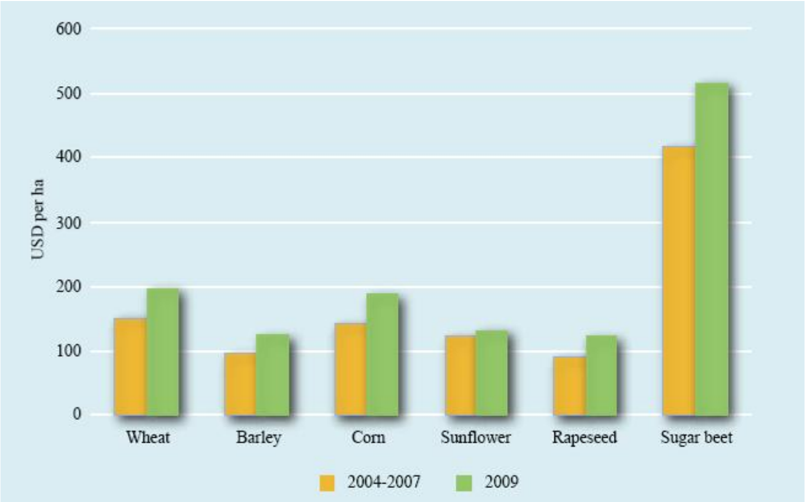


Figure 5.5. Direct crop input costs for small-scale agricultural enterprises (EBRD 2010)

1.4.1.1 Wheat

Main grain crop in Ukraine is winter wheat accounting for nearly 20% of sown area. It provides up to 50% of the gross grain harvest in the country. The main winter wheat growing areas -forest-steppe and steppe zones and partly Polesie (Figures 5.6, 5.7). A lot of new high yielding varieties of winter wheat have been selected in Ukraine, also recognized outside of the country. Spring wheat has lower yield than winter one. Therefore, it is less common (All-Biz no date). Wheat is grown throughout the country, but Ukraine is the key production zones. About 95 percent of Ukrainian wheat is winter wheat, planted in autumn and harvested during July and August of the following year. On the average, approximately 15 percent of fall-planted crops fail to survive the winter. The amount of winterkill varies widely from year to year, from 2 percent in 1990 to a staggering 65 percent in 2003, when a persistent ice crust smothered the crop. Wheat yield declined during the 1990's following the breakup of the Soviet Union and the loss of heavy State subsidies for agriculture. Farms struggled with cash shortages, and the use of fertilizer and plant-protection chemicals plummeted. Due to a combination of favorable weather and a modest but steady improvement in the financial condition of many farms, wheat production has rebounded in recent years (except for the disastrous 2003/04 crop which fell victim to unusually severe winter weather). Ukraine produces chiefly hard red winter wheat (bread wheat), and in a typical year roughly 80 percent of domestic wheat output is considered milling quality, by Ukrainian standards. Feed consumption of wheat dropped sharply during the 1990's, from over 12 million tons to less than 5 million. Meanwhile, food consumption has remained steady at around 10 million tons (Ukraine 2004).

Wheat production volumes have varied significantly. Wheat produced in Ukraine has traditionally been used for milling and feeding purposes. Importantly, the government does not seem to stimulate the growing of milling-quality grain. In fact, wheat quality standards are often adjusted so as to consider relatively poor-quality wheat as milling wheat at the time of purchase from farmers. The smallest harvest area and yield (5161,6 thousands ha and 19.8 centners per hectare of the harvested area) in more than 45 years was produced in MY 2003/2004 (Table 5.4) (Agriculture of Ukraine 2008; Agriculture of Ukraine 2009; Agriculture of Ukraine 2010). In 2008 after 1990 wheat production reached 25885,4 thousands tonnes – the highest official estimate since the 1991 – due to increased area and favourable weather conditions. By comparison, the country's largest crop was 30373,7 thousands tonnes, produced in 1990/1991 – just prior to the break-up of the Soviet Union (Agriculture of Ukraine 2008; Agriculture of Ukraine 2009; Agriculture of Ukraine 2010; EBRD 2010).

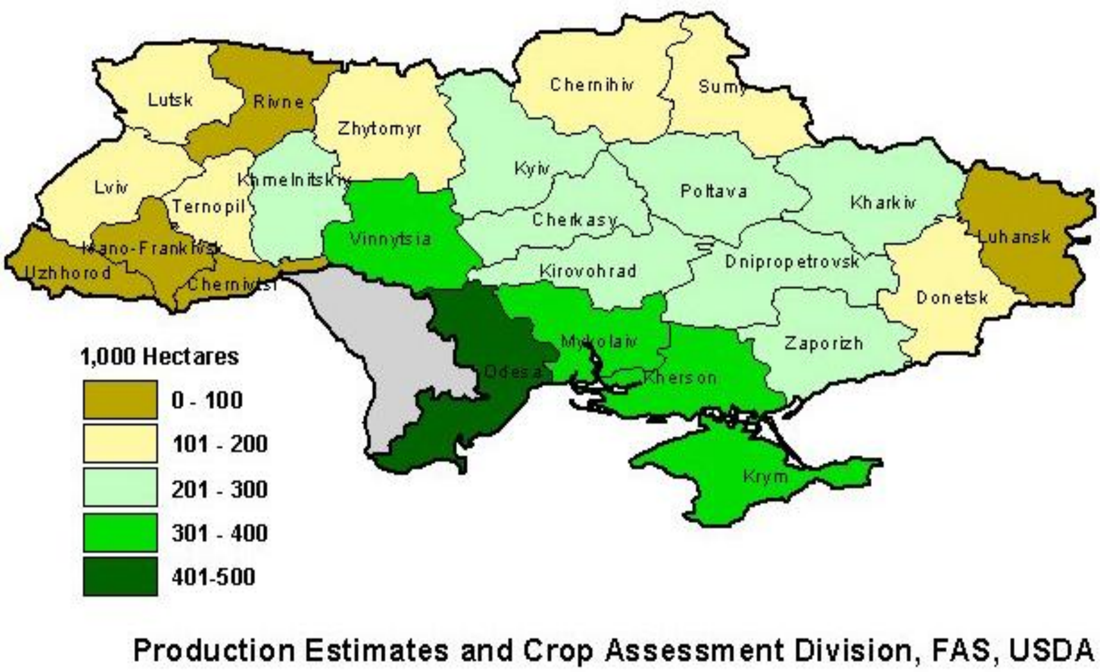


Figure 5.6. Estimated Whinter Wheat Area by Oblast (Ukraine 2004)

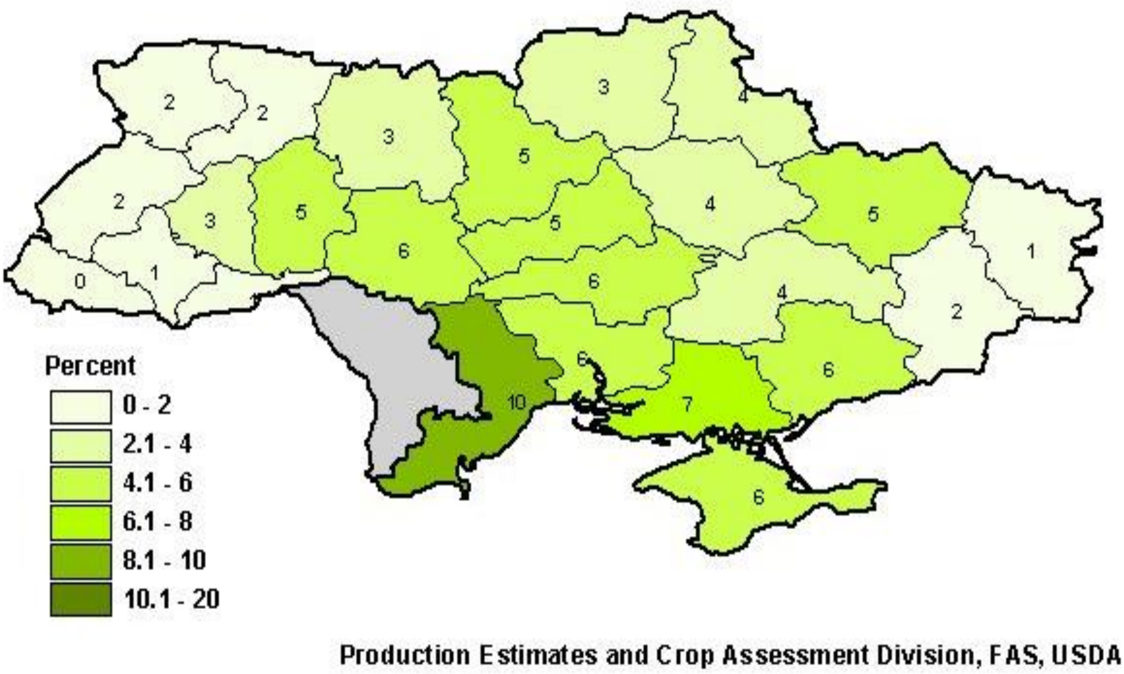


Figure 5.7. Percent of total winter wheat area by Oblast (Ukraine 2004)

Table 5.4. Wheat, 1990–2010 (Agriculture of Ukraine 2008; Agriculture of Ukraine 2009; Agriculture of Ukraine 2010).

Years	Production of wheat, thousands tons	Yield of wheat, centers per hectare of the harvested area	Harvested area of wheat, thousands hectares
1990	30373,7	40,2	7557,7
1995	16273,3	29,7	5479,4
2000	10197,0	19,8	5161,6
2004	17520,2	31,7	5533,7
2005	18699,2	28,5	6571,0
2006	13947,3	25,3	5511,0

2007	13937,7	23,4	5951,3
2008	25885,4	36,7	7053,6
2009	20886,4	30,9	6752,9
2010	16851,3	26,8	6284,1

1.4.1.2 Barley

Barley is spring grain crop, the second after winter wheat in size of sown area and gross harvest of grain (20%). Barley has been the top feed grain in Ukraine for most of the past ten years in terms of consumption, surpassing wheat in the early 1990's. Spring barley accounts for over 90 percent of barley area, and the main production region is eastern Ukraine (Figure 5.8, 5.9). Spring barley is typically planted in April and harvested in August, and is the crop most frequently used for spring reseeding of damaged or destroyed winter-grain fields. Area is inversely related, to some degree, to winter wheat area. Winter barley is the least cold-tolerant of the winter grains, and production is limited to the extreme south. Consumption of barley for malting purposes has surpassed 300,000 tons, but still accounts for only 5 percent of total barley consumption (Ukraine 2004).

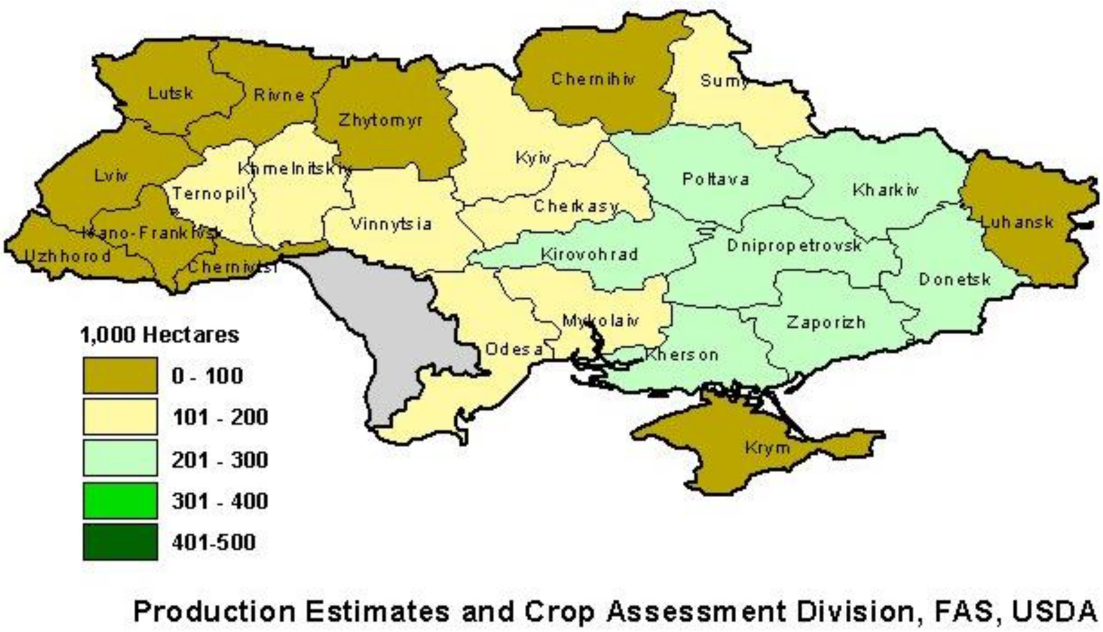


Figure 5.8. Estimated spring barley area by Oblast (Ukraine 2004)

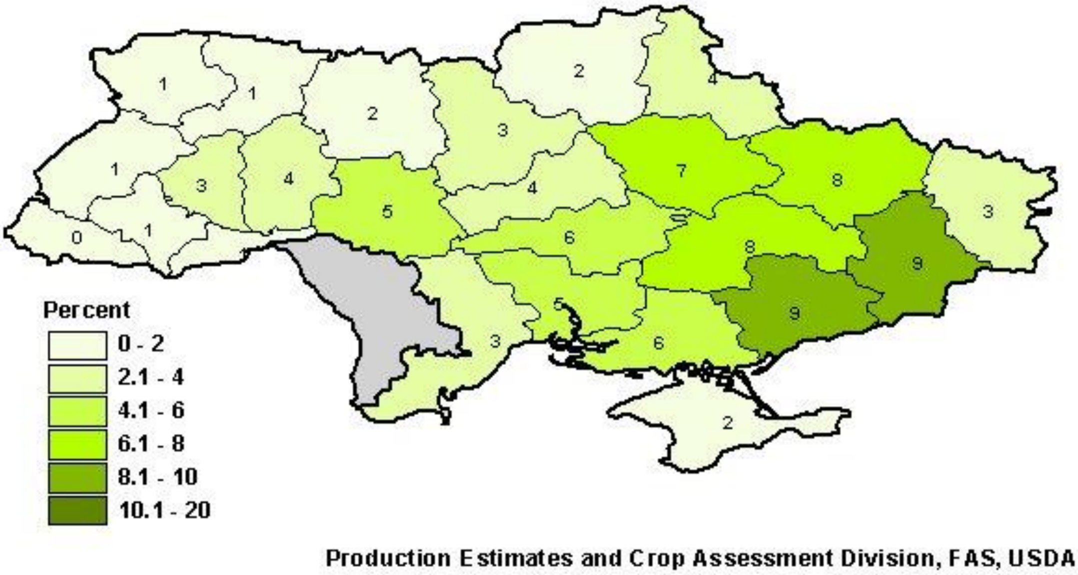


Figure 5.9. Percent of total spring barley area by Oblast (Ukraine 2004)

Barley production has also varied significantly. Barley is the principal grain used for spring reseeding of damaged or destroyed winter-crop fields (including winter wheat, as well as winter barley and rapeseed). On average, 90% of Ukraine's barley production is accounted for by the spring-sown crop. The area sown with spring barley typically fluctuates in response to the level of winter wheat that is sown in the autumn and the amount of winter wheat that suffers winter kill. Barley has recently competed for area in spring with maize and oilseeds, as gross margin for these crops have been strong. In 2007 drought and excessive heat drove the barley yield to 14,6 per centners hectare of the harvest area (Table 5.5), its lowest level since 1963. In contrast, barley yields in 2008 is 30,3 per centners hectare of the harvest area. These were record-high levels after 1990 – the yield were 33,8 per centners hectare of the harvest area (Agriculture of Ukraine 2008; Agriculture of Ukraine 2009; Agriculture of Ukraine 2010; EBRD 2010).

Table 5.5. Barley, 1990–2010 (Agriculture of Ukraine 2008; Agriculture of Ukraine 2009; Agriculture of Ukraine 2010)

Years	Production of barley, thousands tons	Yield of barley, centners par hectare of the harvested area	Harvested area of barley, thousands hectares
1990	9168,9	33,8	2712,0
1995	9633,2	21,8	4413,2
2000	6871,9	18,6	3689,1
2004	11084,4	24,6	4514,7
2005	8975,1	20,6	4350,4
2006	11341,2	21,7	5236,2
2007	5980,8	14,6	4088,4
2008	12611,5	30,3	4167,2
2009	11833,1	23,7	4993,5
2010	8484,9	19,7	4316,9

1.4.1.3 Maize

Maize is the third important feed grain in Ukraine. Planted area has increased despite several impediments: obsolete and inadequate harvesting equipment, high cost of production (specifically post-harvest drying expenses), and pilferage. The main production region is eastern and southern Ukraine (Figure 5.10), although precipitation amounts in some oblasts in the extreme south are too low to support maize production. Maize is typically planted in late April or early May. Harvest begins in late September and is usually nearing completion by early November. Only 25 to 50 percent of total maize area is harvested for grain; the rest is cut for silage, usually in August (Ukraine 2004). The USDA maize estimates refer to maize for grain only. Maize is used chiefly for poultry and swine feed, and production and consumption have risen since 2000 concurrent with a rebound in poultry inventories (Ukraine 2004).

Maize production is resurging. Traditionally, maize-for-grain comprises two-thirds of total maize seeded area with the remainder intended for silage. The area intended for silage declined sharply in the post-Soviet era, concurrent with the decline in livestock production in Ukraine. The resurgence of maize-for-grain is largely the result of strong gross margins on maize production. In terms of production volumes, Ukraine has shifted from 3391,8 thousands tons in 1995 range to the 11953,0 thousands tones in 2010 (Table 5.6). Thanks to favourable weather, Ukraine produced 11446,8 thousandstonnes in 2008, according to the final official estimates. The 2008 crop was the largest on record since 1962. Improvements in seeds and application of agricultural inputs also contribute to increasing maize production. However, maize yields in Ukraine are still far below crop potential. For instance, the record-high yield of 50,2 per centners hectare of the harvested area in .Should the government of Ukraine approve the planting of genetically modified maize varieties, it is likely that average yields as well as areas seeded would increase further. However, the regulatory framework for genetically modified plant varieties in Ukraine appears to be in a stalemate (EBRD 2010).

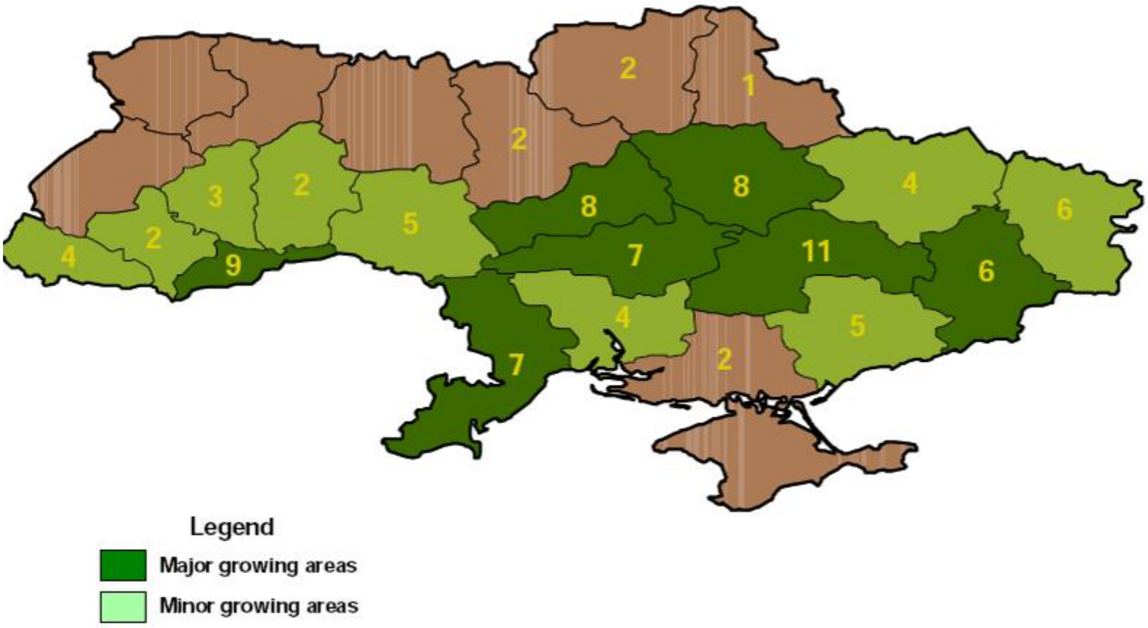


Figure 5.10. Percent of total maize area by Oblast *(*yellow numbers indicate percent of national total each Oblast contributes to national area. Oblasts not numbered contribute less than 1% to the national total) (USDA no date)

Table 5.6. Maize for grain, 1990–2010 (Agriculture of Ukraine 2008 Agriculture of Ukraine 2009 Agriculture of Ukraine 2010)

Years	Production of maize for grain, thousands tons	Yield of maize for grain, centners per hectare of the harvested area	Harvested area of maize for grain, thousands hectares
1990	4736,8	38,7	1223,1
1995	3391,8	29,2	1161,3
2000	3848,1	30,1	1278,8
2004	8866,8	38,6	2299,6
2005	7166,6	43,2	1659,5
2006	6425,6	37,4	1720,3
2007	7421,1	39,0	1902,8
2008	11446,8	46,9	2440,1
2009	10486,3	50,2	2089,1
2010	11953,0	45,1	2647,6

1.4.1.4 Sunflower

Production of sunflower seed, Ukraine's major oilseed crop, increased considerably in the period 2000–2007 in response to increasing demand from local and international oilseed processors (Figure 5.11). While sunflower seed yields kept relatively stable at a level between 0.93 and 1.25 tonnes/ha, output growth was accounted for mainly by acreage expansion. According to Ukragroconsult's estimates, areas sown with sunflower seed expanded from 2.5–2.8 million ha in 1999–2000 to 4.3–4.5 million ha in MY 2006/2007. In MY 2007/2008, the acreage shrank to 4.06 million ha primarily as a result of the expansion of rapeseed and wheat production (EBRD 2010).

Figure 5.11. Sunflower harvested area and yield (EBRD 2010).

Sunflower is Ukraine's chief oilseed crop. Production is concentrated in the southern and eastern oblasts (Figure 5.12, 5.13). Sunflowers are typically planted in April and harvested from mid-September to mid-October. Because of a combination of high price, relatively low cost of production, and traditionally high demand, sunflowerseed has become one of the most consistently profitable crops. Its high profitability fueled a significant expansion in planted area beginning in the late 1990's. Many farmers in Ukraine abandoned the traditional crop-rotation practices recommended by agricultural officials which called for planting sunflowers no more than once every seven years in the same field. The aim of the 1-in-7 rotation is to prevent soil-borne fungal diseases and reduce the depletion of soil moisture and fertility. Because of their deep rooting system, sunflowers reportedly extract higher amounts of water and nutrients from the soil than do other crops in the rotation (Ukraine 2004).

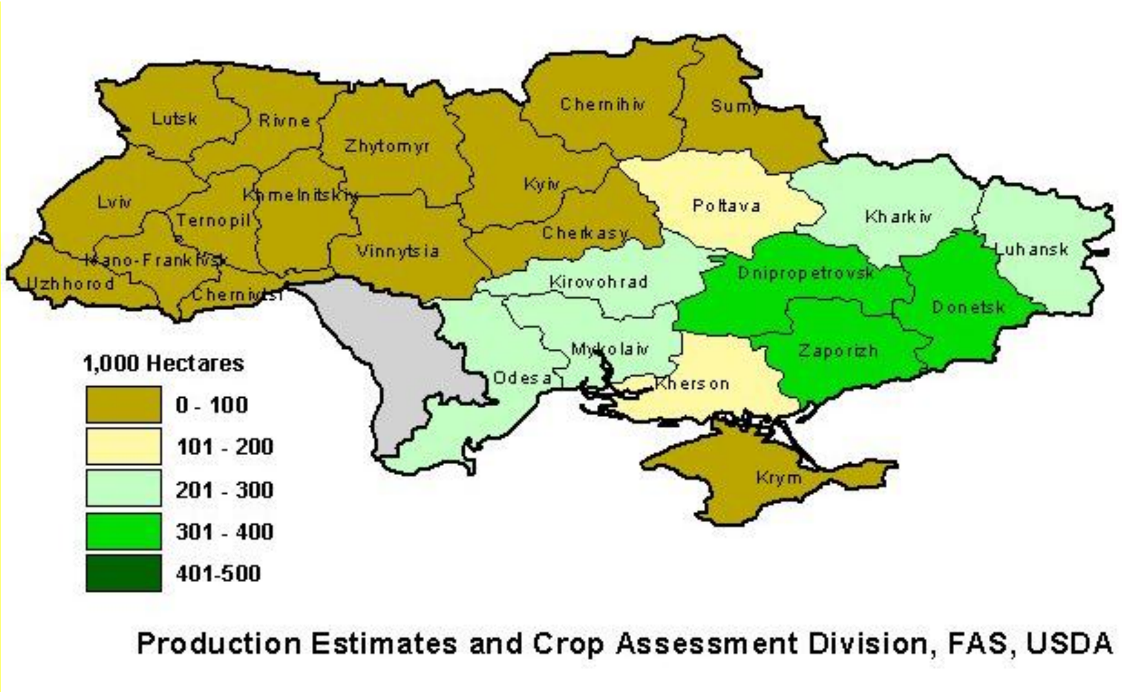


Figure 5.12. Estimated sunflower area by Oblast (Ukraine 2004).

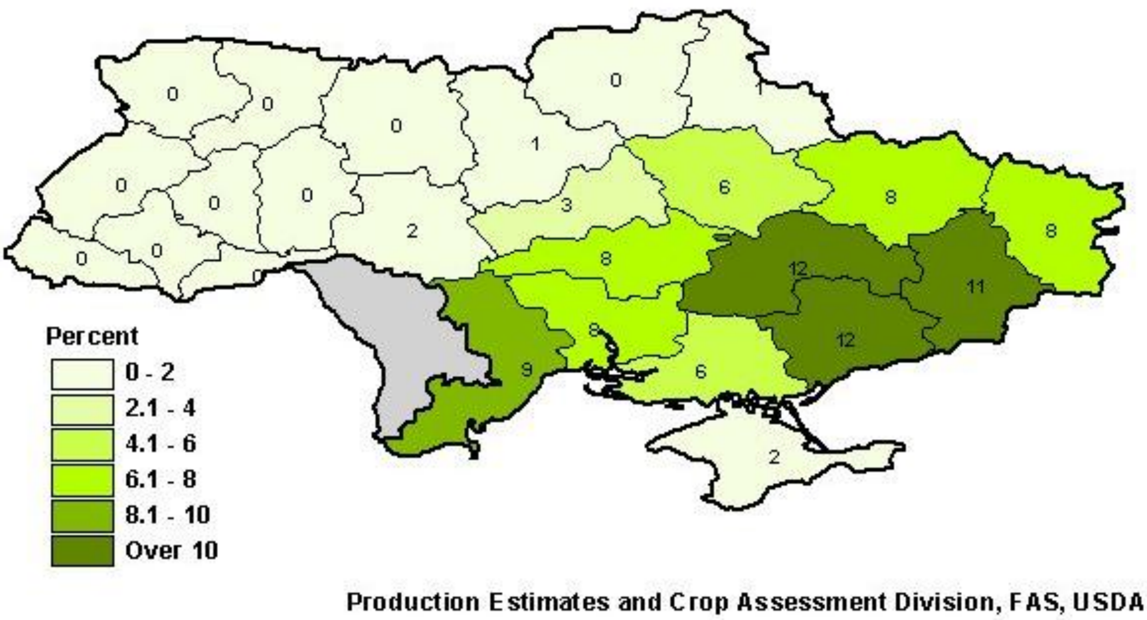


Figure 5.13. Percent of Total Sunflower Area by Oblast (Ukraine 2004).

1.4.2 Export potential of Ukraine in main agricultural crops

During the last years Ukraine is steadily augmenting its export agricultural potential and expands its foreign market representation. According to the data of 2010 (OCHAG 2001). Ukraine occupies 1st place in the world in export of sunflower and sunflower oil, 2nd place in the world in export of barley, 6th place in the world in export of corn, 8th place in the world export wheat, 9th place in the world in exports of cereals (collectively), 16th in the world in exports of cheese, 19^{th} place in the world in exports of dairy products, eggs, honey, other edible animal products (collectively). According to the results of the year 2011 (GLAVCOM 2011). Ukraine was among the world's leading exporter of grain and had the lead in exports of sunflower oil and barley, and occupied the sixth place among world wheat exporters.

Historically part of wheat market occupied by the five major exporters (USA, EU, Canada, Australia and Argentina) accounted for 90% of the total market. But in the beginning of 2000s arrival of the Black Sea countries (Russia, Ukraine, Kazakhstan) has changed the balance of power (Table 5.7). During 10 years five traditional exporters have lost up to 20% of their market share. This trend hides, however, very different things (UGA-PORT 2011).

Table 5.7. The proposal of wheat (including durum wheat), the average for 2006-2008 (UGA-PORT 2011)

	USA	EU	France	Canada	Russia	Argentina	Australia	Ukraine	Kazakhstan	World
Place in rating of exporters in 2008 according to FAO (http://faostat.fao.org)	1	2	3	4	5	6	7	8	10	-
Area (million hectares)	20,7	25,3	5,3	9,5	25,0	5,2	12,7	6,2	12,8	218
Yield (t / Ha)	2,8	5,2	7,1	2,6	2,1	2,7	1,2	6,2	1,1	218
Production volume (million ton)	58	132	37	25	53	14	15	18	14	630
Export (million tons)	29	17	16	18	14	9	10	6	7,5	124
Exports (% of total production)	50	13	43	73	26	64	66	33	52	20
Market Share (%)	23	14	-	15	11	7,5	8	5	6	-

Therefore Ukraine is currently ranking eighth in the world export of grain. Geography of grain export in 2009/2010 is shown in figure 5.14.

Countries-importers of Ukrainian wheat in 2009/2010

Countries-importers of Ukrainian barley in 2009/2010

Countries-importers of Ukrainian maize in 2009/2010

Figure 5.14. Exporting crops in 2009/2010 (ZERNO 2010)

However, financial crisis made negative effect on international trade indices. Foreign trade turnover of agricultural products has reduced by 17,2 per cent in 2009 against 2008, export volumes & by 13.5 per cent. While the exports share in the total volume of Ukraine foreign economic turnover has grown on the whole from 16 to 23.6 percent. Grain and oil and fat products prevail in the export structure (figure 5.15). Confectionery, beer and soft drink, distilled and salt production industries are competitive in the international market (PANORAMA 2009).

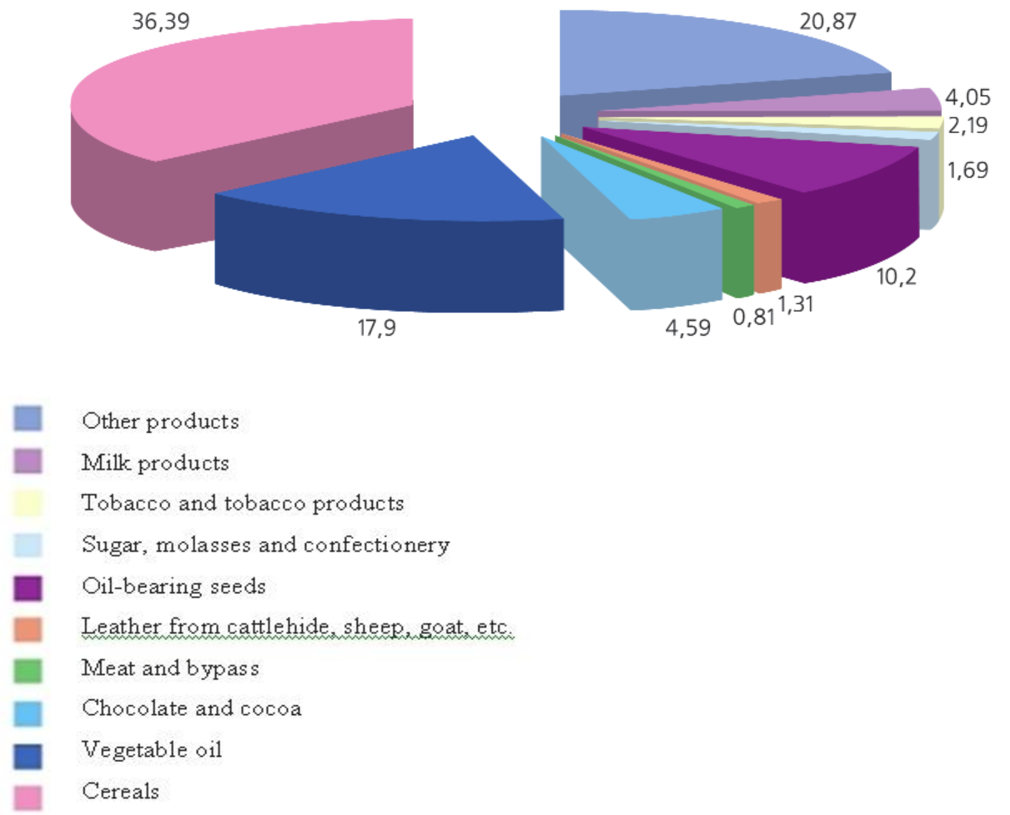


Figure 5.15. Export structure of agricultural and food products in 2009, %

(PANORAMA 2009).

As the analysis of the balance of grain in Ukraine (Table 5.8) in 2008 was produced 53.29 million tons of grain - the largest number for 1995 -2010 - from which exported 16,668 tons , in 2009 made it less than in 2008 - 46,028 tons, but exports rose to 26,160 tons.

Table 5.8. Grain balance (including products of grain processing counted as grain) (thousands tons) (Osaulenko O.G. (ed) 2010; Osaulenko O.G. (ed) 2009)

	1995	2000	2004	2005	2006	2007	2008	2009	2010
Output	33930	24459	41809	38016	34258	29295	53290	46028	39271
Change of stocks at end of year	-757	1329	7817	-314	-2304	948	9952	-6079	-2054
Import	200	1010	875	226	235	343	222	136	175
Total of resources	34887	24140	34867	38556	36797	28690	43560	52243	41500
Export	814	1330	7786	12650	11168	4490	16668	26160	14239
Expenditures of fodder	18527	11056	13852	13817	13750	12845	13580	13997	14787
Expenditures of sowing	4600	3597	3584	3294	3301	3280	3489	3558	3222
Loses and wastes	1220	309	545	375	633	507	1177	752	794
Processing on the non-food purposes	876	100	1150	670	645	478	1625	916	1650
Found of consumption	8850	7748	7950	7750	7300	7090	7021	6860	6808

According to the Grain Ukraine Company the list of countries being the largest buyers of Ukrainian grain has undergone significant changes at the end of May 2011. As in 2008/2009, the maximum amount was purchased by Saudi Arabia - this country imported 1.6 million tons of grain against 3.8 million tons in 2009/2010 (Table 5.7). The second was Egypt, which bought 1.4 million tons of Ukrainian grain against 2.1 million tons a year earlier. And Israel closes the top three (845 tons). Bangladesh, where almost 1.4 million tons of grain was delivered last year (Table 5.9), this season became only the tenth largest importer (Table 5.8) (UGA-PORT 2011).

Table 5.9. Top 20 countries - buyers of Ukrainian grain * in 2009/2010 (UGA-PORT 2011)

Country	Grain imports from Ukraine, thousand tons
1 Saudi Arabia	3762
2 Egypt	2101
3 Bangladesh	1413
4 Israel	1287
5 South Korea	1285
6 Spain	1087
7 Tunisia	1062
8 Syria	1026
9 Iran	754
10 Libya	710
11 Kenya	641
12 Jordan	624
13 Japan	437
14 Turkey	345
15 Vietnam	303
16 Portugal	271
17 Algeria	267
18 Lebanon	209
19 Philippines	194
20 Ethiopia	188
………….	………….
46 Russia	14

*barley, wheat, maize

Due to natural disasters, Japan has gone down from 13 place to 20, having bought only 84 thousand tons of grain. Instead, Georgia and Armenia significantly increased their purchases of grain, entering the top 20 importers – most probably the grain was delivered to an intergovernmental contract. However, more resonant breakthrough made Russia - country that in the season 2009/2010 ranked 46th among importers in fact closing the list of buyers (14.2 thousand tons of grain only were supplied to their market), became the 21st this year, having bought from Ukraine 83.6 thousand tons of grain (Table 10) (UGA-PORT 2011).

Table 5.10. Top 20 countries - buyers of Ukrainian grain * in 2010/2011 (UGA-PORT 2011)

Country	Grain imports from Ukraine, thousand tons
1 Saudi Arabia	1616
2 Egypt	1448
3 Bangladesh	845
4 Turkey	686
5 Spain	600
6 Iran	572
7 Libya	541
8 Syria	441
9 Tunisia	438
10 Bangladesh	287
11 Georgia	279
12 Portugal	277
13 The Netherlands	237
14 Lebanon	229
15 Italy	182
16 Kenya	182
17 South Korea	119
18 Vietnam	112
19 Armenia	105
20 Japan	84
21 Russia	84

*barley, wheat, maize

In general, experts point out, the absence the usual buyers in the list of top 20 importers does not mean their rejection of Ukrainian grain. "We sell the grain to the same countries as before, but through intermediaries" - says Yuri Voskoboynik, Head of Pricing and Market Conditions Department of the National Scientific Center "Institute of Agrarian Economics," - "Germany, Poland and even Russia can buy our grain and sell it to Saudi Arabia”. He noted that those are logical consequences of unpredictable State policy in the grain market. "Of course, last season our image has suffered. There are cases – it happened more than once, that buyers did not want to make contracts with us. It is unreliable: as a result of the buyer could get no grain or receive it behind time".

1.4.2.1 Wheat

Wheat has the largest export volume among cereals with an average of 4.5 million tonnes between 1998 and 2008. Nevertheless, in 2000 and 2003 Ukraine imported wheat. The share of wheat among world's top net exporters averaged around 5%. Due to favourable weather conditions and excellent harvest, wheat export peaked in 2008 at almost 9 million tonnes. FAPRI projects that Ukraine’s wheat export share in the total net export is about 7-8% (EnviroGRIDS 2011). Analysis of data on the export of wheat in 1987-2011 (INDEX MUNDI 2011) presented in Figure 5.16 shows that the maximum value of wheat exports (13,037 tons) was reported in the 2008.

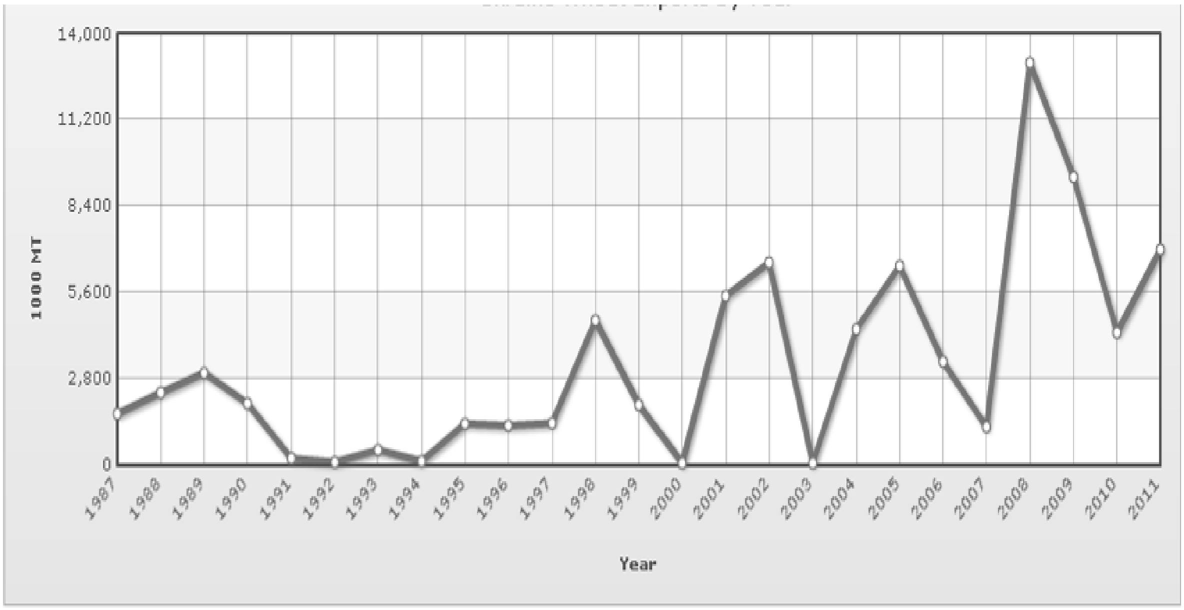


Figure 5.16. Ukraine wheat exports by year (INDEX MUNDI 2011)

Wheat produced in Ukraine is exported to 50 countries. The list of countries importing the largest amount of Ukrainian wheat in 2009-2010 is presented in Table 5.11. Analysis of distribution (%) of the main buyers of Ukrainian wheat in 2010/2011 season is presented in Figure 5.17 and shows that about 59% of the total volume of wheat is exported to six countries (Bangladesh, Egypt, Turkey, Israel, Georgia, Libya).

Table 5.11. Countries-importers of the highest volume of Ukrainian wheat in 2009-2010 (ZERNO 2010)

Importers of the highest volume of Ukrainian wheat in 2009-2010	Total, tons	Importers of the highest volume of Ukrainian wheat in 2009-2010	Total, tons
Bangladesh	1268895	Malaysia	36262
Republic of Korea	1130479	Mauritania	34626
Spain	782486	Nigeria	30514
Kenya	472709	Netherlands	28190
Egypt	416695	Sri Lanka	28081
Tunisia	388446	United Kingdom	27888
Israel	337984	Yemen	25066
Syria	253093	Japan	24143
Iran	212032	Somalia	22000
Vietnam	211895	Georgia	15038
Indonesia	107831	Korea	10120
Djibouti	102615	Taiwan	10088
Italy	97091	Austria	9084
Libya	86871	Thailand	7909
Lebanon	75211	Myanmar	6534
Turkey	74223	Singapore	6005
Sudan	69575	Belarus	5622
Algeria	67381	India	3449
Philippines	67052	Saint Vincent and the Grenadines	3438
Ethiopia	64711	Rwanda	3000
South Africa	53127	Albania	2850
Jordan	49351	Colombia	2163
Switzerland	45214	Congo	2119
Uganda	38360		
Hungary	36516		

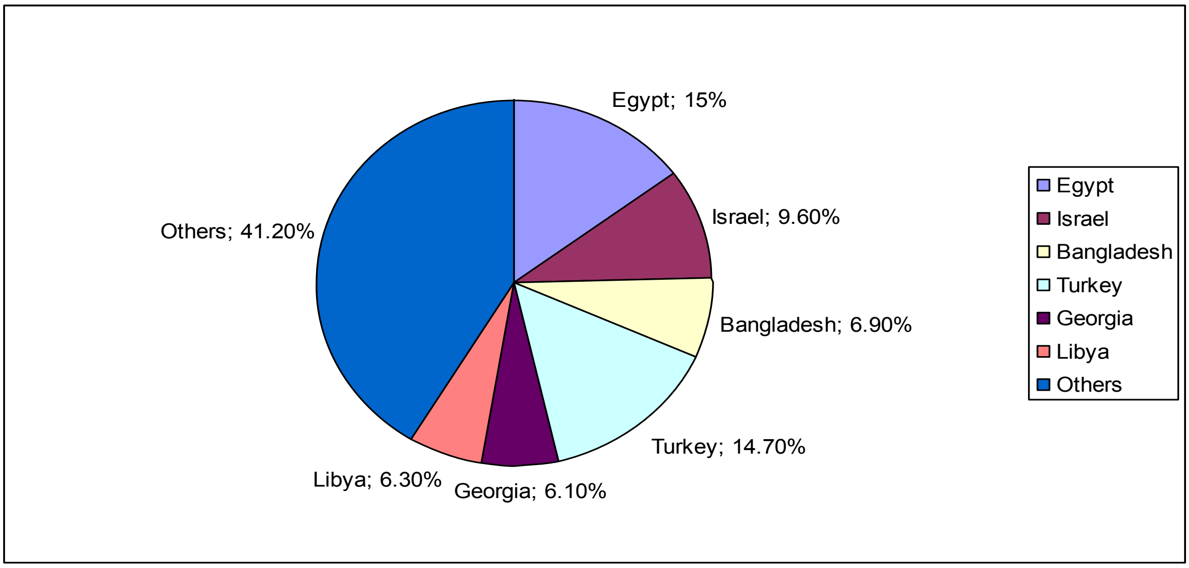


Figure 5.17. Distribution (%) of the main buyers of Ukrainian wheat in the season 2010/2011 (ZET 2011)

1.4.2.2 Barley

One of Ukrainian main exports is barley with an increasing share in the world export. In 2006/07 export amounted more than 5 million tonnes that gave 36% of the total net export, turning Ukraine the world's largest exporter that year. After a weaker year in 2008/09, Ukrainian barley export is projected to peak at almost 5.5 million tonnes contributing 30% to the world net export. This year Ukraine is projected to become again the world's largest exporter of barley leaving behind countries like the EU, Argentina, Canada or Australia, all notable exporters of cereal products. In the projection period its share in net export seems to stabilize at around 25-27% (EnviroGRIDS 2011).

Analysis of information on export of barley from Ukraine presented in figure 5.18 shows that since 2000 there has been a continuous growth in exports of barley. The greatest amount of barley in the period 1897-2011 was exported in 2008 (6371 tons).

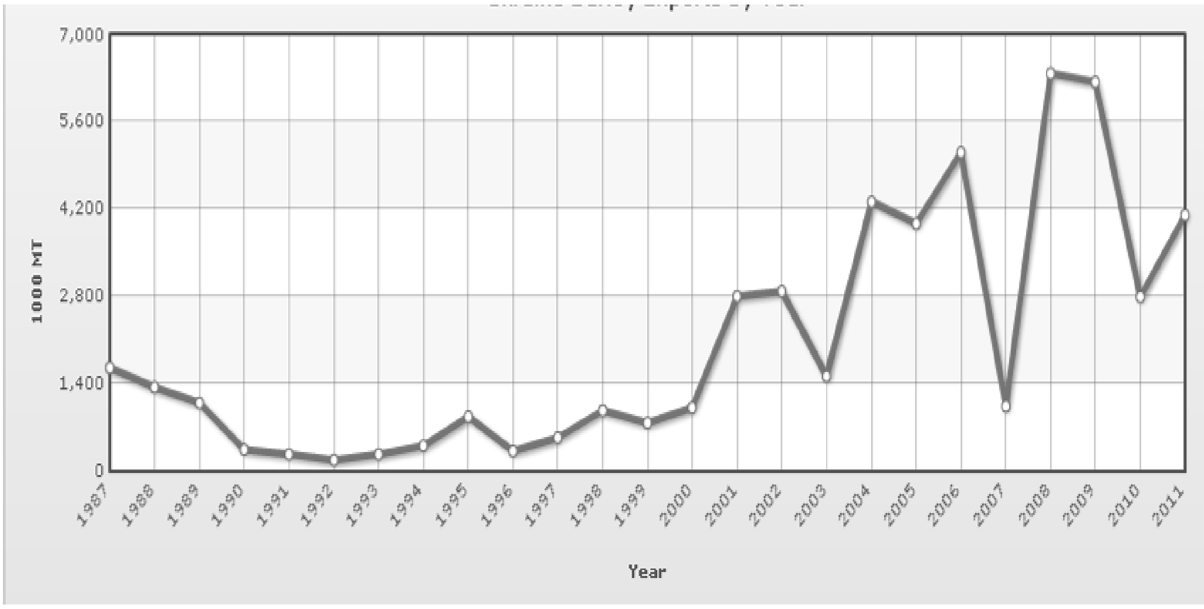


Figure 5.18. Ukraine barley exports by year (INDEX MUNDI 2011).

Barley produced in Ukraine is exported to 26 countries. The list of countries importing the largest volume of Ukrainian barley in 2009-2010 is presented in Table 5.12.

Table 5.12. Countries-importers of the highest volume of Ukrainian barley in 2009-2010 (ZERNO 2010)

Importers of the highest volume of Ukrainian barley in 2009-2010	Total, tons	Importers of the highest volume of Ukrainian barley in 2009-2010	Total, tons
Saudi Arabia	2289174	United Kingdom	22549
Jordan	202032	Cyprus	14836
Israel	197996	Algeria	13002
Libya	180581	France	12119
Iran	175471	OA Emirates	10286
Japan	160017	Kazakhstan	10032
Syria	99301	Latvia	8959
Morocco	88949	Spain	8012
Kuwait	88473	Uzbekistan	6252

Turkey	74608	Gibraltar	5100
Switzerland	60747	Vietnam	1649
Netherlands	51279	Georgia	1496
Hungary	22170		
Lebanon	16853		

1.4.2.3 Maize

Maize remains the most produced among the species of grain (765 million tons), but not the best-selling. About 12% of the maize produced is sold (UGA-PORT 2011). However, since 2000, there has been a steady increase in maize exports to other countries.

Maize export has the lowest share among main cereals and also in the world total net export. However, the export volume has been gradually increasing from 328,000 tonnes in 1998 to almost 12.0 million tonnes in 2011 (Figure 5.19). The share of Ukrainian maize among top net exporters is small, although it is slightly increasing. While in 1998 that share did not even reach 1%, at the end of the projection period it should reach around 6% (EnviroGRIDS 2011).

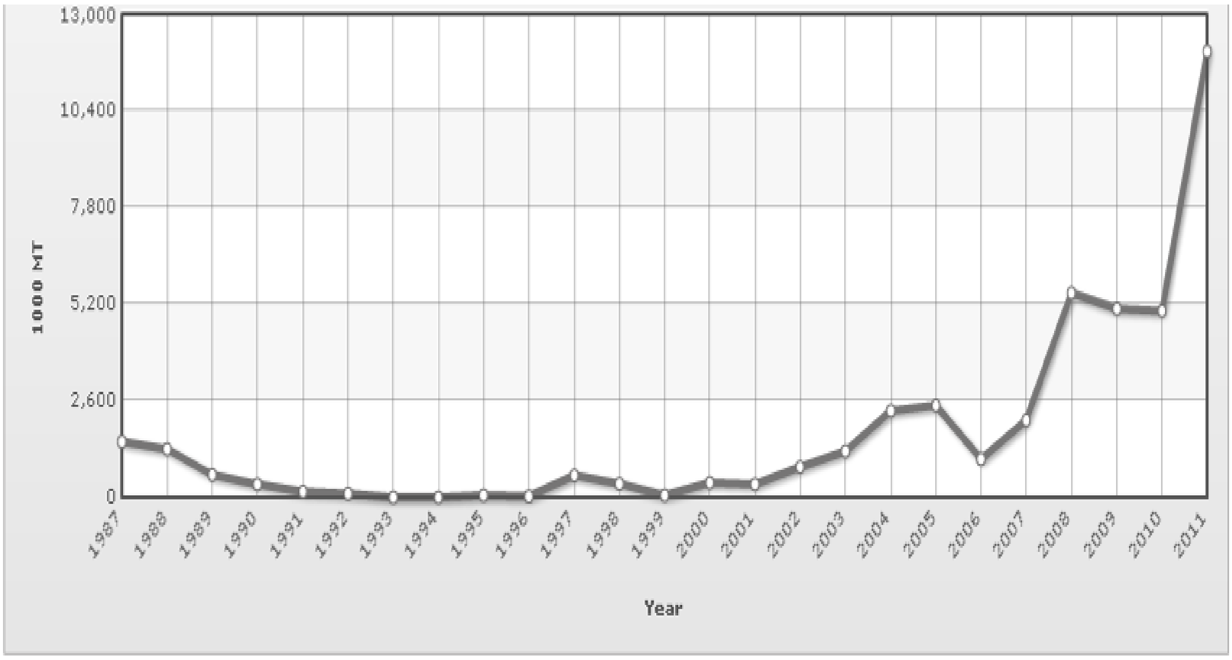


Figure 5.19. Ukraine maize exports by year (INDEX MUNDI 2011)

In 2009-2010 Ukrainian maize was exported to 24 countries (Table 5.13).

Table 5.13. Countries-importers of the highest volume of Ukrainian maize in 2009-2010 (ZERNO 2010)

Importers of the highest volume of Ukrainian maize in 2009-2010	Total, tons	Importers of the highest volume of Ukrainian maize in 2009-2010	Total, tons
Egypt	766812	Lebanon	44106
Syria	418123	Kenya	40113
Spain	208583	Iran	37497
Libya	179570	Netherlands	31068
Israel	167988	Georgia	14951
Algeria	128569	Switzerland	10161
Tunisia	125789	Azerbaijan	6858
Japan	99364	Hungary	6614
Portugal	70096	Malaysia	3984
Turkey	47686	Cyprus	3006
		Belarus	1845
		United Kingdom	1658
		USA	1618
		Turkmenistan	1135

1.4.2.4 Sunflower

Ukraine has developed its sunflower oil production by introducing export tariffs on sunflower seeds in 1999 . The aim was to strengthen domestic crushing industry and to export sunflower oil in order to gain higher export earnings. This measure successfully increased sunflower oil production from around 1,5 million tonnes to around 2,2 million tonnes between 1998 and 2008. The same amount of production is projected by FAPRI in the future. Consumption has remained low, offering a large share of the production for export (EnviroGRIDS 2011).

Ukraine plays an important role in sunflower seed and soybean world export (Figure 5.20). Sunflower seed export has fluctuated heavily. In 2000 export declined significantly, particularly after the introduction of export restrictions. In 2003 record export reached 926 000 tonnes of sunflower seed contributing with more than 60% to the world net export. In 2004 the lowest sunflower seed export amounted 6 000 tonnes. FAPRI projects sunflower seed share among world's top net exporters to be at around 40% over the projection period.

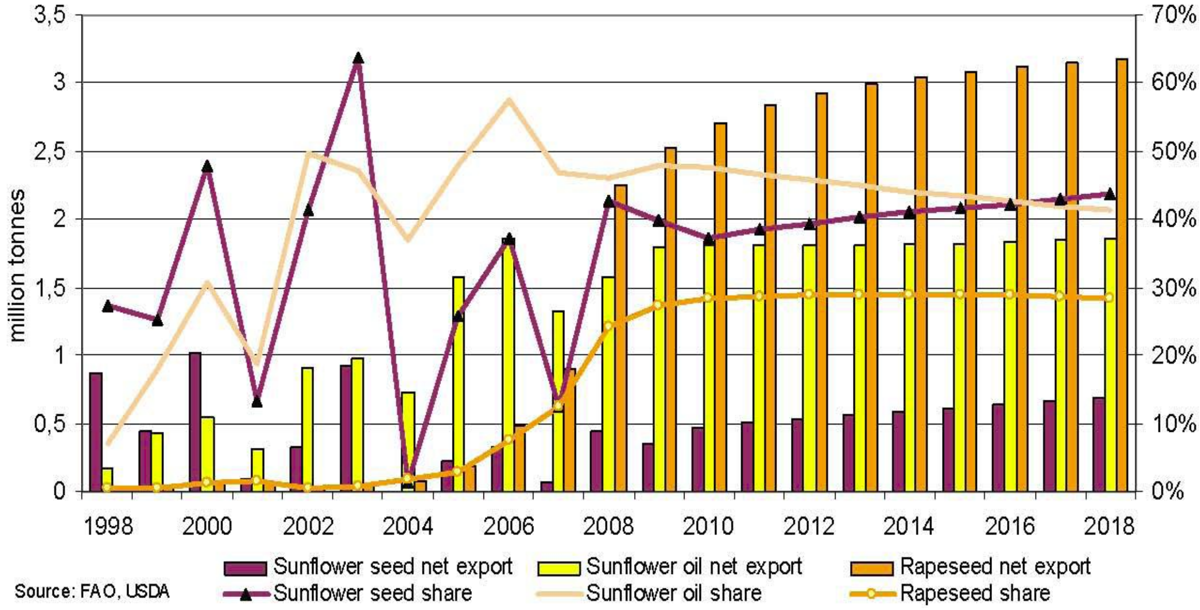


Figure 5.20. Net exports of sunflower and rapeseed and share among top net exporters

Rapeseed export has an increasing role in the world export. The first significant export in 2006 amounted 483 000 tonnes that comprised 8% of world's top net exporters. In 2009 rapeseed net exports is expected to hit a record of 2,5 million tonnes (27% share among world's top net exporters). In the projection period export seems to further increase to around 3 million tonnes per year, turning Ukraine into the second largest exporter of the world after Canada.

Sunflower oil is an important export product for Ukraine. While in 1998 only 175 000 tonnes were exported, in 2008 net exports has risen to around 1,5 million tonnes; and is expected to remain stable over the projection period. Ukraine gained an important role in sunflower oil exports around the world by being responsible for almost half of the world's sunflower oil trade.

Net exports of soybeans are not yet significant; however, an increasing trend is observed between 1998 at around 7 000 tonnes and 2009 at more than 230 000 tonnes. The list of countries importing the largest amount of Ukrainian sunflower in 2009-2010 is presented in Table 5.14.

Table 5.14. Countries-importers of the highest volume of Ukrainian sunflower in 2009-2010 (ZERNO 2010)

Importers of the highest volume of Ukrainian sunflower in 2009-2010	Total, tons
Netherlands	27317
Georgia	7607
Germany	4829
Turkey	4338
Poland	2145
Belarus	1495

1.4.3 Problems of main crops production development in Ukraine

Grain sector of Ukraine is a strategic sector of state economy, which determines the supply and cost of basic foodstuffs for population, in particular products of grain processing and animal products, forms an essential part of the income of agricultural producers, determines the status and trends of development of rural areas, creates foreign exchange revenues of the state from exports. Grain industry is the basis and source of sustainable development for most sectors in agriculture and of agricultural export.

In 1990 yield of grain and leguminous crops in Ukraine was 35.1 centners/Ha and the yield of wheat - 40.2 centners/Ha. Cereal yields in countries supplying grain to the world market was, according to U.S. Department of Agriculture, in 2006 as follows: in the European Union - 48.7 centners /Ha, in the U.S. - 63.8 centnerc/Ha.

According to State Statistics Committee of Ukraine yields of grain and leguminous crops in 2004 was 28.3 centners/Ha, in 2005 - 26.0 centners/Ha, in 2006 - 24.1 centners/Ha. Yield of wheat in 2004 was 31.7 centners/Ha, in 2005 - 28.5 centners/ Ha, in 2006 - 25.3 centners/ Ha. According to (ZERNOLAB 2009), in 2007 grain yields decrease had to be much greater.

In 2005 and 2006 for most crops decrease of productivity was observed and of gross collection (ZERNOLAB 2009).

Profitability level of grain production is going down. In 2006 it was 7.4%, in 2005 - 3.1%. Production of oats, peas and other crops in 2006 was on the average unprofitable, which constrained the possibility of an extended reconstruction of their production (ZERNOLAB 2009).

According to experts, to implement an effective grain production minimum profitability of grain production should be 20%, and the rational (under conditions of Ukraine) - at least 40% (ZERNOLAB 2009).

Only such profitability will create the necessary conditions for renewal of fixed assets and for implementation of grain production technology, which subsequently will help to increase productivity. Profitability of wheat production declined from 30.4% in 2004 to 9.9% in 2006. Profitability production level of barley fell from 5% in 2004 to 3.7% in 2006 (ZERNOLAB 2009).

During 2000-2010 there has been steady increase in production of main crops export & directions in Ukraine. A slight decrease in agricultural production in 2010 (1% less was produced than in 2009) was due to lower yields of all crops (except fruits and berries) because of unfavourable weather conditions. As a result, the volume of crop production decreased 4.6%.

In recent years, reaching a peak in 2008, rape acreage began to decline and yield of crop in 2010 decreased by 21.5% to 1.5 million tons. Sown area of potatoes, remains virtually unchanged, in 2010, 18.7 million tons were harvested, which was 4,9% less than in 2009. Collection of vegetables in 2010 decreased by 2.6% to 8.1 million tons, grapes - by 13.0% to 0.4 million tons. Sown area of winter crops for harvest in 2011 decreased by 8.1% to 9.3 million hectares compared to 2010, including wheat - 1.7%, to 6.5 million Ha, rape - by 23.7% to 1.1 million Ha, which will lead to an increase in farm work during the spring sowing campaign (ZERNOLAB 2009).

Logistic support for grain production and labour efficiency do not meet international standards and needs of the industry. Lack of sufficient financial resource hinders introduction of new technologies, use of quality seeds, limits the use of other resources. Grain production is becoming more dependent on the effects of weather factors (ZERNOLAB 2009).

Inefficient use of land resources and the low culture of agriculture lead to depletion and degradation of soils, reducing the content of humus and nutrients. Labour resources are insufficient, as well as scientific and advisory support of grain production (ZERNOLAB 2009).

State regulation of the grain market does not play stimulating role in grain production and market methods can not effectively respond to the impact of global grain market (ZERNOLAB 2009).

The effectiveness and predictability of state regulation of grain growth is an objective prerequisite of grain sector growth in Ukraine. Insufficient consistency and harmonization of the legislation of Ukraine, as well as its selective implementation, has significant negative impact on the state of grain production and grain marketing effectiveness, resulting in losses to the participants of grain market and the economy as a whole (ZERNOLAB 2009).

Strategic approach to government regulation of grain market and improvement of legislative and regulatory framework, which regulates legal relations in grain market, can significantly improve the productive performance indicators of both individual entities in grain market and the whole agro-food sector of Ukraine (ZERNOLAB 2009).

With Ukraine entering the World Trade Organization (WTO) regime of value added tax accumulation by agricultural operators ceases to operate, which is estimated to lead to additional losses of agricultural producers totalling to 4 billion UAH. In case no adequate measures are taken this will lead to losses in grain production. In addition, Ukraine's accession to the WTO requires a revision of existing support system for producers of grain. Lack of experience in the use of alternative measures to support the industry will affect negatively the performance of grain producers (ZERNOLAB 2009).

The absence of systematic approach to regulation of grain markets can lead to subsequent decrease in rates of productivity and production of grain in Ukraine, reduction of income for agricultural producers, in particular, it will threaten food supply security of the country. In addition, market participants will suffer losses associated with supply of goods for grain production and with grain marketing, in particular the elevator industry, transport infrastructure etc.

A further consequence could be increase of income gap between urban and rural population, increase of the share of rural population living below the poverty line and associated social stress (ZERNOLAB 2009).

Important is the threat of further deterioration of soil quality and ecological status of the territories.

Reducing of grain supply volume to foreign markets will affect the country's trade balance.

In case of unstable situation and absence of grain industry development the growth of most sectors of Ukrainian agriculture will be slowed down, in particular flour and cereals, baking, livestock, biofuels etc., which will affect the speed of economic development and tell upon inflationary processes (ZERNOLAB 2009).

At the same time, higher export prices for grains and increase of grain transhipment capacities of port terminals over 25 million tons in Ukraine create nowadays an opportunity for effective development of grain industry and measurable increase of grain producers' income (ZERNOLAB 2009).

Effective use of these opportunities and prevention of negative factors development can be realized through a complex of measures aimed at improvement of State regulation, which will contribute to growth of investment attractiveness and competitiveness of grain production, contribute to investment attractiveness and competitiveness of quality grain production, responding to needs of the market (ZERNOLAB 2009).

The need for integrated improvement of grain market functioning, increasing of the volume of high quality grain production and creation of conditions for realization of the industry's export potential are based on key government priorities in agricultural policy defined by the Law of Ukraine "On main principles of state agricultural policy for the period till 2015" and are in line with the specified in legislation strategic objectives of agrarian policy, particularly in terms of ensuring state food security and the transformation of the agro-sector into highly efficient and competitive in the domestic and foreign markets sector of state economy (ZERNOLAB 2009).

1.4.4 Plans and programs to increase production of main crops in Ukraine

The basic tasks of the Ministry of Agrarian Policy of Ukraine comprise: providing state agrarian policy realization; organizing, elaborating and implementation of measures on the guarantee of state food security; recycling of agricultural products (further – spheres of agroindustrial production); organizing and providing implementation of agrarian reform; exercising its monitoring; working out and realizing means of structural evolution of agroindustrial spheres; participating in realization of state policy in the sphere of enterprise; participating and forming and implementing of social policy in a countryside; coordinating the activity of executive power bodies on issues of state agrarian policy realization; social policy in a countryside, ensuring food state security, carrying out agrarian reform MINAGRO (2012).

1.4.4.1 National programs and plans

The main objectives of the state target program of grain sector development "Grain of Ukraine 2008-

2015" are:

- to guarantee satisfaction of growing needs of Ukrainian people and processing industries (flour, cereals, animal feed, alcohol, biofuel etc.) in grain of good quality;
- to increase export of Ukrainian grain to rise producers' income, to ensure effective work of market infrastructure and increase foreign investments into Ukrainian economy.

To resolve the issue of grain sector and grain market of Ukraine effective development, the following will be done:

1. opportunities identified and measures taken aimed at improving of organizational structures and management of grain farms, modern innovative approaches to business used;

2. improvement of land use, crop structure and the use of the best precursors to increase grain production efficiency and ensure preservation and improvement of land, particularly in terms of environmental state of territories; the definition and implementation of measures to improve soil fertility;

3. dissemination of modern technologies in grain production, in particular using GIS and precision farming, to ensure optimal soil cultivation, fertilization, irrigation, using plant protection and biological products;

4. increase of the level of producers' provision with logistical resources (equipment, fertilizers, plant protection means etc.) both native and foreign, in particular by reducing (exemption) of import duties on certain types of resources, tax incentives, provision of grain producers with target credit resources;

5. improvement of grain quality, in particular by increasing of quality seeds availability for farms, newest varietal resources (with appropriate compensation for the cost of their purchase), informing grain producers about market needs, in particular the world market;

6. improvement of standardization, certification and grain quality control systems in accordance with the requirements of the global market and Ukraine's intentions in European integration, modernization and certification of grain quality laboratories according to international standards;

7. scientific and methodological support, linkage of scientific, educational, public organizations and advisory companies with grain industry, studying and meeting the needs of the industry in high-quality labour resources, strengthening of the role of private and public sectors in the development and implementation of regulatory documents;

8. development of infrastructure of Ukrainian grain market, storage and transportation systems, in particular, tariffs on grain transportation, deepening of harbour waters, development of alternative ways of grain transportation, optimizing of sales channels, supporting of economic mechanisms that will encourage modernization and renovation of fixed assets in elevator industry;

9. dissemination of information and communication technologies, in particular establishment of systems

for monitoring of grain market, studying and operative dissemination of information on the status and trends of global and regional grain markets, introduction of space-based surveillance of the state of crops for harvest prediction and assessment, preparation of agreed cross-sectoral forecast balance of grain market for official disclosing and use for government decision-making;

10. improving of the paperwork systems in grain warehouse, establishing of a system to guarantee the rights of owners of the grain, which is in storage, insurance of crops and grain in storage, improvement of loan systems for owners of grain;

11. development of grain marketing, in particular by removing obstacles for grain export to the border, at the border and outside border; distribution of world grain trade practices, including through access to standardized international contracts, international arbitration; simplification of procedures for obtaining permits and customs clearance for grain exports;

12. improvement of state regulation of grain market, entering changes to legislative and regulatory instruments, in particular with respect to intervention and other regulatory measures, tax, tariff, customs and trade policies;

13. improvement of state support mechanisms for participants of grain market in accordance with World Trade Organization requirements, identification of opportunities and taking measures to replace price support with direct support in accordance with international practices; development of WTO ‘green box’ mechanisms.

14. improvement of image of Ukrainian grain in the world grain market, the informing about qualitative characteristics of the leading Ukrainian importers’ grain;

15. ensuring of high investment attractiveness in grain sector, creation of favourable environment to attract international and domestic financial and credit resources;

16. development of international cooperation, in particular active participation in the International Grains Council and other important institutions of the world grain market;

17. ensure stability and predictability of government policy in relation to the grain market, monitoring of current legislation implementation by executive authorities at all levels;

18. development and implementation of measures aimed at providing subsidies to vulnerable layers of population in order to create conditions for gradual liberalization of grain products (bread) markets.

Total period of the program implementation is until January 1, 2016. The term of the program implementation could be extended according to the procedure established in legislation (ZERNOLAB 2009).

1.4.4.2 Regional plans and programmes

Based on State programme each Oblast of Ukraine has developed regional (Oblast) programmes. As an example, Table 5.15 shows the main activities and measures of the regional programme for Odessa Oblast (OBLRADA 2010).

Implementation of activities included into the Programme will enable the Oblast to achieve the following (OBLRADA 2010):

- to rise gross output of grain by 2015 to 2.8 million tons, which would satisfy the demand of the region for food and fodder grain, as well as for technical purposes. Significant share of the grain will be sold outside the region (1.3-1.5 million tons), particularly abroad;

- to increase income of grain producers, for the market infrastructure and ensure efficiency of its work;

- to create additional jobs in agro-industrial complex;

- to provide elite and highly reproductive seeds for grain production. In accordance with requirements of the Ministry of agrarian policy of Ukraine and recommendations of the National Academy of agrarian sciences of Ukraine, winter grain crops production shall be supplied with high-quality stock seeds in the nearest future. For this purpose purchase of super elite and elite seeds from the research institutes and seed-farms shall be increased up to 10 thousand tons, and on highly reproductive – up to 70 thousand tons. At that, taking into account the availability of their own seeds, at least 50-60 thousand Ha will be sown with elite seeds and 650-700 thousand Ha – with highly reproductive. This will ensure annual increase in grain production 150-200 thousand tons, which in its turn will ensure growth of gross product for the sum almost 200 million UAH.

- to speed up technical and technological re-equipment of the agricultural branch. The level of farm's technological demand satisfaction for durable equipment in the Oblast does not exceed 65%.

Over 80% of durable equipment is being operated beyond amortization period and economically expedient time; 70% of tractors and combines is in operation for about 20 years.

Only in 2009, 2482 units of equipment and machines had been written-off by farms, including 747 tractors and 240 grain combine harvesters, and only 147 new tractors and 90 grain combine harvesters were bought.

The most critical situation is with park of grain harvesters. Farms of all forms of property have altogether 3614 harvesters out of which 2681 are being in use for more than 10 years, while actual technological need is for 5500grain harvesters.

As the result, the load on tractors and harvesters increased and reached 191 and 340 Ha, which exceeds norms almost three times and entails extension of tillage and harvesting time, losses of grain for the sum of 125 million UAH. Besides, every year more than 1000 combines are hired from other Oblasts, and 60 million UAH are annually paid for their harvesting service. Costs connected with repair and maintenance of old machinery are reaching 30 million UAH.

Recently 197 grain harvesters, 129 tractors and 42 sprinkling machines have been bought with partial support from Oblast budget. This form of help to agrarian sector will continue in 2012-2015 and 36-47 million UAH will be allocated by Oblast budget annually.

Total economic effect will depend on the market, on efficiency of state policy tools for regulation of grain production, on the payback of technologies employed in grain growing, on structure and quality of products. The volume of grain production declared in the Programme will ensure 30-40% profitability of expenses, at the cost of which the conditions will be created to increase grain production (OBLRADA 2010).

Table. 5.15. Measures and activities of the "Grain of Odessa Oblast, 2011-2015" regional programme» (OBLRADA 2010).

Activity (priority task) and list of measures in the programme	Fulfilment time	Responsible agency	Funding sources	Forecasted volumes of funding (million UAH)						Expected result
				Years						
				Total	2011	2012	2013	2014	2015	
1. Technical provision of grain production										
Cheapening of cost of complicated agro-machinery purchasing (grain harvesters, tractors, sprinkling machines)	2011-2015	General Department of agro-industrial development, Raion State Administrations	Total, including:	1706,0	236,0	288,0	341,0	394,0	447,0	Increase of volumes of grain production, Decrease of its self-cost due to resource-saving technologies introduction
			- Oblast budget	206,0	36,0	38,0	41,0	44,0	47,0	
			- other sources	1500,0	200,0	250,0	300,0	350,0	400,0	
2. Introduction of modern varieties and hybrids, improvement of sees farming										
Partial compensation of cost of highly reproductive elite and super elite seeds of winter and spring grain and leguminous crops	2011-2015	General Department of agro-industrial development, Raion State Administrations	Total, including:	770,0	120,0	130,0	150,0	170,0	200,0	Increase of grain production, improvement of its quality
			- Oblast budget	36,2	6,0	6,5	7,2	7,9	8,6	
			- other sources	733,8	114,0	123,5	142,8	162,1	191,4	
3. Introduction of system of fertilization										
Purchasing of mineral fertilizers	2011-2015	General Department of agro-industrial development, Raion State Administrations	Total, including:	6100,0	1000,0	1100,0	1200,0	1300,0	1500,0	Increase of grain production, improvement of its quality
			- Oblast budget	-	-	-	-	-	-	
			- other sources	6100,0	1000,0	1100,0	1200,0	1300,0	1500,0	
4. Introduction of integrated schemes of grain crops protection from pests, weeds and diseases										
Purchasing of crop-protection agents	2011-2015	General Department of agro-industrial	Total, including:	218,0	39,0	41,0	43,0	45,0	50,0	Increase of grain production, improvement of its
			- Oblast	-	-	-	-	-	-	

Activity (priority task) and list of measures in the programme	Fulfilment time	Responsible agency	Funding sources	Forecasted volumes of funding (million UAH)						Expected result
				Years						
				Total	2011	2012	2013	2014	2015	
		development, Raion State Administrations	budget							quality
			- other sources	218,0	39,0	41,0	43,0	45,0	50,0	
5. Scientific and methodological support of grain production										
Information and communication technologies, seminars, workshops, trainings	2011-2015	General Department of agro-industrial development, Raion State Administrations	Total, including:	1,0	0,1	0,15	0,2	0,25	0,3	Increase of grain production, improvement of its quality
			- Oblast budget	-	-	-	-	-	-	
			- other sources	1,0	0,1	0,15	0,2	0,25	0,3	
6. Sustainable management of irrigated areas										
Preparation of irrigation networks for irrigation, partial modernization of equipment	2011-2015	General Department of agro-industrial development, Raion State Administrations	Total, including:	3,9	0,5	0,7	0,8	0,9	1,0	Increase of grain production, improvement of its quality
			- Oblast budget	-	-	-	-	-	-	
			- other sources	3,9	0,5	0,7	0,8	0,9	1,0	
7. Improvement of infrastructure of grain market										
Building and reconstruction of grain storages and elevators	2011-2015	General Department of agro-industrial development, Raion State Administrations	Total, including:	840,0	50,0	90,0	150,0	250,0	300,0	Additional space for storage of 250 thousand tons of grain
			- Oblast budget	-	-	-	-	-	-	
			- other sources	840,0	50,0	90,0	150,0	250,0	300,0	
Altogether for all activities, including:				9638,9	1445,6	1649,9	1885,0	2160,1	2498,3	
- from Oblast budget				242,2	42,0	44,5	48,2	51,9	55,6	
- from other sources				9396,7	1403,6	1605,4	1836,8	2108,2	2442,7	

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1.7 Annexes

The Annexes (about 500 pages) are available on the enviroGRIDS website, as a separate document.

2 Part 2: Romania

Agriculture productivity greatly depends on the variability of environmental conditions, being particularly vulnerable to climatic stresses and land management measures, thus requiring in-depth investigations on crop efficiency measures and adaptation support strategies. Crop growth models are of increasing relevance for water and food policies as they provide estimations on aspects such as yields, water necessity and water – food relationships. In this sense, a systematic tool that analyses the crop productivity in terms of land use management, plant characteristics and environmental conditions, is very useful. GEPIC model (i.e. GIS-based EPIC model – Environmental/Policy Integrated Climate Model) is a spatial-based tool developed by a research team at EAWAG, Switzerland that integrates a crop growth model with a Geographic Information System using a series of spatial and ancillary data sets.

Since agriculture is strongly sensitive to different environmental conditions, the objective of the present study is to estimate crop yields (maize and winter wheat) and water supply for irrigation in the Oltenia Plain, SW Romania (one of the most important agricultural region in Romania) under the current environmental conditions. The crop yield simulations in this study are done by applying the GEPIC model at a high spatial resolution (~ 200 m). Based of the results of this investigation, there could be derived information for the improvement of irrigation and fertilizer management, having in view the emergent need to take into consideration measures for crop and water use efficiency.

An overview of the agricultural situation of the case study region starts this analysis, forming the bulk of the general information which is necessary for the detailed qualitative and quantitative aspects of the further investigation. Therefore, the aim of the first section is a general investigation of the case study region on the basis of the geographic and land use aspects in order to gain insights into the importance of the agriculture sector for the region. Furthermore, climatic conditions in the Oltenia Plain are overviewed as they show their relevance for agriculture sector (productivity) and the motivation of choosing this region as a case-study in the enviroGRIDS project.

In the next section the GEPIC model is presented followed by the application of the model for the Oltenia Plain. Subsequently, the model outcomes are explained in terms of their relevance for the management measures to improve the water use efficiency while ensuring sustainable yields.

2.1 THE CASE STUDY REGION – PAST AND PRESENT (STATUS QUO)

The aim of this section is the creation of a framework for in depth analyses regarding the Romanian agriculture. The focus resides in presenting the geophysical conditions, particularly the climatic conditions and land use patterns, emphasizing on the relevance of the region's agricultural sector that is to be investigated in terms of crop yields estimations and water use efficiency.

2.2 GENERAL DESCRIPTION OF THE CASE STUDY REGION

One of the most important agricultural regions in Romania is the Oltenia Plain, in the south-western part of the country (Fig. 1). Situated in SW Romania, the Oltenia Plain is a drought-prone area covering about 8 300 sqkm. The area has an important crop productivity potential, benefiting from soils of superior conditions such as, chernozems and alluvial soils and being equipped with a large irrigation system (458165 ha equipped for irrigation), which nowadays is not used at its capacity due to outdated technology and/or high water price. Cereals are cultivated on more than 75% of the arable land, followed by technical crops and vineyards. A productive agriculture in this region is possible through efficient use of the irrigations.

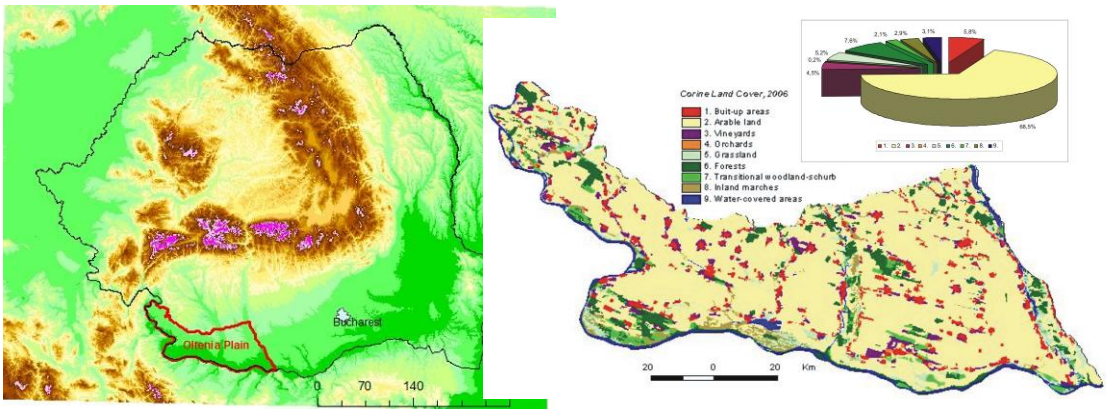

Fig. 1. Location and land use of the Oltenia Plain, Southwestern Romania

It has a relatively low relief with piedmont plains, river terraces, which are extensively covered by aeolian sands, and floodplains. The propitious natural conditions made the region inhabited from the earliest times, settlements developing and becoming traditionally agricultural. It is dominantly rural, with 73.35% of its population living in the country-side.

The Oltenia Plain is dominantly rural, with 148 settlements, of which 9 small towns with under 20,000 inhabitants each and with a population density of 76 inh./km^2 (below the country average of 90 inh./km^2).

Current land use. Oltenia Plain is one of the most important agricultural regions in Romania. The natural conditions (relief, soils, climate, etc.) were propitious for expansion of *agricultural land* to over 79% of total surface area. Agricultural terrains include *arable land* (68.53% of total plain area), *pastures and natural hayfields* (4.46%), *vineyards and orchards* (4.7%).

In terms of structure, most of the arable area is cultivated with grain cereals –wheat and rye, maize - (over 80%) which are suggestive of a cereal-growing agriculture, followed by oleaginous plants (mainly sun-flower) over 14% and other crops (potatoes, vegetables, sugar beet, etc.) 6%.

Natural and semi-natural vegetation cover relatively small surfaces - 14.5%, of which *forests* represent 7.6%, *transitional woodland-shrubs* 2.1%, and *grassland* 5.2% because favorable natural conditions have in time led to the extension of farmland (Fig. 1).

These categories of lands are more extended along the Valley of the Danube and of the main rivers (the Olt and the Jiu) that run across the plain from north to south.

Wetlands have the largest spread along the floodplains of large rivers (the Danube, the Olt and the Jiu) and together with *water-covered areas* hold near 6% of the study-area. During the socialist period, wetlands had shrunk significantly as a result of the ample drainage and embankment works in the Danube Floodplain in view of expanding the agricultural areas.

Built-up areas cover only 5.81% of the terrains and include urban and rural settlements, different buildings for agricultural and industrial activities (greenhouses, silos, industrial sites, etc.), commercial units, sport and leisure facilities, road and rail networks, mineral extraction sites, lands covered with domestic and industrial waste, etc. The Oltenia Plain is dominantly rural, with 148 settlements, of which 9 small towns with under 20,000 inhabitants each and with a population density of 76 inh./km^2 (below the country average of 90 inh./km^2).

Impact of political, socio-economic and climatic drivers on land use pattern. Over the last 20 years, land use/land cover in Romania underwent significant changes being the result of the dynamics of political, socio-economic, technological, as well as, biophysical and climatic drivers.

As from 1989, the fall of the communist regime marked the beginning of a new, transitional period towards the market economy, a new stage in the evolution of agriculture and implicitly in land use. The most important changes of that period were seen in the space dynamics of the main land use/land cover categories and their quality, a new type of landed property and land exploitation (Popovici, 2008, 2010).

In the transition period (1990-2003), the permanent expansion of private property is the direct outcome of the decollectivisation and privatisation of agriculture, a process that begun in 1990, by the enactment of Land Law 18/1991, completed and modified by Law 169/1997 and Law 1/2000 (Popescu, 2001; Bălteanu et al., 2004, 2005). This set of laws stipulated the retrocession of agricultural and forest land to their former owners or their heirs; initially it was to be 10 ha equivalent arable land/family, eventually Law 247/2005 providing for *restitution in integrum*.

In the post-transition period (2003-to-date) corresponding to Romania's pre- and post-accession to the European Union, the main land use changes being connected with the adoption and implementation of the Common Agricultural Policies (CAP).

Some of the negative effects of the post-communist land reform were the excessive fragmentation of farming land, the emergence of large numbers of individual farms practicing subsistence agriculture, poor services for agriculture (irrigation, fertilization, mechanization, etc.). All of these have contributed to the severe degradation of the agricultural land quality, with direct impact on crop production and rural welfare.

The political and socio-economic changes that marked the transition period have created a land use system far more vulnerable to climate changes, also depleting adjusting capacity and resilience (Fraser et al., 2009). At the same time, the absence of irrigation and other land improvement systems has led to yearly crop output variations, largely dependent on climate conditions.

Over the last 20 years, climate changes were some of the most important driving forces of land use changes in the south Oltenia, especially by intensification of extreme climatic events (droughts, desertification, hail storms and floods).

In order to highlighting the changes in the land use/land cover pattern, we analyze the main phenomena of conversion, of substitution of one type of land cover for another. It is a GIS based study of Corine Land Cover data from 1990, 2000 and 2006, the main land use/land cover changes being identified and analyzed over two time spans: 1990-2000 and 2000-2006 periods (Table 1; Fig. 2).

Table 1. Land cover/Land use changes in the South Oltenia (1990-2006)

CLC classes	area 1990 ha	area 2000 ha	area 2006 ha	changes 1990-2000	changes 2000-2006
1. Artificial surfaces	47,451.2	47,696.2	47,116.7	245.0	-579.5
2. Arable land	535,198.6	535,772.9	555,615.2	574.3	19,842.3
3. Vineyards	40,368.7	40,219.1	36,699.8	-149.6	-3,519.3
4. Orchards	2,772.9	2,514.5	1,416.1	-258.5	-1,098.3
5. Grassland	55,672.5	55,774.2	42,508.2	101.7	-13,266.0
6. Forest	60,810.7	61,441.5	61,931.9	630.8	490.3
7. Transitional woodland-shrub	20,061.3	19,329.7	16,674.0	-731.6	-2,655.7
8. Inland marches	22,131.7	22,822.6	23,447.4	690.9	624.7
9. Water-covered areas	26,179.6	25,224.5	25,385.7	-955.1	161.2

Over the 1990-2000 period, structural land use changes affected some 0.87% of the overall surface, while in 2000-2006 over 6.62% of it underwent these changes. Conversion occurred either inside land use agricultural categories, or between these categories and other land use/land cover classes, such as forest or wetlands.

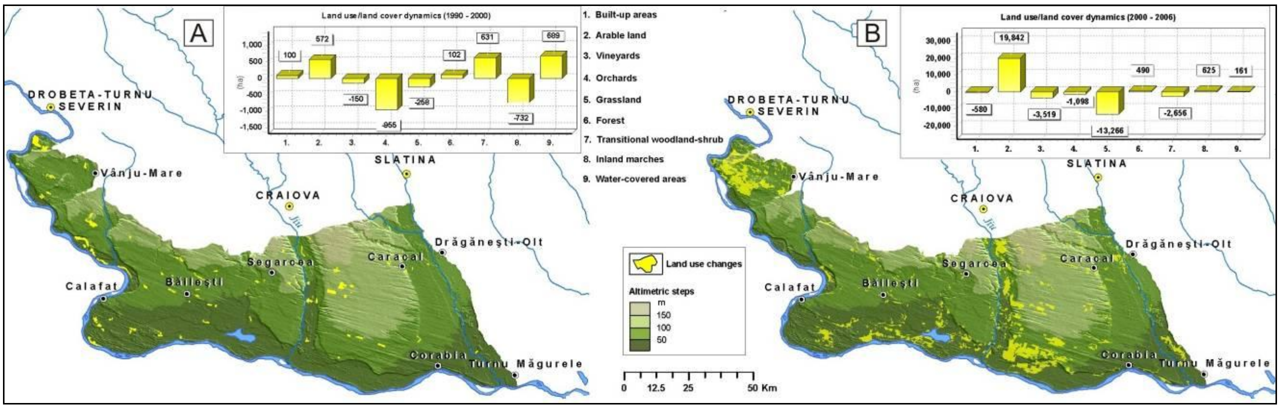

Fig. 2. Land use /land cover changes in southern Oltenia (1990-2000; 2000-2006)

Arable lands registered most significant evolutions over the 2000-2006 period (more than 19.8 thou ha), extending to the detriment of grassland, vineyards and orchards, in that, within the same interval, over 60% of Sadova-Corabia vineyard were cleared and replaced by arable terrain. Even if the arable area increased, their productive potential was largely degraded, with negative effects on the quantity and quality of agricultural production. A major problem of southern Oltenia's agriculture is the abandonment of arable terrains, particularly in low-productive regions (sand-covered areas).

If arable land stays fallow for several years, they get covered with vegetation; since identifying them on satellite images is sometimes difficult, they are listed under grassland. Several other causes for abandoning arable lands is their high fragmentation (parcels under 2 ha), money shortage with the small farmers, the absence of markets to sell the products, few if any irrigation systems, etc.

Over the 1990-2006 period orchards and vineyards areas shrank by some 5,000 ha. Large areas of ***orchards*** and ***vineyards*** were abandoned or cleared after being restituted to their former owners or to their heirs under Land Law 18/1991, new fruit-trees and vineyards being planted usually on small, dispersed plots.

Pastures and ***hayfields*** would expand to the detriment of vineyards and orchards; lose in favour of arable land, especially in the post-transition period.

Forest and Transitional woodland-shrubs. Forested areas extend in either internal, while the surface of the latter class shrank by up to 2.6 thou ha, the tree-covered surface kept growing due both to the conversion of more than 1,960 hectares of class 7 into class 6 over 1990-2000, basically 607 ha after 2000, and the reforestation of some sandy soils. Significant class 7 areas were turned into arable (2), vineyards (3), orchards (4) and inland marshes (8).

Over the 1990-2007 period, in the southern Oltenia, land use/land cover conversion mostly took place within the following classes: grassland to arable; pastures to arable; arable, grassland and forest to build-up areas; vineyards and orchards to arable or to pastures, forest to transitional woodland-shrub, arable to inland marches etc.

The climate change impact on land-use structural changes is seen, particularly in sandy soil areas (Sadova, Bechet, Corabia, Apele Vii, etc.) through intense aridization phenomena liable to enhancing future desertification over larger surfaces.

The absence of irrigation and the uncontrolled deforestation of protection belts accelerated the northward extension of desertification-affected surfaces, conducive to depleted arable-land productivity and, in time, abandonment of these lands.

Irrigation systems in the region were not operational, crops being irrigated here and there by individual owners of wells dug in the fields.

2.2.1 WHY CHOSING THIS REGION (FOR THIS SECTORAL CASE STUDY)

There is a wide range of external and internal stresses (e.g. global/local market, property change, drought) that pose great challenges for the agricultural sector, at national level as well as at regional level, generating multiple implications particularly for water and food policies. Form this point of view, the Oltenia Plain can be considered a relevant case-study that can exemplify many of the issues related to sustainable development of the agriculture sector under various environmental conditions and management practices.

Further, as stated before, the Oltenia Plain is an important agriculture region of the country affected by drought and desertification. In this case, a productive agriculture is possible through efficient use of the irrigations. In the study region, maize and wheat have the greatest share in the crop structure of the area and are further considered in the analysis.

Additionally, the main applications of the GEPIC model were conducted at global or regional scales (Liu et al., 2008; 2007; Liu, 2009). The crop yield simulations in this study are realized by applying the GEPIC model at a high spatial resolution (~ 2km). Using the model at smaller spatial scales would demonstrates the capacity of the model to be applied for local case studies and to support various land management decisions.

2.2.2 CLIMATIC CONDITIONS

There are particular local traits that characterize the climatic conditions of the case study area of the Oltenia Plain. More importantly, aridity, which is determined by general causes (solar radiation and the general atmospheric circulation) and local (the characteristics of the active surface) significantly mark the climate.

It develops thermal characteristics of more then 10 ^{o}C (exceeding 11 ^{o}C in the Danube Floodplain), precipitation between 500-600 mm/year, air humidity amid 78-80% and mean annual potential evapotranspiration of over 700 mm/year (Sandu et al, 2008; Dragotă et al., 2011), specific for the plain areas in the south of the country. Its climatic individuality, mainly supported by the coupling of air temperature and precipitations, is given by the aridity and drought phenomena. In the framework of the actual climate changes, these restrictive climatic phenomena represent the main natural hazards which are affecting the study-area (Fig. 3).

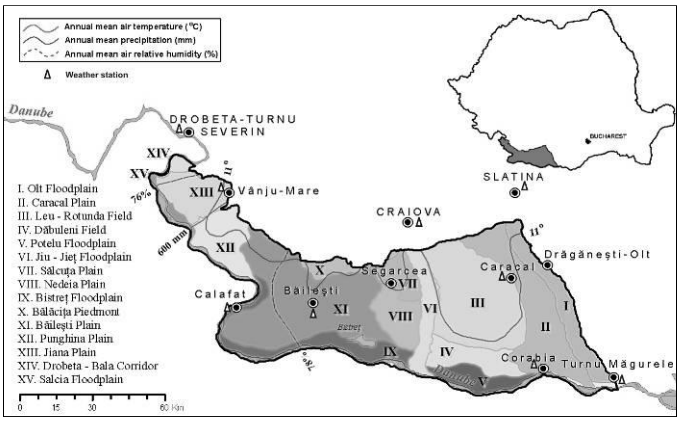

Fig. 3.The main meteorological elements in the South Oltenia

2.2.3 Meteorological conditions and their significance for agriculture

Agriculture in the Oltenia Plain is highly dependent on the meteorological conditions. Meteorological conditions as air temperature, precipitations, wind, sunny hours influence the agricultural productivity of the area in ways like variation in the crop yields and land management practices. The interval for which climatic data were collected for the present investigation is 2000-2009 (i.e. the period for which the simulations were done). This interval can be considered a period without exceeding precipitation (Fig.x). Nevertheless, one of the doughtiest years over the 2000 – 2009 interval was 2007, being further emphasized in the present investigation.

2.3 The GEPIC model

2.3.1 Brief description of the model

Developed at the Swiss Federal Institute of Aquatic Science and Technology (EAWAG) (Liu et al., 2007; 2009; http://www.eawag.ch/forschung/siam/software/gepic/index), the GEPIC model is a spatially explicit model aimed at simulating the spatial and temporal dynamics of various processes found at the interface between land and atmosphere based on a wide range of environmental conditions, plant parameters and land management measures. As such, the model is useful in investigations concerning the agroecosystems, by estimating crop yields and a series of indicators that indicate various situations of land erosion, climate influences on plant growth, water crop productivity, environmental stresses (e.g. Nitrogen and Phosphorous leaching, denitrification), land management practices, water use efficiency.

The core of the GEPIC model is a widely applied and well calibrated EPIC model which simulates the processes specific to the agroecosystems using a series of biophysical parameters and running on a daily time step. Extending the EPIC model at a spatial level was made possible through GIS techniques using a loose coupling approach that transfer the data files between the EPIC model and GIS (Liu et al., 2008).

The type of input data necessary for the GEPIC model are in raster format and include site information (latitude, longitude, elevation and slope), soil parameters, land use data, climate data, plant parameters, and management data (i.e. irrigation and fertilizer application).

2.3.2 Application of the GEPIC model for the Oltenia Plain case-study

The GEPIC model was applied for the Oltenia Plain in the southwest Romania to demonstrate the simulated crop yields of wheat and maize under environmentally stressed conditions, knowing that the area is strongly affected by drought. Subsequently, the model was used to analyze the impacts of water irrigation on wheat and maize productivity, also emphasizing on aspects of water use efficiency in case of low precipitation input.

2.3.2.1 Input data, data sources and data processing

The simulation is based on the spatial distributed parameters represented in raster maps at a spatial resolution of about 2 km x 2 km in each grid cell. The input data used for the Oltenia Plain included the following:

- ***Soil data*** (spatial data extracted from soil maps of scale 1: 200 000); the soil attributes refer to soil type, depth, bulk density, percent of sand, percent of silt, pH, etc. This set of data was obtained from the National Institute of Research and Development in Soil Science, Agro-chemistry and Environment.
- ***Climate data*** (.cvs files); data were obtained from National Meteorological Administration and represent the monthly average for precipitation, temperature and their standard deviation over 20 year interval-time (1990-2009), for 8 meteorological stations in the case-study area.
- ***Land management data*** obtained from the National Administration for Land Management – Dolj County Branch and from the Agriculture and Rural Development Agency in Dolj County referring to: irrigation water for maize and wheat (thou cubic meters) and the irrigated area, and the quantity of fertilizers applied for corn and wheat crops and the fertilized area for the 2006-2009 interval.
- ***Location data*** provided by the Institute of Geography.
- ***Land use data*** downloaded from European Environment Agency – EEA, http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-raster.

It was necessary to integrate the input data (indicators) into the GEPIC model through a series of GIS techniques and file transfer operations between the spatial data format and the EPIC format. Consequently, rasters were created for all input datasets for the Oltenia Plain: a) DEM, b) slope, c) cultivated area, d) amount of fertilizers applied for winter wheat and maize, e) annual irrigation depth, f) raster of soil types, g) raster representing the climate stations. Maps of DEM, slope, irrigation, and fertilizer show the real values of elevation (m), slope (percent), annual irrigation (mm), maximum annual fertilizer application (kg ha^{-1}). In the case of soil and climate data, the data file editor UTIL (Universal Text Integration Language) was used in order to transfer raw input data into EPIC required inputs and formats. Therefore, each grid cells of the climate and soil maps are codes that connect the grid cell with the climate and soil files. Climate files include monthly maximum and minimum temperatures, precipitations and number of wet days (monthly averages for 2000-2009 interval). The soil files refer to the following parameters for each type of soil: depth and texture (percent sand and tilt), PH, organic carbon content, calcium carbonate fraction. All rasters have a common resolution of approximately 2000 m grid cell.

Subsequent to the generation of the input rasters, the GEPIC model was run to estimate the winter wheat and maize yields both under rainfed and irrigated conditions. Emphasis was given to the analysis of a drought years, in order to assess the yields under climate stressed conditions. From climatic point of view, the period of 2000 – 2009 (i.e. for which the simulations were run) can be considered a period without exceeding precipitation. Nevertheless, one of the doughtiest years over the 2000 – 2009 interval was 2007; 2001 was chosen as a relatively normal pluvial year for the Oltenia Plain. Worth mentioning that in the study region, the irrigation is very scarcely and spatially varied (i.e. 50

mm/ha), therefore automatic flood irrigation was used in the GEPIC model.

2.3.2.2 Results

Figure 4 shows the distributions of the average rainfed crop yield for maize and wheat in 2001 and 2003 for the Oltenia Plain. Particularly maize crops show lower values of yields in the southern part of the area, one where sandy soils dominates and that is frequently found under drought stress, requiring an effective irrigation management in order to mitigate the aversive effect of climatic conditions. In these years, the maize yields in this drought-affected part of the plain reached 2 600 kg/ha as compared to 3 300 kg / ha, the value representing the average for the whole area. For wheat crops the yields in the southern Oltenia were similar to the average, around 2 900 kg /ha.

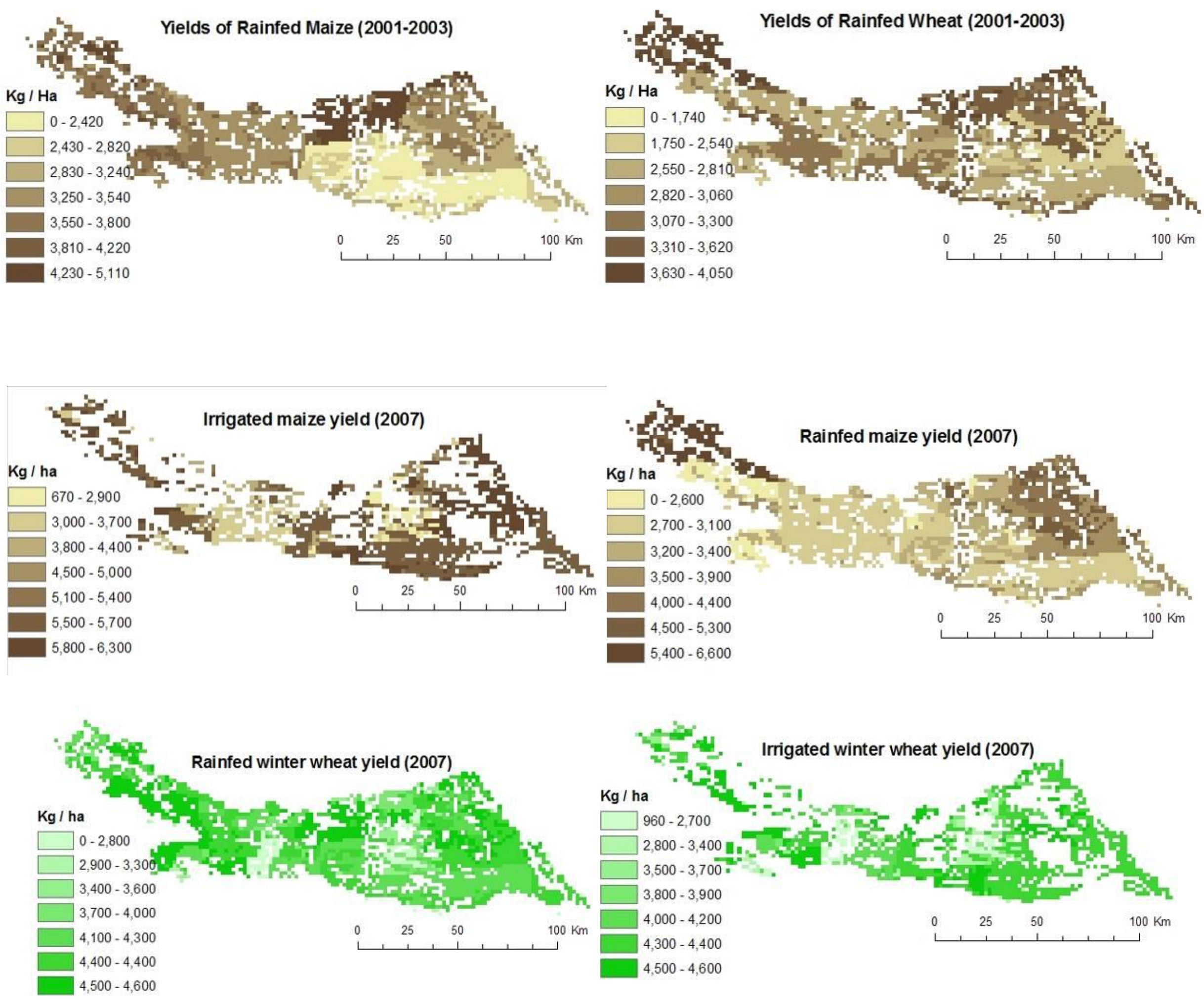

Fig. 5. Spatial distribution of rainfed and irrigated crop yields of maize and wheat in the Oltenia Plain

For simulating irrigated maize and wheat yields in the Oltenia Plain automatic flood irrigation was used in the GEPIC model. In the area there is a lack of irrigation due to outdated infrastructure corroborated with unsustainable land management and high water costs. In such situation, the irrigation is very scarcely and little (i.e. 50 mm/ha) in the Oltenia Plain.

Therefore, in the presence of sufficient irrigation, in a relatively normal rainy year the maize yields would increase by average ***1.6 times*** than the rainfed yields while in a droughty year by ***0.5 times***. The irrigation level was simulated at 236 mm in 2007 and 364 mm in 2001, on average.

The yields for irrigated wheat, in the presence of sufficient irrigation, would not differ much from the rainfed yields. For example, in a relatively normal rainy year, the wheat yields would increase by average only ***0.2 times***, while in an droughty year the difference would be nearly ***0 (-0.01 times)***. The irrigation level was simulated at 34.8 mm in 2007 and 151 mm in 2001, in average.

2.3.2.3 Irrigation scenario

In order to examine the effect of water use in agriculture, two irrigation scenarios were envisaged. One simulation was performed with the assumption of 400 mm / ha water supply in case of maize crops and 200 mm in case of wheat crops, holding other factors unchanged. For a droughty year as it is 2007, it is expected that the weighted average of rainfed and irrigated maize yields would increase by 12% on average as compared with the situation of sufficient water use for the whole area. In case of a relatively normal rainy year, the weighted average of maize yields would increase by 9% on average as compared with the situation of sufficient water use.

In case of wheat crops, applying 200mm / ha won't change the yields values obtained with sufficient water use. The potential maize and wheat yields are presented in Figure 6.

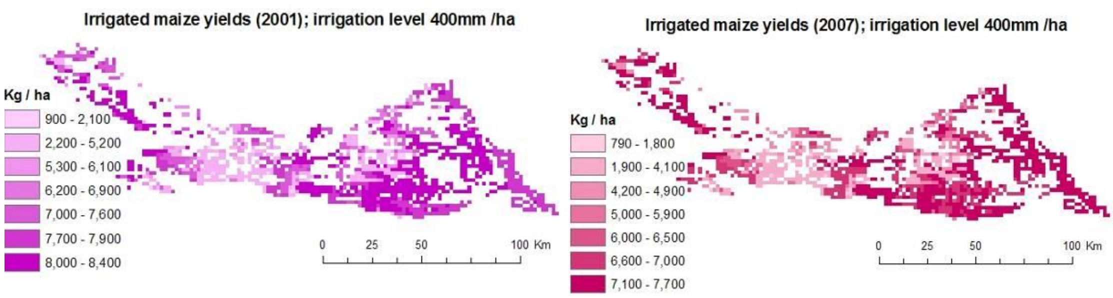

Fig. 6. Potential yields obtained with increased level of irrigated water up to 400 mm / ha

The second imagined situation was done by performing a simulation applying an irrigation level of 500 mm / ha in the case of maize crops, and 400 mm / ha in the case of wheat crops. In case of wheat crops, applying 400mm / ha won't change the average yields values obtained with sufficient water use, implying that the GEPIC model assumes a higher level of land management at least in terms of irrigated water use. Likewise, the simulation results do not change in case of increasing the irrigation level for maize crops up to 500 mm / ha as compared to a supply level of 400 mm / ha. Therefore, it can be inferred that the same yields might be obtained with less water use, holding all other parameters constant.

2.3.2.4 Fertilizer scenario

The influence of fertilizer application on crops was evaluated by one assumption of optimum (N 120 kg/ha – wheat; N 180 kg/ha – maize) nitrogen application for rainfed wheat and maize crops in the Oltenia Plain. The rates of nitrogen fertilizers were annually applied considering a constraint of sufficient phosphorous fertilizer supply (i.e. a basal dressing of 50 kg P_2O_5 / ha). The level of nitrogen supply was considered based on several long term experiments on maize and wheat cultivars carried out on one of the most common soil type (clayey-illuvial chernozem) in the Caracal Plain, which is part of the Oltenia Plain (Nedelciuc et al., 1998).

In case of an optimum use of fertilizers and of sufficient water use as it is applied in the GEPIC model, the wheat yields would increase by 5% in a droughty year, such as 2007, while the maize yields would raise insignificantly (1.6%) (Fig. 7).

For a better evaluation of the agricultural productivity under different management practices other scenarios will be created in the future, including minimum (e.g. N 60 kg/ha – wheat; N 80 kg/ha - maize) and maximum (e.g. N 180 kg/ha – wheat; N 250 kg/ha - maize) use of nitrogen, different irrigation and fertilizer levels, etc.

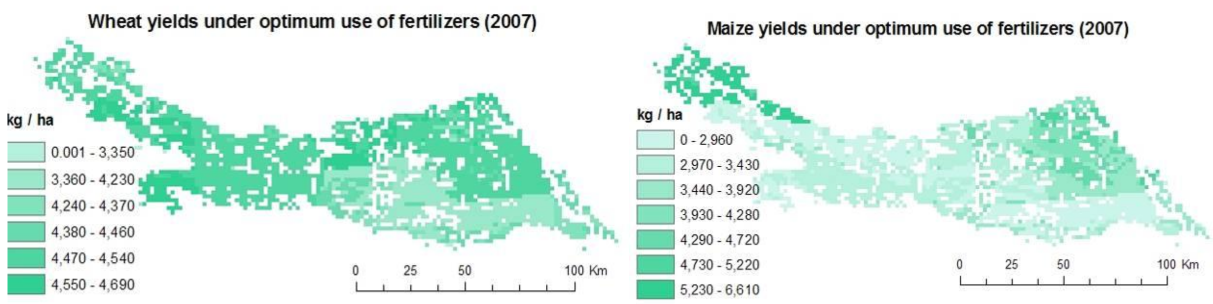

Fig 7. Potential yields obtained by applying an optimum level of fertilizers under rainfed conditions

2.3.2.5 Validation

The statistical and simulated average yields and the difference between them for maize and wheat crops are reported in Table 2 and Table 3 In Figure 8, the dashed line is the 1:1 line and the solid line is the linear trend line setting intercept at the origin. The simulated yields and the statistical yields are more or less comparable as indicated by the R^2 value (~ 0.50) for both maize and wheat crops. Therefore, the deviations of simulated yields from statistical yields could be considered moderate (Figure 8).

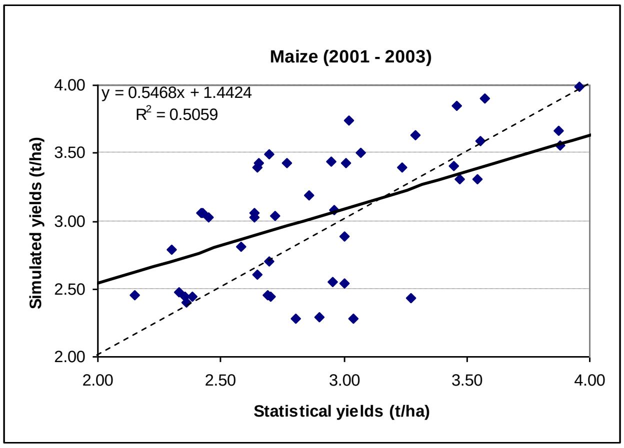

Fig. 8. Comparison between simulated maize yields and statistical maize yields over 2001 and 2003 years for the communes in the Oltenia Plain whose difference between the two datasets was below 30%.

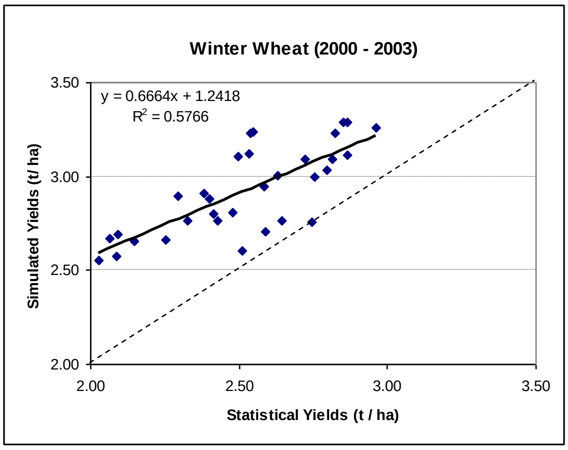

Fig. 9. Comparison between simulated winter wheat yields and statistical wheat and rye yields over 2000 and 2003 years for the communes in the Oltenia Plain whose difference between the two datasets was below 30%. For these years the statistical data do not differentiate between winter and spring wheat, but report it as wheat and rye altogether.

The reason of the deviations between simulated and statistical yields is the assumption of the automatic flood irrigation used in the GEPIC model. This assumption does not take into account the irrigation management and technology level which have a great impact on the crop yields. As already mentioned the irrigation management in the Oltenia Plain is poor due to a number of reasons among which the most important are water costs and outdated technology. Therefore, the crop yields might be largely overestimated because of the higher management level assumed in the GEPIC model than that existent in reality. Besides, the National Institute of Statistics reports wheat and rye yields altogether at commune level, while in this investigation only wheat crop was considered. More processing steps are necessary in order to precisely compare the reported and estimated results.

Table 2. Averages of statistical yields (Ystat) and simulated yields (Ysim) for maize over 2001 and 2003 years, in the Oltenia Plain. The percentage difference between the two is defined as Ydf = (Ysim - Ysta)/Ysta *100

Communes	$Y_{sta\ 2001\text{-}2003}$ ($kg\ ha^{-1}$)	Y_{sim} ($kg\ ha^{-1}$)	Y_{dif} (%)
Afumati	3447	3408	-1
Amarastii de Jos	2301	2784	21
Apele Vii	3071	3501	14
Babiciu	2454	3198	30
Bailesti	3236	3395	5
Barca	2961	3082	4
Bechet	2651	2605	-2
Brancoveni	3079	4284	39
Brastavăþu	2129	2992	40
Bucinisu	2298	3120	36
Burila Mare	3024	3738	24
Calafat	2070	3691	78
Calarasi	2702	2444	-10
Caracal	2771	3425	24
Castranova	2933	4443	51
Celaru	2421	3056	26
Cerat	2717	3652	34
Cetate	3574	3904	9
Cezieni	2565	3453	35
Cilieni	2901	2290	-21
Cioroiasi	2290	3499	53
Corabia	2359	2398	2
Cusmir	4082	3695	-9
Daneti	3498	2301	-34
Darvari	3554	3590	1
Desa	2477	3455	39
Devesel	3459	3849	11
Deveselu	2651	3392	28
Diosti	2586	3490	35
Dobrosloveni	2695	3488	29
Draghiceni	2654	3423	29
Dranic	2233	3990	79
Falcoiu	2276	3583	57
Farcasele	3469	3309	-5
Gangiova	2153	2453	14
Garcov	2955	2548	-14
Garla Mare	4706	3672	-22
Gighera	1707	2601	52
Giuvarasti	3005	2886	-4
Gogosu	4232	3830	-10
Goicea	2173	3361	55
Gostavatu	3541	3311	-6
Grojdibodu	2333	2472	6
Gruia	4320	3601	-17
Islaz	2584	2815	9
Izbiceni	3272	2431	-26

Communes	$Y_{sta\ 2001\text{-}2003}$ ($kg\ ha^{-1}$)	Y_{sim} ($kg\ ha^{-1}$)	Y_{dif} (%)
Jiana	4420	3833	-13
Leu	3050	4337	42
Lita	2638	3063	16
Lunca	2721	3040	12
Macesu de sus	3003	2536	-16
Marsani	1835	2452	34
Negoi	2950	3433	16
Obarsia	4328	2929	-32
Obarsia de Camp	3882	3553	-8
Orlea	2691	2451	-9
Osica de Jos	1835	3686	101
Ostroveni	2695	2698	0
Patulele	3875	3665	-5
Perisor	1925	3622	88
Piscu Vechi	2747	3735	36
Plopii-Slavitesti	2144	3218	50
Poiana Mare	2227	3687	66
Pristol	3290	3635	10
Punghina	3958	3992	1
Radovan	1608	3580	123
Rotunda	2057	3304	61
Rusanesti	2637	3027	15
Sadova	2357	2439	3
Salcia	5146	3885	-25
Scarisoara	2857	3186	12
Seaca De Camp	4385	3596	-18
Segarcea	2212	4469	102
Segarcea-Vale	2452	3022	23
Silistea Cruciil	1959	3534	80
Slobozia Mandra	2225	3031	36
Stoenesti	3006	3422	14
Studina	1970	3353	70
Teslui	2219	3630	64
Traian	2232	3349	50
Tuglui	3000	4495	50
Turnu Magurele	2426	3057	26
Urzica	3040	2279	-25
Vadastrita	2806	2280	-19
Valea Stanciului	2381	2443	3
Vanatori	4276	3652	-15
Vanju Mare	3455	4378	27
Vanjulet	3235	4269	32
Visina	1824	2278	25
Visina Noua	1805	2306	28
Vladila	2229	3422	53

Table 3. Averages of statistical yields (Ystat) and simulated yields (Ysim) for winter wheat over 2001 and 2003 years, in the Oltenia Plain. The percentage difference between the two is defined as Ydf = (Ysim - Ysta)/Ysta *100

Communes	Y_{sta} (kg ha^{-1})	Y_{sim} (kg ha^{-1})	Y_{dif} (%)
Garla Mare	2790	2757	-1
Burila Mare	2559	3722	45
Gruia	2822	3229	14
Pristol	2588	2704	4
Salcia	2863	3114	9
Devesel	2315	3815	65
Gogosu	2513	3743	49
Dranic	2031	3140	55
Segarcea	2964	3262	10
Cerat	2269	3014	33
Giurgita	2184	2882	32
Radovan	2057	2745	33
Dobresti	1581	2959	87
Calopar	2299	3596	56
Unirea	1589	2744	73
Cetate	2254	3257	45
Motatei	1723	3019	75
Bratovoesti	1444	3601	149
Valea Stanciului	2030	3012	48
Marsani	1190	3031	155
Castranova	1771	3638	105
Apele Vii	1815	2554	41
Leu	1916	3508	83
Maglavit	2338	3167	35
Piscu Vechi	1730	3101	79
Seaca De Camp	1994	3151	58
Afumati	1769	2695	52
Giubega	1727	2786	61
Galicea Mare	1936	2740	42
Cioroiasi	1964	2786	42
Silistea Crucii	1694	2855	69
Perisor	1925	2981	55
Celaru	1809	2980	65
Daneti	2087	2576	23
Sadova	1638	2964	81
Amarastii de Sus	2027	2551	26
Amarastii de Jos	2254	2661	18
Dabuleni	2400	2879	20
Poiana Mare	2016	2827	40
Gangiova	1520	3025	99
Macesu de Sus	2164	3161	46
Ostroveni	1817	3222	77
Gighera	2220	3241	46
Bechet	2495	3110	25
Barca	2296	2892	26
Negoi	1950	2817	45
Bistret	2040	3132	53
Goicea	1898	3146	66
Bailesti	2207	3031	37
Rast	1690	3216	90
Urzicuta	1798	2926	63
Lipovu	2003	2911	45
Teslui	2450	3440	40
Diosti	1906	3233	70
Calafat	1978	2823	43
Ciupercenii Noi	1823	2712	49
Macesu de Jos	2549	3237	27

Communes	Y_{sta} (kg ha^{-1})	Y_{sim} (kg ha^{-1})	Y_{dif} (%)
Patulele	2867	3286	15
Jiana	2841	3725	31
Vanju Mare	2499	4150	66
Vanjulet	2448	4031	65
Obarsia de Camp	3142	2603	-17
Vanatori	2631	3007	14
Cujmir	2948	2789	-5
Darvari	2744	2760	1
Caracal	2539	3233	27
Deveselu	2536	3122	23
Stoenesti	2229	3129	40
Farcasele	2583	2944	14
Brancoveni	2418	3734	54
Pirscoveni	1868	3760	101
Izbiceni	2430	2765	14
Tia Mare	2480	2808	13
Visina Noua	2414	2803	16
Dobrosloveni	2457	3356	37
Falcoiu	1729	3501	102
Gostavatu	2213	2909	31
Babiciu	2091	2691	29
Vladuleni	2111	3521	67
Osica de Jos	1987	3433	73
Cezieni	2435	3399	40
Rotunda	2382	2907	22
Obarsia	2146	2653	24
Bucinisu	2518	2546	1
Vadastrita	2834	2765	-2
Stefan Cel Mare	2861	2762	-3
Ianca	1540	2938	91
Urzica	2979	2765	-7
Visina	2326	2765	19
Brastavatu	2511	2607	4
Studina	3063	3009	-2
Rusanesti	2712	2705	0
Orlea	2056	2989	45
Redea	2849	3290	15
Traian	2755	2997	9
Scarisoara	2066	2671	29
Vladila	3261	3151	-3
Cilieni	2644	2763	4
Corabia	3410	2917	-14
Grojdibodu	2255	2987	32
Calarasi	2087	2923	40
Desa	1909	2647	39
Giuvarasti	2794	3030	8
Turnu Magurele	2815	3090	10
Segarcea-Vale	2253	3006	33
Islaz	2134	3052	43
Lunca	2171	3047	40
Slobozia Mandra	2205	3104	41
Lita	2723	3092	14
Plopii-Slavitesti	1937	3240	67

2.4 Conclusion

GEPIC provides a useful tool for simulating crop yields by integrating EPIC model with GIS. For this particular case-study the comparison between the simulated and the INS statistical yields for the communes in the Oltenia Plain suggest a moderate consensus among the figures. This could be due to a number of limitations. For instance, the accuracy of the GEPIC results depends mainly on the quality of input data. In spite of a relatively large input datasets, for this particular case-study, some parameters (e.g. fertilizers, soil profiles) were missing, especially for some areas of the NW and SE parts of the Oltenia Plain. For those areas, input values were either used from neighboring areas or as a mean for the whole county.

Nevertheless, the results suggest that the yields can be sustainable increased. This implies that better water and fertilizer management can enhance the production of cereals in the studied area. The current low values are mainly due to poor water management or low fertilizer application.

2.5 References

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