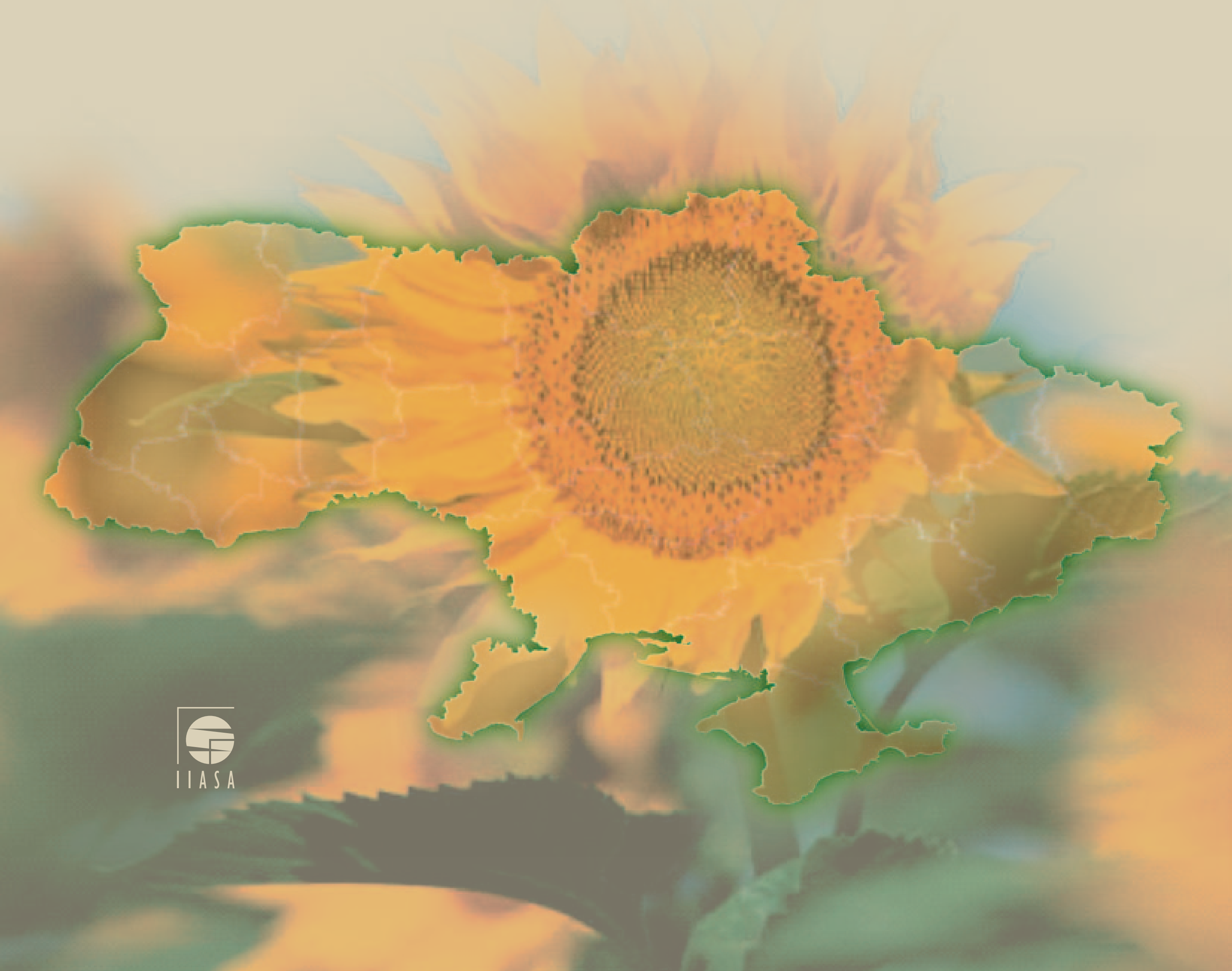
Agro-ecological Assessment for the Transition of the Agricultural Sector in Ukraine

Methodology and Results for Baseline Climate

Kateryna Gumeniuk, Natalia Mishchenko,
Günther Fischer, and Harrij van Velthuizen



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This report presents the results of a joint study between IIASA
and the Institute for Economics and Forecasting, NAS of Ukraine.
The results presented in this report are based on peer-reviewed methodologies.

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Foreword

While economic conditions for agriculture have changed considerably since the beginning of the 1990s, agricultural policy in Ukraine was focused on trying to revive the production level, without the comprehensive analysis of agro-ecological conditions, internal and external markets, infrastructure, farmers' incentives etc. Rational agricultural land use is imperative in Ukraine. Existing agricultural systems are not appropriate for changing production, technological, economic or ecological realities.

There is an urgent need for major policy changes in Ukraine towards rural welfare growth, sustainable agriculture and efficient land management, and the establishment of agricultural market networks supported by adequate legislation. With the additional pressure of transition to a market economy, a new agricultural paradigm is required.

A major challenge facing any scientific analysis of complex societal issues is the communication of research results in a way that provides policy makers and the public with helpful and reliable insights. The results reported in this study form a first comprehensive and integrated inventory of natural (land, climatic) resources and the evaluation of biophysical limitations and potentials of the crop production in Ukraine at the national, regional and subregional levels. It is hoped that the information presented in this report will contribute significantly to further development and elaboration of integrated strategies and policies towards an environmentally sustainable and internationally competitive agricultural sector.

This study builds on the collaborative research between IIASA's Land Use Change Program and Institute for Economics and Forecasting, NAS of Ukraine.

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Glossary

Agro-ecological Zones. Land resources units, with unique combination of climate, landform, soils, land cover factors..

Agronomically attainable yields. The maximum yield that can be achieved under given input and managrement circumstances for a given cultivar in a given area, taking account of climatic, soil and other physical and biological constraints.

Crop environmental requirements. The environmental conditions of land necessary or desirable for the successful growth of a crop.

Growing period. The period during the year when both moisture and temperature conditions are suitable for crop production.

Temperature growing period. The period during the year when temperature conditions are suitable for crop production).

Land. An area of the earth's surface, the characteristics of which embrace all reasonable stable, or predictably cyclic, attributes of the biosphere vertically above and below this area including those of the atmosphere, the soil and underlying geology, the hydrology, the plant and animal populations, and the results of past and present human activity, to the extent that these activities exert a significant influence on present and future uses of land by man.

Land quality. A complex attribute of land which acts in a manner distinct from the action of other land qualities in its influence on the suitability of land for a specified use.

Land suitability. The fitness of a given type of land for a specified kind of land use.

Land use. The management of land to meet human needs. This includes rural land use and also urban and industrial use.

Land utilization type. A use of land defined in terms of a product, or products, the inputs and operations required to produce these products, and the socio-economic setting in which production is carried out.

Matching. The process of comparing land use requirements with land qualities or land characteristics, to arrive at a land suitability classification.

Sustainability. A measure of whether or not a defined system of land use can be maintained at acceptable levels of productivity or service with realistic levels of input yet without progressive physical, biological, economic, or social damage to the environment on a specific site over a stated period of time.

Acronyms

AEZ	Agro-ecological Zones
CRU	Climate Research Unit of the University of East Anglia
CV	Coefficient of variation
EROS Data Centre	Earth Resources Observation Systems Data Center
FAO	Food and Agriculture Organization of the United Nations
GAEZ	Global Agro-ecological Zones
GCM	Global Circulation Model
GIS	Geographic Information System
GPCC	Global Precipitation Climatology Centre
IIASA	International Institute for Applied Systems Analysis
LAI	Leaf area index
LGP	Length of Growing Period
LGP_t	Length of Thermal Growing Period
LUC	Land Use Change Project
LUT	Land Utilization Type
mS	Marginally Suitable
MS	Moderately Suitable
NASA	National Aeronautics and Space Administration
NGA	National Geospatial-Intelligence Agency
NS	Not Suitable
S	Suitable
SI	Suitability Index
SRTM	Shuttle Radar Topography Mission
TR	Thermal Regimes
UNESCO	United Nations Educational, Scientific and Cultural Organization
VmS	Very Marginally Suitable
VS	Very Suitable

Agro-ecological Assessment for the Transition of the Agricultural Sector in Ukraine: Methodology and Results for Baseline Climate

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1. Agro-ecological zones methodology

1.1. Introduction

The AEZ methodology for land productivity assessments follows an environmental approach and provides a framework for establishing a spatial inventory and database of land resources and crop production potentials. This land resources inventory is used to assess, at specified management conditions and levels of inputs, how suitable crops/LUTs are in relation to both rain-fed and irrigated conditions, and to quantify the expected production of cropping activities relevant in the specific agro-ecological context. The characterization of land resources includes components of climate, soils, landform, and current land cover.

In its simplest form, the AEZ framework can be described in five basic elements. They are illustrated in Figure 1.1 and include:

1. *Land Utilization types (LUTs)* - Selected agricultural production systems with defined input and management relationships, and crop-specific environmental requirements and adaptability characteristics;
2. *Natural Resources database* - Geo-referenced climate, soil and terrain, land use and land cover data which are combined into a land resources database;
3. *Crop biomass and yield and LUT requirements matching* - Procedures for the calculation of potential yields and for matching crop/LUT environmental requirements with the respective environmental characteristics contained in the land resources database, by land unit and grid-cell;
4. *Assessments of crop suitability and land productivity*, and
5. *Applications for agricultural development planning*.

Over the past two to three decades, the term agro-ecological zones methodology has become widely used. However, it has been associated with a wide range of different activities which are often related yet quite different in scope and objectives. FAO and IIASA differentiate the AEZ methodology in the following activities:

First, AEZ provides a standardized framework for the characterization of climate, soil and terrain conditions relevant to agricultural production. In this context, the concepts of length of growing period (LGP) and of latitudinal thermal climates have been applied in mapping activities focusing on zoning at various scales, from sub-national to global level.

Second, AEZ matching procedures are used to identify crop-specific limitations of prevailing climate, soil and terrain resources, under assumed levels of inputs and management conditions. This part of the AEZ methodology provides maximum potential and agronomically attainable crop yields for basic land resources units.

Third, AEZ provides the frame for various applications. The previous two sets of activities result in large databases. The information contained in these data sets form the basis for a number of AEZ applications, such as quantification of land productivity, extents of land with rain-fed or irrigated cultivation potential, and multi-criteria optimization of land resources use and development.

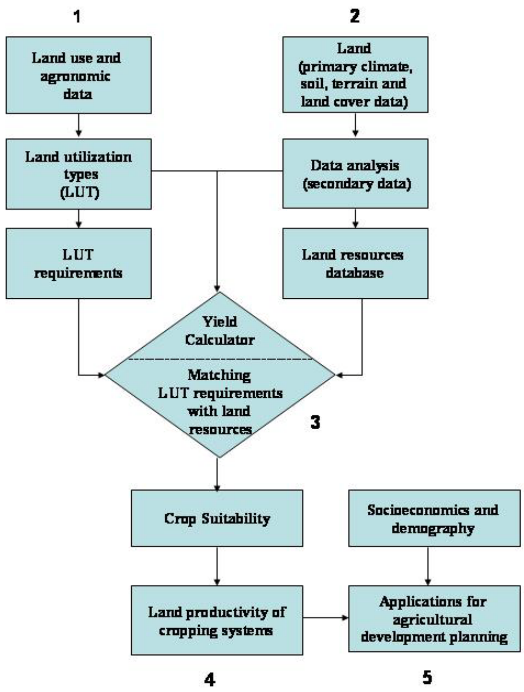

Figure 1.1. Conceptual framework of Agro-ecological Zones methodology

1.2. Overview

Figure 2.1 provides a general overview of the flow and integration of information as implemented in the agro-ecological zones (AEZ) assessment. The figure is explained in the following subsections. The subsection numbering corresponds with the numbers used in the figure.

(1) Land utilization types (LUTs):The first step in an AEZ application is the selection and description of land utilization types to be considered. LUT is defined as follows: "A Land Utilization Type consists of a set of technical specifications within a socioeconomic setting. As a minimum requirement, both the nature of the produce and the setting must be specified." Attributes specific to particular land utilization types include crop information such as cultivation practices, input requirements, crop calendars, utilization of main produce, crop residues, and by-products. For the Ukrainian study, the AEZ implementation distinguishes 79 crop, fodder, and pasture LUTs, each at three generically defined levels of inputs and management – termed high, intermediate, and low.

(2) Crop catalog: The crop catalog database provides a quantified description of LUTs. Factors included are crop characteristics such as: length of crop growth cycle, length of individual crop development stages, photosynthetic pathway, crop adaptability group, maximum leaf area index, harvest index, development stage- specific crop water requirement coefficients, yield reduction factors relating moisture stress and yield loss, food content coefficients (energy, protein), extraction/conversion rates, crop by-product/residue coefficients, and commodity aggregation weights (An example for winter wheat is shown in Table 2.1). Also included are parameters describing, for both rain-fed and irrigated LUTs, thermal requirements, vernalisation growing period requirements, and soil and terrain requirements.

(3) Climate database: Climatic data is essential for agro-ecological assessments. For the Ukrainian case study this inventory has been compiled on the basis of gridded climate parameters available from East Anglia University (CRU climatology, version 2.1) and precipitation data from the Global Precipitation Climatology Centre (GPCC) for the average climate conditions (years 1961 - 1990) as well as data for individual years from 1971 to 2000. The data has been organized in a 5-min latitude/longitude grid (100x221 grid-cells).

***(4) Climate scenarios*:** Sensitivity tests and general circulation models (GCM) based climate scenarios can be used in GAEZ. This enables the assessment of crop suitability and crop biomass and yields for assumed or predicted future climatic conditions (see Report III).

(5) Scenario derived climatic parameters: At minimum, four climatic parameters from the GCM results are used to adjust the baseline climate conditions of each grid-cell. The *difference* (ΔT) in monthly mean maximum and minimum temperatures, between a GCM climate change run and the respective GCM control experiment, is added respectively to the mean monthly maximum and minimum temperatures of baseline climate surfaces. Multipliers, i.e., the *ratio* between GCM climate change and control experiment, were used to impose changes in precipitation (ΔP) and incident solar radiation (ΔRad), respectively. When available from a GCM, changes in wind speed and relative humidity were considered as well. Each climate scenario is also characterized by level of atmospheric CO_2 concentrations (Δ CO_2) and assumed changes of crop water-use efficiency. These parameters affect both the estimated reference evapotranspiration as well as the crop biomass estimations (see Report III).

(6) Land characteristics coverages (GIS): Soils, physiography, elevation, terrain slopes, forest areas, protected areas, present land cover and land use, and administrative divisions are kept as individual layers in the geographical information system. For soils data use has been made of the soil map at 1:1,500,000 scale of the Sokolovsky Institute of Soil Sciences and Agro-chemistry in Kharkiv, Ukraine. Distributions of slope gradient and slope aspect classes by 1 km grid cell were calculated from the Shuttle Radar Topography Mission (SRTM) elevation data (3 arc-sec resolution). The SRTM is a joint project between the National Aeronautics and Space Administration (NASA) and the Department of Defense's National Geospatial-Intelligence Agency (NGA). Processed SRTM data have been used for calculating: (i) terrain slope gradients for each 3 arc-sec grid cell; (ii) aspect of terrain slopes for each 3 arc-sec grid cell; (iii) terrain slope class for each 3 arc-sec grid cell; and (iv) aspect class of terrain slope by 3 arc-sec grid cell. Products (iii) and (iv) were then aggregated to provide distributions of slope gradient and slope aspect classes by 30 arc-sec grid cell and for 5 arc-min grid cells used. Distributions of slope gradients were calculated grouping values into 9 classes: 0 - 0.5 %, 0.5 - 2 %, 2 - 5 %, 5 - 10 %, 10 - 15 %, 15 - 30 %, 30 % - 45 %, > 45 % and Slope gradient undefined (i.e. outside land mask).

A map of the protected areas at 1:500,000 scale was obtained from the Intelligence Systems GEO Ltd. (2004), and includes areas, which are not used in the agricultural production. Forest map at 1:500,000 scale was provided by the Forestry Institute of the Ukrainian National Agrarian University (2006). The Chernobyl’s exclusion zone mask was derived from National Geographic Society (2006).

The map of irrigated areas was derived from the Global Map of Irrigation Areas (FAO, 2007), which was developed by combining sub-national irrigation statistics with geospatial information on the position and extent of irrigation schemes to compute the fraction of 5 arc-min cells that was equipped for irrigation, which is called irrigation density.

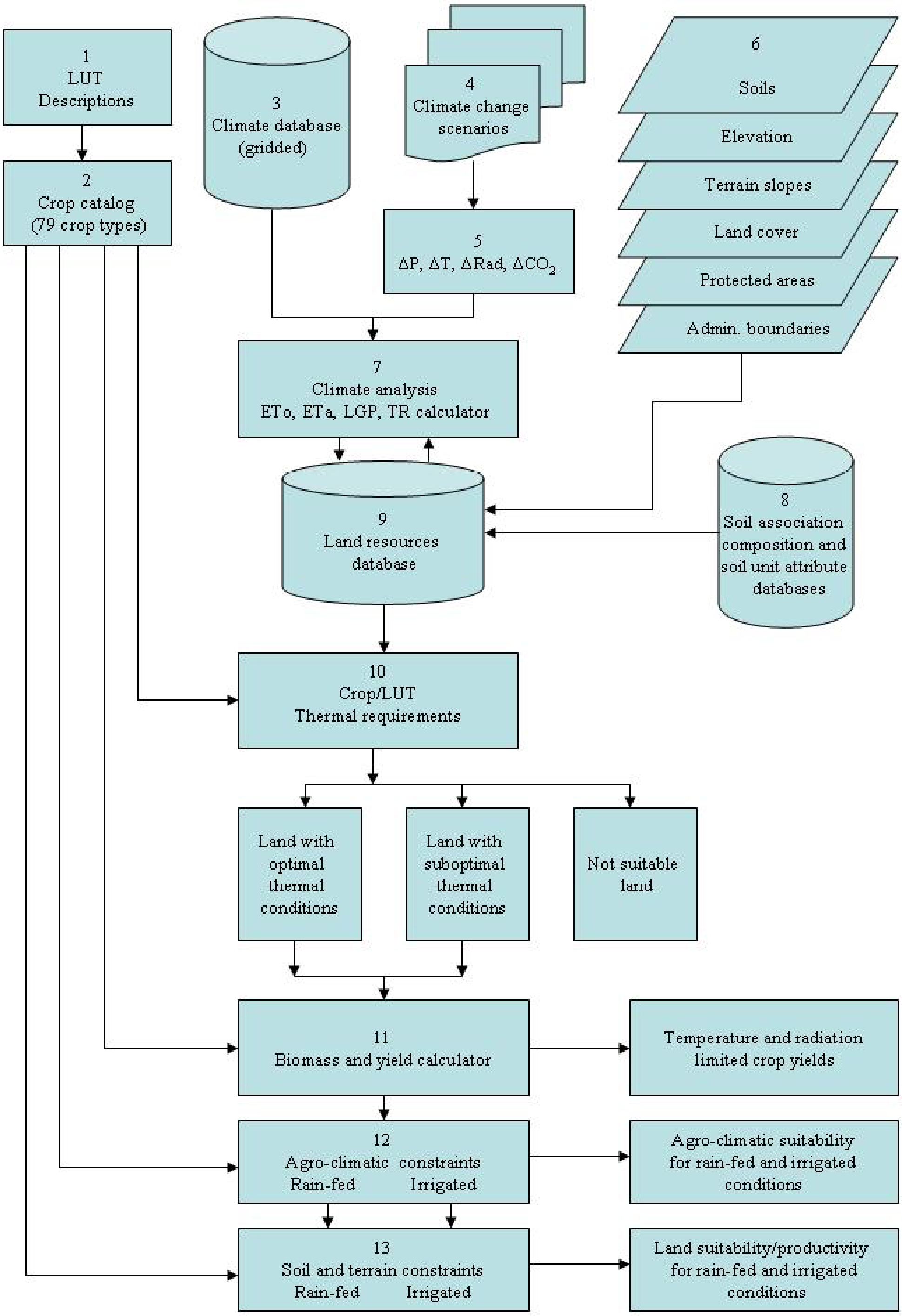

Figure 1.2. Agro-ecological Zones methodology

(7) ***Climate data analysis (ETo, ETa, LGP, and TR calculation):*** From the attributes in the climate database, monthly totals of reference evapotranspiration (ETo) are calculated for each grid-cell according to the Penman–Monteith equation. A water-balance model, comparing moisture supply to crops from precipitation and storage in soils with potential evapotranspiration, provides estimations of actual evapotranspiration (ETa), and length of growing period (LGP). The LGP calculations also indicate the number and type of growing periods per year, their starting and ending dates, and moisture excess and deficits during the

growing periods. Thermal regimes (TR) are quantified for each grid-cell in terms of four kinds of attributes, namely: thermal climates, temperature profiles, temperature growing periods (LGPt), and accumulated temperature (Tsum) calculated for various base temperatures both over an entire year as well as over growing periods.

Table 1.1. Parameterization of winter wheat, (high level of inputs)

Crop characteristics		
Adaptability Group		C3/1
Growth Cycle		110-130 days
Pre-dormancy period		30 days
Post-dormancy period		90 days
Maximum Leaf Area Index		4.5
Crop stages (%)	Initial	10
	Crop development	30
	Mid-season	35
	Late season	25
Crop water requirement	Initial	0.4
(Kc-factor)	Crop development	0.4-1.1
	Mid-season	1.1
	Late season	1.1-0.4
Moisture-stress related yield reduction	Initial	0.2
(Ky-factor)	Crop development	0.6
	Mid-season	0.75
	Late season	0.50
Crop requirements		
Thermal climates		Boreal, temperate, subtropics
Temperature profile		see Chapter 3
Growing period		see Chapter 3
Dormancy		required
Vernalization		see Annex XI
Post-dormancy accumulated temperature (optimal)		>1,400
Post-dormancy accumulated temperature (sub-optimal)		>1,300
Sensitivity to soil moisture depletion		Class 3
Soil and terrain conditions		see Chapter 3
Crop conversion factors		
Harvest index		0.45
Cereal equivalent ratio		1.0
Extraction rate		75%
Energy contents (Kcal/1000 g)		3640
Protéine contents (g/1000 g)		110
Crop residue-factor (kg dry matter/kg yield)		1.0
Crop residue utilization rate		40%
Crop by-product factor (kg dry matter/kg yield)		0.20
Crop by-product utilization rate		90%

(8) Soil association composition and soil unit attribute database: The composition of the soil associations, of the 1:1,500,000 scale soil map of Ukraine, in terms of percentage occurrence of soil units is recorded in the soil association composition database. The characterization of the soil units in terms of physical and chemical properties, prepared by the Sokolovsky Institute of Soil Sciences and Agro chemistry in Kharkiv, Ukraine, is part of this database.

(9) Land resources data base: The individual GIS layers with their attribute data and distributions at a 30 arc-sec latitude/longitude grid together with climatic resources layers of all climatic parameters (year by year) required for crop biomass and yield calculations and the assessment of agro-climatic suitability and productivity at a 5 arc-min resolution, form the AEZ land resources database.

(10) Crop/LUT Thermal requirements: Temperature profile requirements, temperature growing period requirements, and temperature sum requirements of LUTs are matched with actual temperature regimes in grid-cells. The temperature profile requirements of crops are formulated on the basis of temperature intervals of 5°C, determined separately for seasons with increasing and decreasing temperature trends. These periods are matched with the temperature profiles calculated from temperature data. When the temperature characteristics in a particular grid-cell match respectively the temperature profile requirement, length of temperature growing period, vernalization and accumulated temperature requirements, then the crop LUT is considered for cultivation and biomass/yield calculations are performed.

(11) Biomass and yield calculation: The calculation of biomass and crop yield used, is fully described in Fischer *et al.,* 2002 (see also Annex I). The constraint-free crop yields computed in the biomass module reflect yield potentials with regard to temperature and radiation regimes prevailing in the respective grid-cells. Results are geographical distributions of temperature and radiation limited yields of individual crop/LUTs.

(12) Agro-climatic constraints: Agro-climatic constraints have their origin primarily due to climate, and cause direct or indirect losses in the yield and quality of produce. Yield losses of a rain-fed crop due to agro-climatic constraints are influenced by the following conditions:

- The variability and degree of water-stress during the growing period;
- The yield-quality reducing factors of pests, diseases, and weeds;
- The climatic factors, operating directly or indirectly, that reduce yield and quality of produce mainly through their effects on yield components and yield formation;
- The climatic factors which affect the efficiency of farming operations and costs of production;
- The risk of occurrence of late and early frost.

The agro-climatic constraints in AEZ are specified by means of adjustment factors linked to the standardized evaluation of the temperature and moisture regimes in each grid-cell, i.e., they are essentially formulated based on length of thermal growing period (LGPt), length of moisture growing period (LGP) and length of growing period with T>10°C ($LGP_{t=10}$). In addition, the factors depend on crop type and level of inputs/management. Applications of the agro-climatic constraints to the calculated radiation limited yields (11) provide agro-climatic suitabilities and agro-climatically attainable biomass and yields for the crops/LUTs assessed.

(13) Soil and terrain constraints: The agro-edaphic suitability assessment is based on the comparison of edaphic requirements of rain-fed and irrigated crop/LUTs and prevailing soil and terrain conditions. The edaphic assessment also reflects constraints imposed by landform and other features that do not directly form a part of the soil but may have a significant influence on the use that can be made of the soil. Distinction is made between internal soil requirements of crop/LUTs, such as soil temperature regime, soil moisture regime, soil fertility, effective soil depth for root development, and other physical and chemical soil properties, and external requirements related to soil slope, occurrence of flooding and soil accessibility. The results of matching the crop/LUT-specific edaphic requirements to the soil and terrain attributes of individual grid-cells, in combination with calculated potential biomass and agro-climatically attainable yields, provides a suitability classification for each rain-fed and irrigated crop/LUT, respectively, at high, intermediate, and low levels of input circumstances.

2. Natural resources

2.1. Introduction

A natural resources database is compiled for assessing under specified management conditions and levels of inputs suitabilities of crops/LUTs for both rain-fed and irrigated conditions, and quantifying expected production of cropping activities relevant in the agro-ecological context of Ukraine. The characterization of natural resources includes components of climate, soils, landform, and present land cover. Inherent in the methodology is the generation of a climatic inventory to predict agro-climatic yield potentials of crops. The Ukrainian AEZ study uses the climatic data set compiled by the Climate Research Unit at the University of East Anglia and precipitation data from the Global Precipitation Climatology Centre (GPCC). The databases offer a spatial resolution of 5 arc-min latitude/longitude and contain climate averages for the period 1961-1990 as well as year-by-year data of the period 1971-2000. The year-by-year historical databases are used to quantify: (i) prevailing thermal and moisture conditions(ii) the length of growing period parameters, including year-to-year variability, and (iii) to estimate for each grid-cell by crop/LUT, average and individual years agro-climatically attainable crop yields, variability etc.

Adequate agricultural exploitation of the climatic potentials and maintenance of land productivity largely depend on soil fertility and the management of soils on an ecologically sustained basis. The climatic inventory was superimposed on gridded1 1:1,500,000 soil map of Ukraine, provided by the Sokolovsky Institute of Soil Sciences and Agro chemistry in Kharkiv, Ukraine. This map presents soil associations in a 30 arc-sec latitude/longitude grid, and forms the spatial basis of soil information in Ukraine AEZ. The composition of soil associations is described in terms of percentage occurrence of soil units. Therefore, each 30 arc-sec grid-cell is considered as consisting of several land units.

Terrain slopes were derived from the Shuttle Radar Topography Mission (SRTM) elevation data a grid of 30 arc-sec latitude/longitude. Rules based on altitude differences of neighboring grid-cells were applied to compile a terrain-slope distribution database at 30 arc-sec grid cell in terms of distribution of nine average slope range classes.

2.2. Climatic resources

In the AEZ approach, as in any bio-geographic inventory, temperature, water and solar radiation are the key climatic parameters. These parameters condition rates of net photosynthesis allowing plants to accumulate dry matter and to accomplish the successive plant development stages. Data on climatic requirements of crop growth, development and yield formation are the basis for the compilation of the AEZ climatic inventory. Also, crops need to be characterized for their thermal and moisture adaptability. Prevailing temperatures determine crop performance when moisture conditions are met. Similarly, when temperature requirements are met, the growth of a crop is dependent on how well its growth cycle fits within the period when water is available. The latter has led to the concept of length of growing period (LGP). It provides for an environmental characterization particularly relevant to agricultural assessments. The length of growing period is defined as the number of days when both water availability and prevailing temperatures permit crop growth. Depending on its length, the growing period may allow for no or only one crop per year or it may allow to grow more than one short cycle crops within one year. In Ukraine AEZ implementation, LGP

[1] The map was converted to the 30 arc-sec grid at IIASA.

is used to determine periods within a year available for rain-fed crop production, and to select applicable agro-climatic constraints.

Climate data

For the update of the Ukrainian AEZ study updated time series data are used from the Climate Research Unit's gridded monthly climate data for the period 1971-2000 (CRU TS 2.1[2]; Mitchell & Jones, 2005) and precipitation data from the Global Precipitation Climatology Centre (GPCC). The grids have been recalculated for 1971-2000. Table 4.1 presents the climate parameters held in the CRU database. Median annual precipitation map produced from the GPCC database is presented below in Figure 2.1.

Table 2.1. Attributes in the CRU climate databases

Monthly variables (Normals 1961-1990)	Monthly variables (Historical data 1971-2000)
• Precipitation	• Wet days frequency
• Wet days frequency	• Mean temperature
• Mean temperature	• Diurnal temperature range
• Diurnal temperature range	• Vapour pressure
• Vapour pressure	
• Cloud cover	
• Sunshine (n/N)	
• Ground-frost frequency	
• Windspeed	

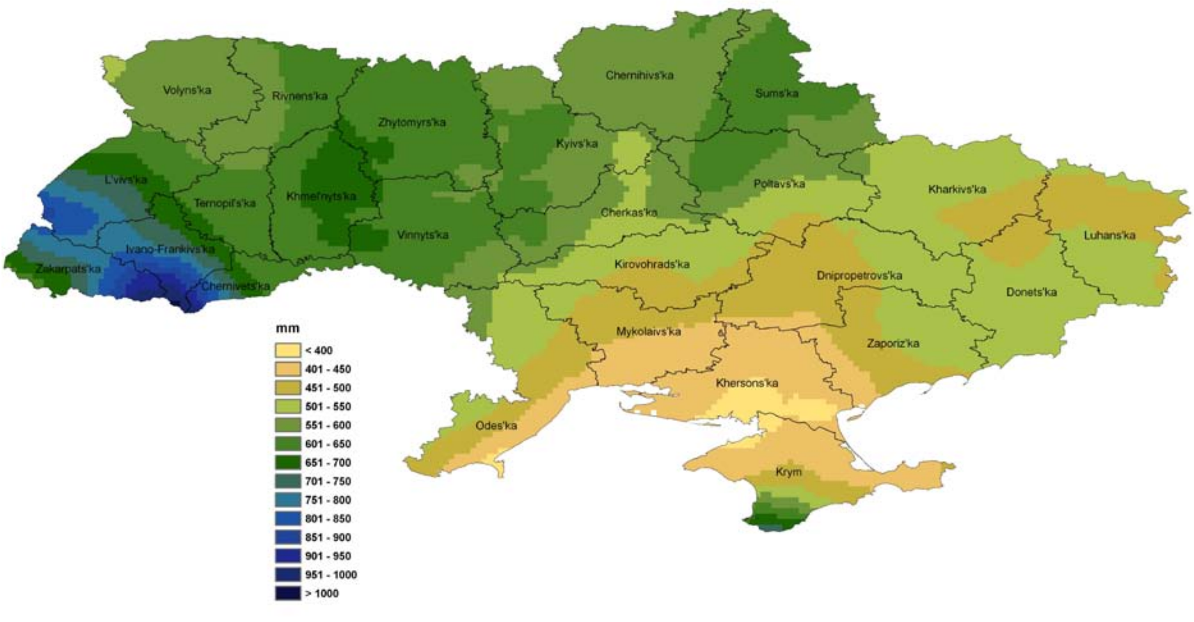

Figure 2.1. Median annual precipitation (1971-2000)

[2] Climate data base itself covers the period from 1901 to 2002.

Thermal regimes

Temperature and radiation influence the rate of photosynthesis. However, plants also have an obligatory development in time, which must be met if the photosynthetic assimilates are to be converted into economically useful yields of satisfactory quantity and quality. Temperature (and day-length in case of photosensitive crops) influences the developmental sequence of crop growth in relation to crop phenology. Therefore, the temperature regime and photo-periodicity govern the selection of the crops that can be cultivated. In some cases, temperature may determine whether a particular development process will be initiated or not (e.g., chilling requirements for initiation of flower buds). Low temperatures can also delay flowering and fruit setting. For photosensitive cultivars, day-length plays an important role in determining the time of flowering.

Evolutionary changes that have occurred in the biochemical and physical characteristics of photosynthesis have resulted in a large variation between crops in both their optimum temperature requirements and the responses of photosynthesis to changes in temperature and radiation. These responses depend on the nature of the photosynthetic pathway. In general, the C3 pathway of assimilation is adapted to operate at optimum rates under lower temperature conditions than the C4 assimilation pathway. However, breeding and selection (both natural and under human influence) have changed temperature responses of photosynthesis in some C3 and C4 species. It is therefore possible to make a division of the major food crops according to their assimilation pathway and corresponding temperature requirements. Four groups have been recognized in AEZ applications:

Group I C3 species adapted to lower temperatures (e.g., wheat, potatoes);

Group II C3 species adapted to higher temperatures (e.g., soybean, rice);

Group III[3] C4 species adapted to high temperatures (e.g, maize);

Group IV C4 species adapted to lower temperatures (e.g., foxtail millet, maize).

Figure 2.2 shows for each crop group examples of the relationship between the rate of photosynthesis at optimum temperature and photosynthetically active radiation. Figure 2.3 illustrates for each group of crops the typical (inverted) u-shaped effect of temperature on the leaf photosynthesis.

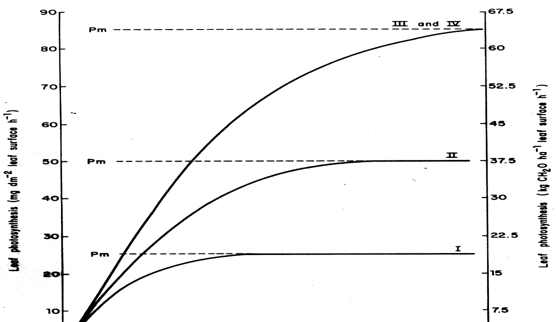

Figure 2.2. Relationship between leaf photosynthesis rate[4] at optimum temperature and photosynthetically active radiation (Ar) for crop groups I, II, III and IV (FAO, 1978-81)

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[3] Not applicable to Ukrainian climatic conditions.

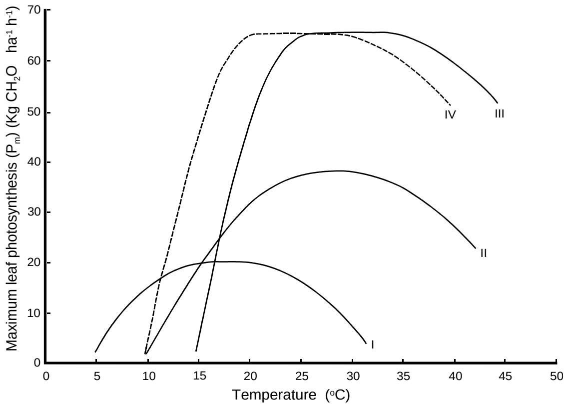

Figure 2.3. Examples of relationships between maximum leaf photosynthesis rate (Pm) and temperature for crop groups I, II, III and IV (FAO, 1978-81)

To cater for differences in thermal requirements of crops, an adequate characterization of the temperature regimes is required, applicable for a wide range of locations. The characterization of the temperature regimes in the present approach comprises of four parts, namely:

- Thermal climates, representing major latitudinal climatic zones;
- Temperature profiles, providing quantification of temperature seasonality;
- Temperature growing periods (LGP_t), representing the periods during which average daily temperatures exceed specified minimum levels; and
- Accumulated temperature, calculated for various base temperatures.

Thermal Climates

The thermal climates are obtained through classifying of monthly temperatures corrected to sea level (with an assumed lapse rate: 0.55°C/100m). For the classification of latitudinal thermal climates, the AEZ major climatic divisions of tropics, subtropics with summer rainfall, subtropics with winter rainfall, temperate, boreal and polar/arctic divisions. Ukraine is situated in the temperate belt which has been further subdivided according to continentality into three classes, namely: oceanic, sub-continental and continental. Table 2.2 presents the thermal climate classification used for temperate climate.

Table 2.2. Thermal climates

Thermal climate classification	
Temperate At least one month with monthly mean temperatures, corrected to sea level, below 5°C and four or more months above 10°C	***Oceanic Temperate*** Seasonality less than 20°C*
	Sub-continental Temperate Seasonality 20-35°C*
	Continental Temperate Seasonality more than 35°C*
* Seasonality refers to the difference in mean temperature of the warmest and coldest month, respectively.	

Temperature profiles

The quantification of temperature seasonality accounts for year-round temperature regimes. They are expressed in number of days falling into pre-defined temperature intervals. These intervals comprise of five-degree centigrade steps, subdivided respectively in periods

[4]The leaf photosynthesis values presented in Figure 4.2 and 4.3 reflect current levels of atmospheric carbon dioxide concentrations.

with increasing and decreasing temperatures. ‘A’ classes are used for increasing temperatures and ‘B’ classes for decreasing temperatures. A complete account of time periods of individual temperature intervals provides a year-round temperature profile. These profiles have been calculated for each grid-cell; examples are shown in Table 2.3

Table 2.3. Examples of mean temperature profiles for Kyiv, Yalta, Uzhhorod and Dnipropetrovs’k

Temperature intervals		Temperature Periods (days)			
		Kyiv	**Yalta**	**Uzhhorod**	**Dnipropetrovs’k**
		Latitude: 50º21’ Longitude: 30º29’ Altitude: 180m	Latitude: 44º54’ Longitude: 34º13’ Altitude: 123m	Latitude: 48º63’ Longitude: 22º29’ Altitude: 126m	Latitude: 48º38’ Longitude: 34º96’ Altitude: 101m
A9	< -5ºC	17	0	0	13
A8	-5-0ºC	32	0	37	36
A7	0-5ºC	20	50	29	19
A6	5-10ºC	18	36	27	16
A5	10-15ºC	25	29	31	23
A4	15-20ºC	81	24	76	41
A3	20-25ºC	0	51	0	45
A2	25-30ºC	0	0	0	0
A1	> 30ºC	0	0	0	0
B1	> 30ºC	0	0	0	0
B2	30-25ºC	0	0	0	0
B3	25-20ºC	0	34	0	23
B4	20-15ºC	40	28	46	26
B5	15-10ºC	26	30	30	21
B6	10-5ºC	24	37	26	24
B7	5-0ºC	28	46	29	30
B8	0- -5ºC	37	0	37	36
B9	< -5ºC	17	0	0	13

Temperature growing periods and temperature sums

In addition to thermal climates and temperature profiles, temperature growing periods (LGP_t) have been inventoried. $LGP_{t=5}$ of 5°C, i.e., the number of days when mean daily temperature exceeds 5°C, represents the period with temperatures suitable for crop growth. Similarly $LGP_{t=10}$ of 10°C approximates the frost-free period. Lengths, beginning dates and ends of such periods are calculated for each grid-cell and are stored in the attribute database. Also, for various base temperatures, accumulated temperatures have been calculated for each grid-cell. Figure 2.4 presents the accumulated temperature on days with mean temperature above 5°C.

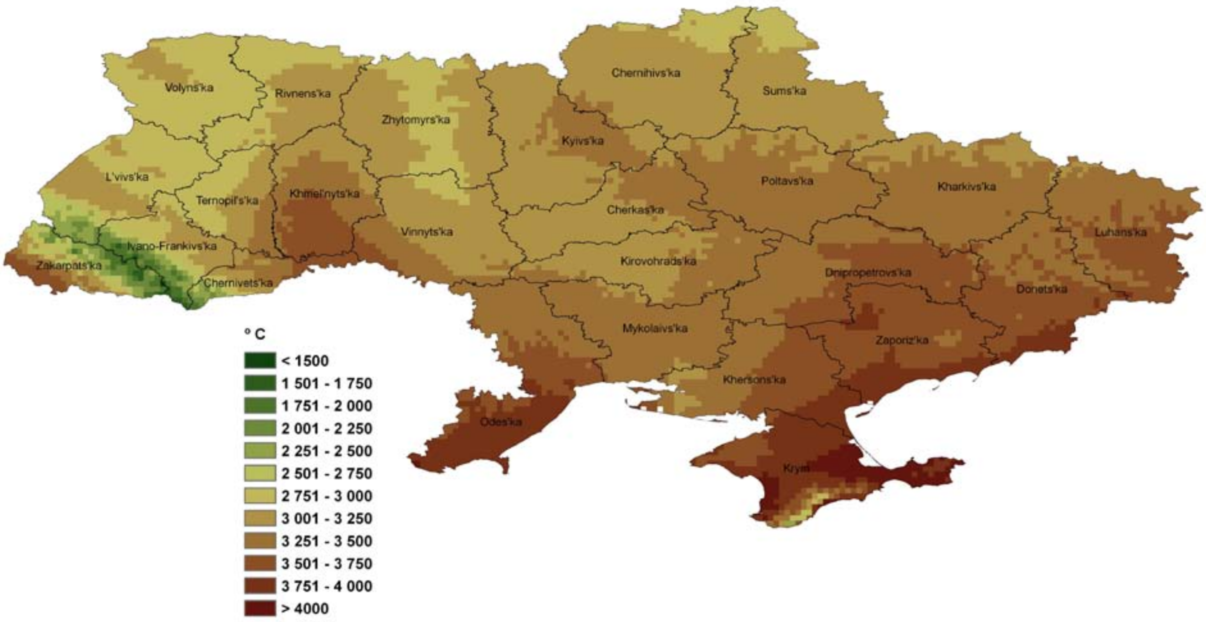

Figure 2.4. Median annual temperature sum (T_{sum} > 5°C) (1971-2000)

Moisture regimes

A general characterization of moisture conditions is achieved through the concept of *length of growing* period (LGP), i.e. the period during the year when both moisture availability and temperature are conducive to crop growth. Thus, in a formal sense, LGP refers to the number of days within $LGP_{t=5}$ when moisture conditions are considered adequate.

The amount of moisture required to sustain growth of germinating crops is well below evapotranspiration demand of crops at maximum canopy cover. For establishing crops, 0.4 - 0.5 times the level of reference evapotranspiration is considered sufficient to meet water requirements of dryland crops. Details of the calculation of potential evapotranspiration are presented in Annex II.

The growing period for most crops continues beyond the rainy season and crops may mature on moisture stored in the soil profile. Depletion of soil moisture reserves causes the actual evapotranspiration to fall short of the potential rate. Soil moisture storage capacity of soils (S_{max}) depends on soil physical and chemical characteristics, but above all on effective soil depth or volume. For the soil units/soil phases of the soil map of Ukraine, AEZ procedures have been applied for the estimation of S_{max} The results are summarized in Table 2.4. The classes that were estimated for individual soil units and are presented in the Annex III. The relevant values for individual soil units in a grid-cell were used to set limits to available soil moisture, enabling calculation of possible extension of the growing period beyond the end of the rainy season by soil unit, soil texture class, and soil phase.

Table 2.4. Soil moisture storage capacity classes derived for soil units and for soil depth/volume limiting soil phases

Class	(mm)	Soils with Skeletic and Rudic Phases)
1	150 mm	75 mm
2	125 mm	65 mm
3	100 mm	50 mm
4	75 mm	40 mm
5	50 mm	25 mm
6	15 mm	n.a.

In addition to taking into account soil specific S_{max} values, a number of specific procedures in the growing period analysis are implemented:

I. The beginning of a growing period is reached when three basic conditions are met:

(i) average daily temperature is above 5°C, (ii) actual evapotranspiration (*ETa)* exceeds a specified fraction of the estimated reference evapotranspiration, i.e.,

$$ETa_j \geq \alpha ETo_j, \qquad \alpha = 0.4 - 0.5^{5} \qquad (4)$$

and, (iii) sufficient moisture has been accumulated in the soil profile for establishing crops. However, the start of a growing period may be delayed because of excessive wetness due to snowmelt, especially in flat terrain with poorly drained, medium to fine textured soils. This may result in saturated soil conditions with low bearing capacities presenting problems for timely seeding/planting. It also will severely affect the oxygen supply to the roots of the hibernating crops.

Depending on the amount of excess moisture the following assumptions were adopted for the delay of the effective start of a growing period:

Table 2.5. Delay of the growing period start due to excess wetness

Excess moisture from snowmelt (mm)	Excess moisture at start of $LGP_{t=5}$ (mm)		Delay of start of growing period due to excess wetness (days)	
	Very poorly drained soils	Poorly/imperfectly drained soils	Very poorly drained soils	Poorly/imperfectly drained soils
40	0	0	0	0
80	20	0	5	0
120	60	30	15	10
180	120	90	30	20
240	180	150	45	30

Note: Drainage classes are according to the FAO Guidelines for Soil Description (FAO, 1990).

A growing period ends when soil moisture supply becomes insufficient or temperature becomes limiting, i.e., on the day when first

$$ETa_j < \beta\, ETo_j, \qquad \beta = 0.4 - 0.5 \qquad (5)$$

or when average daily temperature falls below 5°C. In this way all the growing periods within a year are fully determined with starting and ending dates, length in number of days, and reference *ETa* values. Where applicable, the procedure also records the dates and length of a dormancy period (see below) and of any humid period during a growing period, defined as days when rainfall exceeds reference evapotranspiration, i.e., with $P > ETo$.

II. The water-balance calculation detects and handles specific conditions during cold-breaks or dormancy:

- frozen topsoil: $T_{mean} < 0°C$*, then (*$ETa = 0$*),*
- LAI development expressed as transpiration gradients, after start of growing period or restart after dormancy period.

The calculation procedures include accumulation of snow stocks and the time periods required to melt snow stocks. Two temperature thresholds control the calculations. When

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[5]In the current calculations the value of $\alpha = 0.5$ was used.

maximum daily temperature falls below a defined limit, then any precipitation occurring is assumed to be in the form of snow and is accumulated as snow stock. During such periods, the sublimation of the snow stock is accounted for. The sublimation rate is a model variable and is set at S_c=0.2. When average daily temperature exceeds the freezing point, melting of snow stocks is modeled by a linear relationship in proportion to maximum daily temperature exceeding a defined threshold (model variables for snow melt are set at 5.5 mm/day/^{o}C, when $T_{max} > 0^oC$).

III. Discontinuous growing periods with a dormancy period have been separated from those with a cold-break on the basis of temperature limits (T_h) for survival of hibernating crops. (Table 2.6). An upper limit to the length of the dormancy period can be set. When the duration of the dormancy period exceeds this maximum, the dormancy period is treated as being a cold-break. In the present calculations, the maximum duration of the dormancy period has been set, as a model variable, at 200 days.

Table 2.6. Temperature limits (average 24-hour monthly temperature) for hibernating crops without snow cover*, °C

Crop	Sub-continental climate , T_h	Continental climate, T_h
Winter rye	-16	-11
Winter wheat	-11	-8
Winter triticale	-10	-7
Winter barley	-7	-5
Winter rape	-5	-3

* each 10 cm of snow cover allows for 1.1°C lower temperate.

IV. A vernalization module accounts for temperature effects on development responses of hibernating crops, and is expressed in effective vernalization days (VD). Vernalization response is important for matching the plant growth cycle to the environment in which it is grown, so it can make the best use of the seasonal opportunities for growth and avoid adverse climatic factors (see Annex XI).

The procedures allow calculation of growing periods for individual years by using in the waterbalance time-series of rainfall and evapotranspiration. This provides a quantification of year to year variability of the moisture regime. Figure 2.5 presents the median length of growing period (LGP) calculated for each individual year on the basis of historical time-series of climate data for the period 1971-2000, assuming 100 mm soil moisture storage capacity. The results by grid-cell have been aggregated and are presented in terms of six broad LGP classes (90–120 days, 120–150 days, 150–180 days, 180–210 days, 210–240 days and ≥ 240 days). Figure 2.6 presents the coefficient of variation (CV) of the LGP (1971-2000) and highlights spatial and temporal variability of length of growing period in Ukraine over 30-years period. Areas with particular high variability in year-by-year growing conditions are found in the Eastern and some areas of the Central parts of Ukraine, where CV of the LGP is higher then 20%.

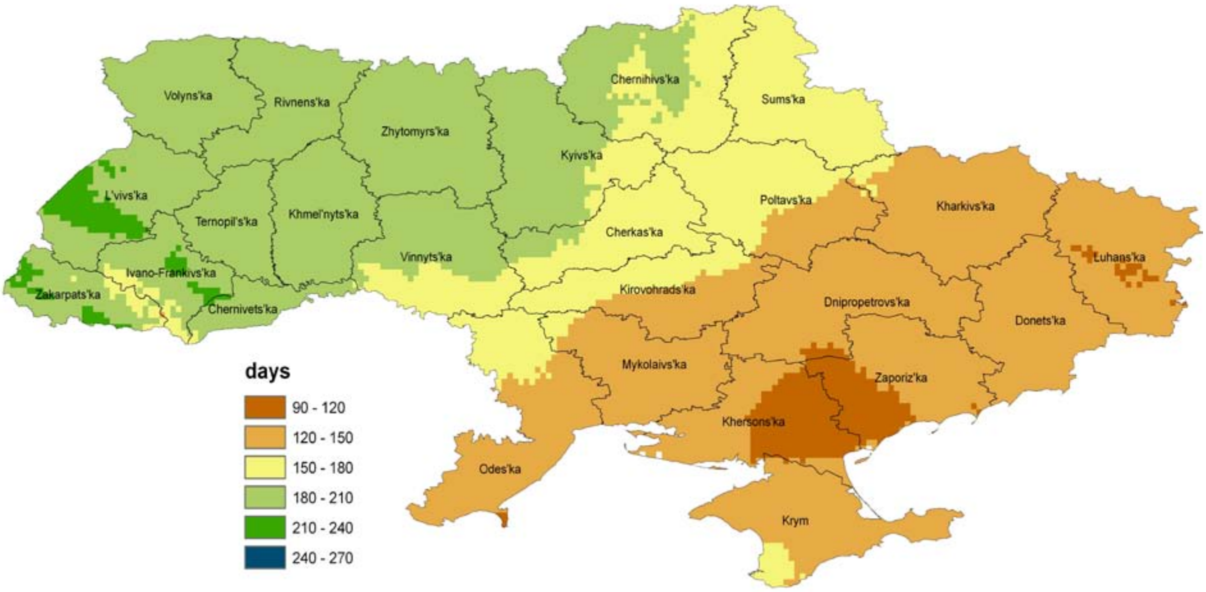


Figure 2.5. Median Length of Growing Period (days) for the period 1971-2000

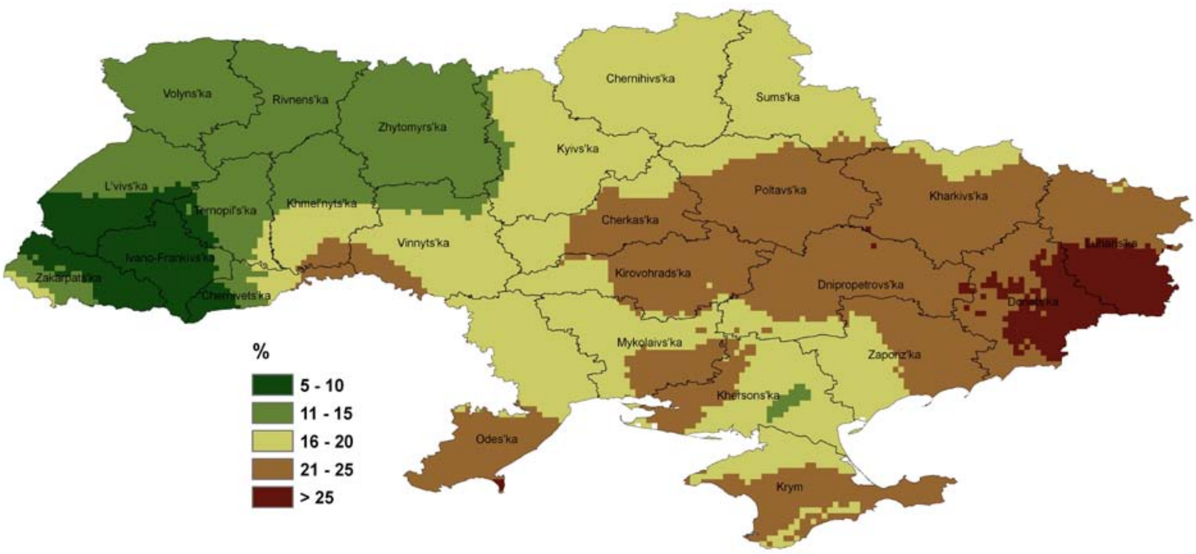


Figure 2.6. CV (%) of Length of Growing Period (LGP) for the period 1971-2000

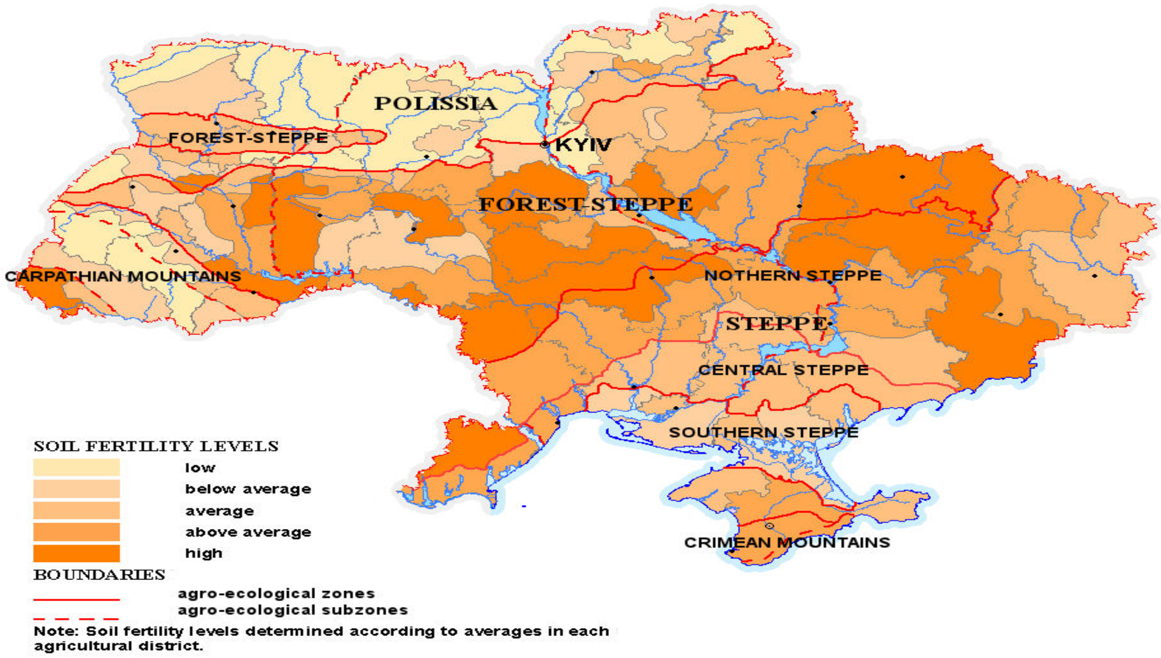
2.3. Soil and Terrain Resources

Soil resources

The source of soil information used in this AEZ study for Ukraine is based on a digital 30 arc-seconds resolution soil inventory of Ukraine. This inventory consisting of a GIS layer of soil associations map units, and to this linked attribute files containing (i) composition of the soil associations and (ii) characterization of the soil units in terms of physical and chemical properties (i.e., soil texture, bulk density, drainage, organic matter, pH (H_2O), calcium carbonate, total exchangeable bases, base saturation, salinity, sodicity and occurrence of gravel), is based on the 1:1,500,000 scale soil map of Ukraine as compiled and published by the Institute of Soil Sciences and Agro chemistry in Kharkiv, Ukraine. The soil unit type information has been correlated to the FAO '90 revised Legend (FAO/UNESCO/ISRIC, 1990), which are defined in terms of measurable and observable properties of the soil unit itself. Many of the properties are directly relevant to agricultural production potential.

Generally, considering the whole of Ukraine, the natural fertility of the soils is high (see Figure 2.7). Agricultural regions are located in central and southern Ukraine. In the total area of the country's arable lands 68% is dominated by Chernozems (Medvedev et al., 2001).

Soil degradation linked to the exploitation of land resources is a widespread problem influencing land productivity in Ukraine. According to the National Report on Environment (1999), topsoil erosion affected 57% of the arable land, of which some 32% by wind erosion, 22% by water erosion, and 3% by a combination of both. According to estimates by the Ukrainian Institute for Soil Science and Agrochemistry Research, loss of organic matter in soils is in the range of 0.6-1.0 ton per ha annually (Medvedev et al., 2001). Main soil degradation problems are: (i) compaction of the topsoil, which is deteriorating the soil structure, water holding capacity, root penetration, tuber development, run-off of mineral fertilizer; (ii) insufficient replenishment of nutrients both chemical and organic fertilizers.



Source: Atlas of Ukraine, 2000, Institute for Geography NASU / Intelligence Systems GEO.

Figure 2.7. Soil Fertility in Ukraine

Terrain resources

The terrain-slope database was established by using a rule-based algorithm to calculate slope distributions in terms of nine slope classes is based on neighborhood relationships among grid-cells in the 30 arc-sec the Shuttle Radar Topography Mission (SRTM) elevation data (Figure 2.8).

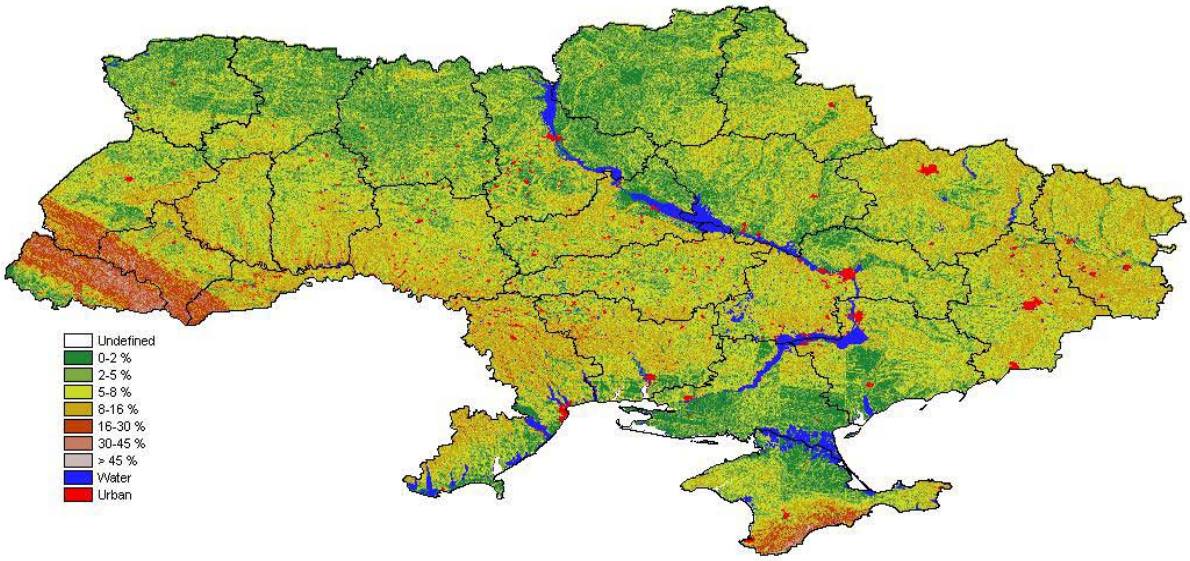


Figure 2.8. Dominant slope classes[6]

Soil and Terrain constraints

In addition to the crop-specific suitability assessments (see Chapter 3), the land resources inventory allows characterization of various regions according to the prevailing soil and terrain constraints. A constraint classification has been formulated and has been applied to each grid-cell of the land resources inventory. The constraints considered include:

- Terrain-slope constraints
- Soil depth constraints
- Soil fertility constraints
- Soil drainage constraints
- Soil texture constraints
- Soil chemical constraints
- Presence of miscellaneous land units

The digital soil and terrain information constitutes part of the land resources database and is kept together with other geographic information (i.e., elevation, terrain slopes, protected areas, land cover, and administrative divisions).

2.4. Land use and land cover

Agricultural land covers almost 42 million ha, of which 78% is sown with annual crops (arable land). The share of the agricultural land is most prominent in Central (Forest-Steppe) and especially in Southern (Steppe) zones, where more than 80% of all land is cultivated.

Forests and forested areas occupied about 10 million ha or 16% of Ukraine, i.e. 0.2 ha per capita. Forests areas are mainly found in the northern flat part of Ukraine (Polissia) and in mountain regions of the Carpathian and Crimean mountains that have the greatest forest areas (see Figure 2.9).

After the Chernobyl accident, large areas of Ukraine, Belarus and Russia were contaminated by radiation. In terms of agricultural land, 4.6 million ha or 12% of Ukraine's farmland areas were affected by high levels of contamination. Presently concern continues

[6] Classes 0-0.5% and 0.5-2% are combined into one class 0-2%.

about the soil and forest contamination with Stroncium-90 and Cesium-137, which have half-lives of about 30 years, i.e. Exclusion Zone.

At the present, agricultural lands occupied roughly 70% of the territory, forest and forest-covered areas 17%, built-up areas – about 4%, and internal waters occupy around another 4%.

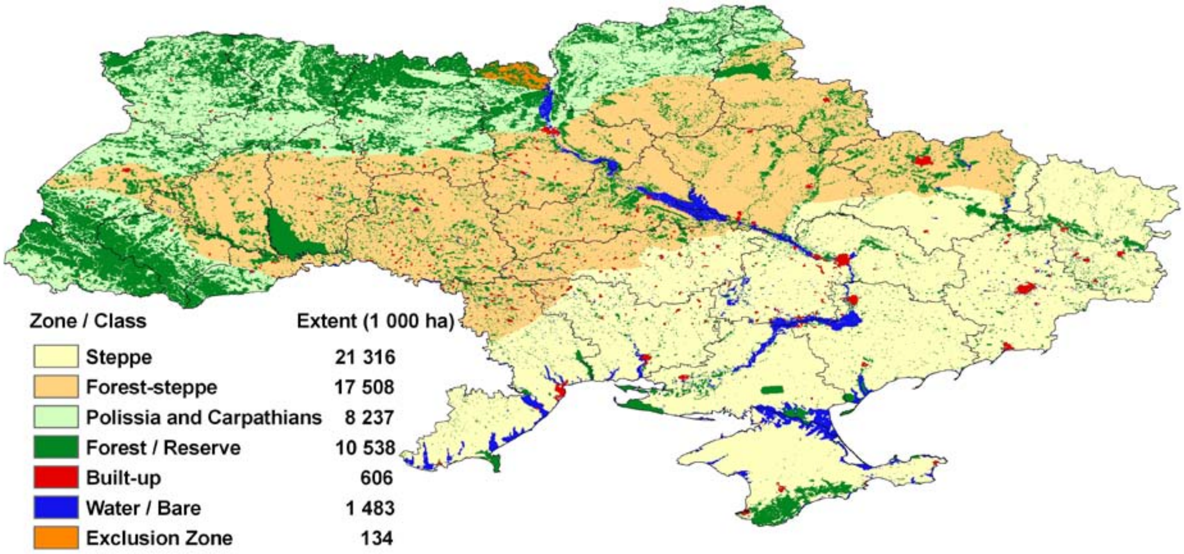


Figure 2.9. Main agro-ecological regions and land use classes

3. Crop/LUT Suitability

3.1. Introduction

For the assessment of rain-fed land productivity, a water-balance model is used to quantify the beginning and duration of the period when sufficient water is available to sustain crop growth. Soil moisture conditions together with other climate characteristics (radiation and temperature) are used in the AEZ crop growth model to calculate potential biomass production and yield. For the assessment of irrigated land productivity, the duration of the period with temperatures conducive for crop growth is used for optimizing the crop calendar and for subsequent calculation of biomass production and yield. The calculated potential yields are combined in a semi-quantitative manner with a number of reduction factors directly or indirectly related to climate (e.g., pest, diseases and workability), and with soil and terrain conditions. The reduction factors, which are applied to the potential yields, vary with crop type, the environment (in terms of climate, soil and terrain conditions) and assumptions on level of inputs/management.

In order to ensure that the results of the suitability assessment relate to production achievable on a long term basis, (i) crop rotation requirements including fallow land have been imposed, and (ii) terrain slopes have been excluded when inadequate for the assumed level of inputs/management or susceptible to severe topsoil erosion.

3.2. Land Utilization Types

A critical step in implementing any AEZ application is the selection and description of land utilization types. The selection of crops for the present Ukrainian AEZ study is based on the considerations listed below:

(i) Most significant sown (harvested) areas of the crops;

(ii) Importance of the crops for the food security;

(iii) Economic effect (profitability) of the production of the crops;

(iv) World's and domestic trends of the economic development;

(v) National Programme of the Development of the Ukrainian Agricultural Sector.

The Ukrainian case study distinguishes in total 79 rain-fed crop, fodder and grassland LUTs, each at three levels of inputs and management (high, intermediate and low). For the irrigation land potential assessment, crop LUTs are used at two levels of inputs and management (high and intermediate). The full list of crops, fodder and grassland types, considered for the Ukrainian AEZ study, is presented in Table 3.1.

The selected agricultural production systems (LUTs) are assessed for defined input and management relationships as summarized in Box 3.1. These three levels of input and management, namely, high, intermediate and low in general describe three main farming types in Ukraine, respectively agricultural enterprises, private commercial farms and subsistence farming (household plots).[7]

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[7] For detailed description of the farming system in Ukraine see Mishchenko N., Gumeniuk K., 2006. *Agro-Ecological Assessment for the Transition of the Agricultural Sector in Ukraine. Part I: Socio-Economic Aspects.* IR-06-052.

Table 3.1. Crop types included in the Ukrainian study.

Crops		Crop Types
Cereals		
Wheat (hibernating)	*Triticum aestivum/durum*	2
Wheat (non-hibernating)	*Triticum durum*	3
Rice Japonica	*Oryza sativa*	2
Rye (hibernating)	*Secale cereale*	2
Foxtail Millet	*Setaria italica*	4
Barley (hibernating)	*Hordeum vulgare*	2
Barley (non-hibernating)	*Hordeum vulgare*	2
Oat (non-hibernating)	*Avena sativa*	3
Grain maize	*Zea mays*	4
Buckwheat	*Fagopyrum esculentum Moench vulgare*	2
Pulses		
Pea	*Pisum sativum*	3
Phaseolus bean	*Phaseolus vulgaris*	3
Root crops		
Potato	*Solanum tuberosum*	4
Sugar crop		
Sugar beet	*Beta vulgaris convar sacchariferae*	4
Oil crops		
Sunflower	*Helianthus annuus*	4
Soybean	*Glycine hispida Maxim Moench*	3
Rape (hibernating)	*Brassica napus oleifera*	2
Rape (non-hibernating)	*Brassica napus oleifera*	2
Fiber crops		
Flax	*Linum usitatissimum*	4
Vegetables		
Cabbage	*Brassica oleracea*	3
Tomato	*Allium cepa*	2
Onion	*Solanum lycopersicum esculentum*	4
Fodder crops		
Silage maize	*Zea mays*	4
Alfalfa	*Medicago sativa*	1
Grass	*Graminaea spp.*	3
Other		
Tobacco	*Nicotiniana tabacum*	2
Olive	*Olea europacae*	1
Total		79

Box 3.1. Farming technology.

High level of inputs/advanced management
Production is based on high-yielding varieties, is fully mechanized with low labor intensity and uses optimum applications of nutrients and chemical pest, disease and weed control, and employs conservation measures. The farming system is mainly market oriented.

Intermediate level of inputs/improved management
Production is based on improved varieties and on manual labor and/or animal traction and some mechanization. It is medium labor intensive, uses some fertilizer application and chemical pest, disease and weed control, adequate fallows and some conservation measures. The farming system is partly market oriented. Production for subsistence plus commercial sale is a management objective.

Low level of inputs/traditional management
Production is based on the use of traditional cultivars (if improved cultivars are used, they are treated in the same way as local cultivars) and labor-intensive techniques, with no application of nutrients. It uses no chemicals for pest and disease control and employs adequate fallow periods and minimum conservation measures. The farming system is largely subsistence based and not necessarily market oriented.

Relevant crop adaptability and crop requirement data are stored in a crop catalog database. These data sets include for each crop/LUT (and by input level where applicable) the following information:

(i) crop characteristics: crop growth cycle lengths; relative lengths of crop development stages; photosynthetic pathway; crop adaptability group (defining maximum rates of photosynthesis); development stage specific coefficients relating crop water requirements to reference evapotranspiration (Kc-factors, see FAO,1992); moisture stress related yield reduction coefficients (Ky-factors, see FAO, 1992);

(ii) parameters describing both rain-fed and irrigated LUTs, thermal requirements, growing period requirements, vernalization requirements, and soil and terrain requirements.

(iii) factors converting biomass to useful products and commodity aggregates: harvest index; food content coefficients (energy, protein); extraction/conversion rates; crop by-product/residue coefficients, commodity aggregation weights.

Table 3.4 present an example for winter wheat, Table 3.2 presents general agronomic characteristics of all crops considered.

Table 3.2. Agronomic Characteristics of Annual crops

Annual/Short term Perennial Crops	Growth Cycle	Harvested Part	Moisture Content of Yield
Wheat (hibernating)	30+90, 40+120	grain	14.5%
Wheat (non-hibernating)	90, 105, 120	grain	14.5%
Rice Japonica	120, 135	grain	17.0%
Rye (hibernating)	30+90, 40+120	grain	14.0%
Foxtail Millet	75, 90, 105, 120	grain	14.0%
Barley (hibernating)	30+90, 35+105	grain	14.5%
Barley (non-hibernating)	90, 105	grain	14.5%
Oat (non-hibernating)	90, 105, 120	grain	13.5%
Grain maize	90, 105, 120, 135	grain	14.0%
Buckwheat	75, 90	grain	14.5%
Pea	90, 105, 120	grain	15.0%
Phaseolus bean	90, 120, 150	bean	15.0%
Potato	75, 90, 120, 150	tuber	70-75%
Sugar beet	120, 135, 150, 165	root	80-85%
Sunflower	105, 120, 135, 150	seed	7.0%
Soybean	105, 120, 135	seed	12.0%
Rape (hibernating)	35+105, 40+120	seed	12.0%
Rape (non-hibernating)	105, 120, 135	seed	12.0%
Flax	75, 90, 105, 120	stem	16-18%
Cabbage	90, 105, 120, 165	fresh head	90%
Tomato	90, 105, 120, 135	fresh fruit	80-90%
Onion	120, 135, 150, 165	fresh bulb	85-90%
Silage maize	120, 135, 150, 165	above ground biomass	
Alfalfa - hay	365	above ground biomass	10-15%
Grass - hay	365	above ground biomass	10-15%

3.3. Climatic suitability analysis

The climatic suitability analysis involves matching crop/LUT requirements with prevailing climatic conditions. It comprises of the following activities:

(a) compilation of crop adaptability inventory for the selected crops and specification of crop/LUT specific temperature and moisture requirements;

(b) matching crop temperature requirements with prevailing temperature regime;

(c) determining optimal cropping calendar and calculation of potential biomass and yield;

(d) calculating crop/LUT specific water deficit and applying moisture stress related yield reduction factors (rain-fed); calculating irrigation water requirements (irrigated);

(e) formulating of crop/LUT specific agro-climatic constraints, accounting for expected yield losses due to factors related to climate conditions, such as incidence of pests, diseases and weeds, workability, and frost occurrence; application of relevant reduction factors to estimate average attainable yield in each grid-cell.

The results of the climatic suitability analysis are calculated in three steps. Step 1 produces a grid-cell specific agro-climatic characterization, including calculation of thermal climates, temperature profiles, and temperature and moisture growing period characteristics. Step 2 calculates temperature and radiation limited potential crop yields, quantifies moisture stress related yield reductions, and determines optimal crop calendars. Finally, Step 3 provides through applying agro-climatic constraints the average climatically attainable crop yields. Results have been classified in five basic suitability classes according to attainable yield ranges relative to maximum potential crop yields (Table 3.3).

Table 3.3. Suitability classes

Suitability class		Percentage of maximum yield
VS	Very Suitable	80 – 100
S	Suitable	60 – 80
MS	Moderately Suitable	40 – 60
mS	Marginally Suitable	20 – 40
vmS	Very Marginally Suitable	5 – 20
NS	Not Suitable	0 – 5

Crop thermal requirements and thermal suitability

Temperature and day-length influence the developmental sequence of crop growth in relation to crop phenology. Crop thermal and day-length requirements for both photosynthesis and phenological development have been taken into account in three regards:

(i) Crops have been classified for day-length requirements. For example, short-day crops have been restricted to the lower latitude zones while long-day crops have been restricted to the higher latitude zones.

(ii) A thermal requirements scheme has been devised for each of the 79 crop/LUTs, such that: (a) it covers sufficiently the requirements for photosynthesis and growth, and considers requirements for phenological development of each crop type, and (b) in seasonal temperate climates. The thermal requirements have been formulated in accordance with the temperature profiles which reflect seasonality characteristics of the individual grid-cells. In this way, the temperature requirements are expressed in terms of the length of periods (duration in days) of the crop cycle falling into temperature intervals of 5°C, separately for increasing and decreasing temperatures. The latter accord with the ‘A’ and ‘B’ type temperature profile periods as described earlier.

The procedures for matching thermal requirements to crop temperature profiles are distinguished in three cases: *Optimal match* when photosynthesis and phenological temperature requirements are fully met; *Sub-optimal match* when the requirements are just sufficiently met for growth and development; and *Not suitable* when either temperature requirements for photosynthesis or for phenological development are not met.

(iii) Crop growth cycle heat requirements (accumulated temperature in degree-days) have been compared with the accumulated temperature actually available in a grid-cell during the growth cycle. When heat requirements are not met, the temperature regime is considered *not* suitable and no further evaluation of the particular crop/LUT for such a grid-cell is undertaken.

In the grid-cells where thermal requirements of a particular crop/LUT are met in optimal or sub-optimal terms, biomass and yield calculations are performed. Table 3.4 shows a representation of thermal requirements for winter wheat. Thermal requirements for all the crops considered are presented in Annex IV.

Table 3.4. Temperature profile and thermal requirements for winter wheat

Crop		Winter wheat (C3/I)			
Climates		Boreal, temperate, subtropics			
Photo sensitivity		Day Neutral/Long Day			
Growth cycle (days) [8]		a + b (30 + 90, 40 +120)			
		Sub-optimal Conditions		Optimal Conditions	
Temperature.		Percentage of Growth Cycle		Percentage of Growth Cycle	
periods [9]		1st req.	2nd req.	1st req.	2nd req.
A9	< -5 °C	0	0	0	0
A8	-5-0 °C	0	0	0	0
A7	0-5 °C	0		0	0
A6	5-10 °C	≤ 50 % b	> 16.7 % b	≤ 50 % b	> 16.7 % b
A5	10-15 °C				
A4	15-20 °C	≤ 100 % b		≤ 100 % b	
A3	20-25 °C				
A2	25-30 °C		≤ 33.3 % b		≤33.3 % b
A1	> 30 °C	0	0	0	0
B1	> 30 °C	0	0	0	0
B2	30-25 °C				
B3	25-20 °C	≤ 50 % b		≤ 50 % b	
B4	20-15 °C		100% a		100% a
B5	15-10 °C				
B6	10-5 °C				
B7	5-0 °C	0	0	0	0
B8	0--5 °C	0	0	0	0
B9	< -5 °C	0	0	0	0
Accumulated temperature during growth cycle (TSgc) [10]		TSgc > 1300 (post dormancy)		TSgc > 1400 (post dormancy)	
$LGP_{t=5}$		< 365		< 365	
Dormancy		Required		Required	
Vernalization		Required		Required	
Permafrost tolerance		No permafrost		No permafrost	

[8] a: pre-dormancy part of growth cycle; b: post-dormancy part of growth cycle.
[9] A9-A1: temperature periods with increasing temperatures, i.e., during winter to summer; B1-B9: temperature periods with decreasing temperatures, i.e., from summer to winter.
[10] Accumulated temperature during post-dormancy part of growth cycle.

Biomass and yield

The constraint-free crop yields calculated in the AEZ biomass model[11] reflect yield potentials with regard to temperature and radiation regimes prevailing in the respective grid-cells. This basically eco-physiological model requires the following crop characteristics: (a) length of growth cycle (days from emergence to full maturity); (b) length of yield formation period; (c) leaf area index (LAI) at maximum growth rate; (d) harvest index (Hi); (e) crop adaptability group; and (f) sensitivity of crop growth cycle length to heat provision. The biomass calculation also includes simple procedures to account for different levels of atmospheric CO_2 concentrations. Annex I provides details of the calculation procedures and Annex V lists the model parameters.

The results of the biomass and yield calculation depend on timing of crop growth cycle (crop calendar). Maximum biomass and yields are separately calculated for irrigated and rain-fed conditions, as follows:

Irrigation:

For each day within the window of time when crop temperature and radiation requirements are met optimally or at least sub-optimally[12], the period resulting in the highest biomass and yield is selected to set the crop calendar of the respective crop/LUT for a particular grid-cell.

Rain-fed:

Within the window with optimal or sub-optimal temperature conditions, and starting within the duration of the moisture growing period, the period resulting in the highest expected (moisture-limited) yield is selected to represent maximum biomass and yield for rain-fed conditions of the respective crop/LUT for a particular grid-cell. Moisture limited yields are calculated by applying crop-stage specific and total growing period yield reduction factors. The yield reduction factors relate relative yield decrease, expressed as $(1-Y_a/Y_m)$, to relative evapotranspiration deficit $(1-ET_a/ET_m)$. In this formulation, Y_a and Y_m denote water-limited and potential yield, respectively; ET_a and ET_m refer to crop-specific actual and potential evapotranspiration in a grid-cell. The obtained relative yield decrease is then applied to the calculated temperature/radiation limited biomass and yield.

In other words, for each crop type and grid-cell the starting and ending dates of the crop growth cycle are determined optimally to obtain best crop yields, separately for rain-fed and irrigated conditions. This procedure also allows adaptation in simulations with year-by-year historical weather conditions, or under climate distortions applied in accordance with various climate change scenarios. Hence, the AEZ method simulates a ‘smart’ farmer. Results of the biomass and yield calculations can be presented in tabular or in map form. Figure 5.1 presents a map of temperature and radiation limited yields for rain-fed winter wheat.

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[11] The calculated biomass and yields are used to formulate indicative yield ranges for each of the five suitability classes employed at each of the three input circumstances.

[12] Only in cases where conclusive data on crop temperature requirements are available, distinction between optimal and sub-optimal conditions could be made.

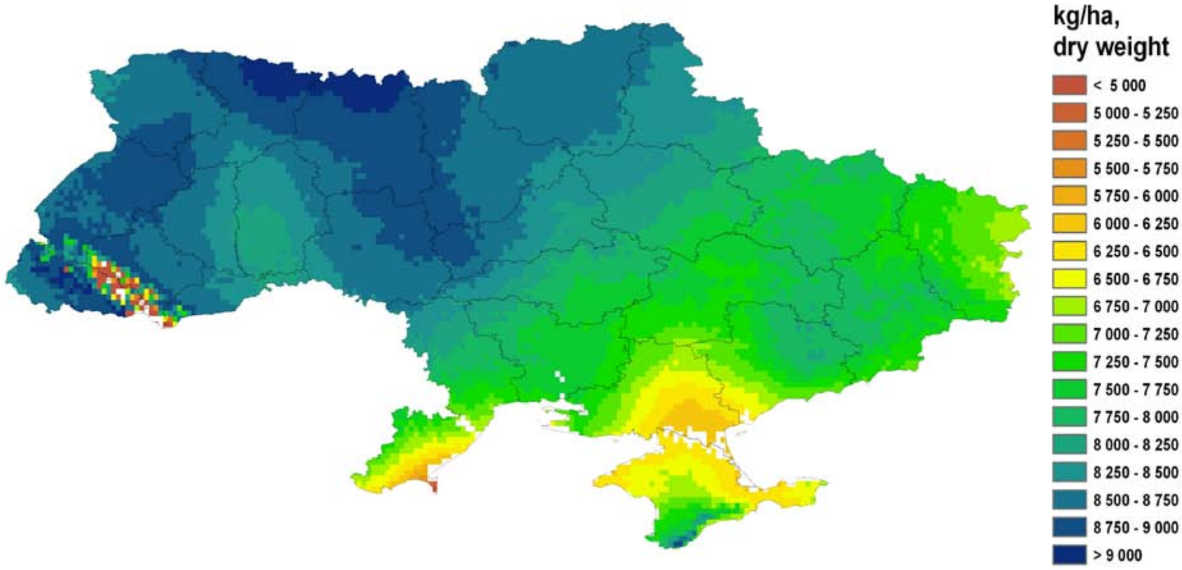

Figure 3.1. Temperature, radiation and water limited yields for rain-fed winter wheat in 1971-2000 (high level of input and management)

Crop moisture requirements and growing period suitability

For most crops crop water requirements are well established and published widely. Various aspects relevant to crop moisture requirements are included in the crop catalog data files: crop growth cycle length, crop stage specific water requirement coefficients, moisture deficit related yield reduction coefficients.

To cater for differences in soil types, the crop water balances were performed for each of the six soil moisture storage capacity (S_{max}) classes (see Table 4.4). Moisture-limited yields of annual rain-fed crops have been calculated by applying crop stage specific and total growing period yield reduction factors in accordance with procedures developed by FAO and as described in the calculation of biomass and yield (Annex I). This provides quantification of crop performance for each of the soil types occurring in a particular soil mapping unit.

Losses in marketable value of the produce due to poor quality in yield as influenced by incomplete yield formation, however, cannot be accounted for in the biomass and yield calculations. These and other losses have been evaluated separately and are referred to as agro-climatic constraints.

Agro-climatic constraints

At the stage of computing potential biomass and yields, no account is taken of the climatic–related effects operating through pests and diseases, and workability. Such effects need to be included to arrive at realistic estimates of attainable crop yields. Precise estimates of their impacts are very difficult to obtain for a global study. Here it has been achieved by quantifying the constraints in terms of reduction ratings, according to different types of constraints and their severity for each crop, varying by length of growing period zone and by level of inputs. The latter subdivision is necessary to take account of the fact that some constraints, such as bollworm on cotton, are present under low input conditions but are controllable under high input conditions in certain growing period zones. While some constraints are common to all input levels, others (e.g., poor workability through excess moisture) are in particular applicable to high input (see Box 3.2)).

Agro-climatic constraints cause direct or indirect losses in the yield and quality of produce. Yields losses in a rain-fed crop due to agro-climatic constraints have been formulated based on principles and procedures originally proposed in FAO1978-81. Details of the conditions that are influencing yield losses are listed below.

(i) ***How well the crop growth cycle fits within the length of growing period***. When the growing period is shorter than the growth cycle of the crop, from sowing to full maturity, there is a loss of yield. The biomass and yield calculations account for direct losses by appropriately adjusting LAI and harvest index. However, the loss in the marketable value of the produce due to poor quality of the yield as influenced by incomplete yield formation (e.g., incomplete grain filling in grain crops resulting in shriveled grains or yield of a lower grade, incomplete bulking in root and tuber leading to a poor grade of ware), is not accounted for in the biomass and yield calculations. This loss is to be considered as an agro-climatic constraint in addition to the quantitative yield loss due to curtailment of the yield formation period. Yield losses can also occur when the length of the growing period is much longer than the length of the growth cycles. These losses operate through yield and quality reducing effects of (i) pests, diseases and weeds, (ii) climatic factors affecting yield components and yield formation, and (iii) climatic conditions affecting the efficiency of farming operations.

(ii) ***The degree of water-stress during the growing period***. Water-stress generally affects crop growth, yield formation and quality of produce. The yield reducing effects of water-stress varies from crop to crop. The total yield impact can be considered in terms of (i) the effect on growth of the whole crop, and (ii) the effect on yield formation and quality of produce. For some crops, the latter effect can be more severe than the former, particularly where the yield is a reproductive part (e.g., cereals) and yield formation depends on the sensitivity of floral parts and fruit set to water-stress (e.g., silk drying in maize).

(iii) ***Pests, diseases and weeds.*** To assess the agro-climatic constraints of pest, disease and weed complex, the effects on yields that operate through loss in crop growth potential (e.g., pest and diseases affecting vegetative parts in grain crops) have been separated from effects on yield that operate directly on yield formation and quality of produce.

(iv) ***Climatic factors directly or indirectly reducing yield and quality of produce***. These include problems of poor seed set and/or maturity under cool or low temperature conditions, problems of seed germination in the panicle due to wet conditions at the end of grain filling, problems of poor seed set in wet conditions at the time of flowering in some grain crops, and problems of excessive vegetative growth and poor harvest index due to high temperatures.

(v) ***Climatic factors affecting the efficiency of farming operations and costs of production***. Farming operations include those related to land preparation, sowing, cultivation and crop protection during crop growth, and harvesting (including operations related to handling the produce during harvest and the effectiveness of being able to dry the produce). Agro-climatic constraints in this category are essentially workability constraints, which primarily account for excessive wetness conditions. Limited workability can cause direct losses in yield and quality of produce, and/or impart a degree of relative unsuitability to an area for a given crop from the point of view of how effectively crop cultivation and produce handling can be conducted at a given level of inputs.

(vi) ***Frost hazard and extreme temperature events.*** The risk of occurrence of late and early frost increases substantially when mean temperatures drop below 10°C. Hence, length of the thermal growing period with temperatures above 10°C (LGP_{t10}) in a grid-cell has been matched with growth cycle length of frost sensitive crops.

The agro-climatic constraints described above are closely related to prevailing climate conditions. For convenience they have been arranged in five groups as follows:

(a) *yield losses due to water-stress constraints on crop growth (e.g., rainfall variability);*

(b) *yield losses due to the effect of pests, diseases and weed constraints on crop growth;*

(c) *yield losses due to climatic conditions stress, excess wetness and pest and diseases constraints on yield components and yield formation (e.g., affecting quality of produce);*

(d) *yield losses due to workability constraints (e.g., wetness rendering produce handling difficulties), and*

(e) *yield losses due to occurrence of early or late frosts.*

Box 3.2. Agro-climatic constraints related to input and management levels

In general, with increasing length of growing period and wetness, constraints due to pests and diseases (groups 'b' and 'c') become increasingly severe particularly to low input cultivators. As the length of growing period gets very long, even the high input level cultivator cannot keep these constraints under control and they become severe yield reducing factors at all three levels of inputs. Other factors, such as poor pod set in soybean or poor quality in short lengths of growing period zones, are of similar severity for all three levels of inputs. Difficulties in lifting root crops under dry soil conditions (short lengths of growing periods group 'd') are rated more severely under the high level of inputs (mechanized) than under intermediate and low level of inputs. For irrigated production the 'c' constraint is applied only at the wet end, i.e., above 300 days in the example for winter wheat shown in Table 3.5.

Although the constraints of group 'd' are not direct yield losses in reality, such constraints do mean, for example, that the high input level mechanized cultivator cannot get onto the land to carry out operations. In practice, this results in yield reductions. Similarly for the low input cultivator, for example, excessive wetness could mean that the produce is too wet to handle and remove, and again losses would be incurred even though the produce may be standing in the field. Occurrence of wet conditions have therefore been incorporated in the severity ratings of agro-climatic constraints in group 'd'.

The availability of historical rainfall data has made it possible to derive the effect of rainfall variability through year-by-year calculation of yield losses due to water stress. Therefore the 'a' constraint, related to rainfall variability is no longer applied. The 'a' is of use with data sets containing average rainfall only.

The 'b', and 'd' constraints and part of the 'c' are related to wetness. The ratings of these constraints have been linked to the LGP.

To account for these significant differences in wetness conditions of long LGPs (> 225 days), agro-climatic constraints have been related to P/ETo ratios by calculating equivalent LGPs, i.e., adjustments where P/ETo ratios where below average. The equivalent LGPs are then used in the application of the 'b', 'c', and 'd' constraints.

Table 3.5 presents an example of agro-climatic constraints for winter wheat. For irrigated production only the agro-climatic constraints related to excess wetness apply. A listing of the agro-climatic constraint parameters considered for all the crop/LUTs are presented in Annex VI.

The application of the agro-climatic constraints to the combined results of temperature suitability and the biomass and yield calculations provides agro-climatic suitabilities. Figure 3.2 present agro-climatic suitability maps for rain-fed winter wheat as well as agro-climatic attainable yields at the high level of inputs.

Table 3.5. Agro-climatic constraints yield reduction factors (%) for winter wheat

Temperate Climate												
Growth Cycle	**40 days pre-dormancy + 120 days post-dormancy**											
$LGP_{t=5}$	**60-89**	**90-119**	**120-149**	**150-179**	**180-209**	**210-239**	**240-269**	**270-299**	**300-329**	**330-364**	**365-**	**365+**
Low input level												
a*	30	30	10	0	0	0	0	0	0	0	0	0
b	0	0	0	0	0	0	10	10	10	10	10	10
c	10	10	0	0	0	0	0	0	10	10	30	30
d	0	0	0	0	0	0	0	0	0	10	10	30
Intermediate input level												
a*	30	30	10	0	0	0	0	0	0	0	0	0
b	0	0	0	0	0	0	0	10	10	10	10	10
c	10	10	0	0	0	0	0	0	10	10	30	30
d	0	0	0	0	0	0	0	0	0	10	10	30
High input level												
a*	30	30	10	0	0	0	0	0	0	0	0	0
b	0	0	0	0	0	0	0	10	10	10	10	10
c	10	10	0	0	0	0	0	0	10	10	30	30
d	0	0	0	0	0	0	0	0	0	10	10	30
All input levels												
$LGP_{t=10}$	60-89	90-119	120-149	150-179	180-209	210-239	240-269	270-299	300-329	330-364	365-	365+
e	100	50	25	0	0	0	0	0	0	0	0	

* The 'a' constraint (yield losses due to rainfall variability) is not applied in the current assessment. This constraint has become redundant due to explicit quantification of yield variability through the application of historical rainfall data sets.

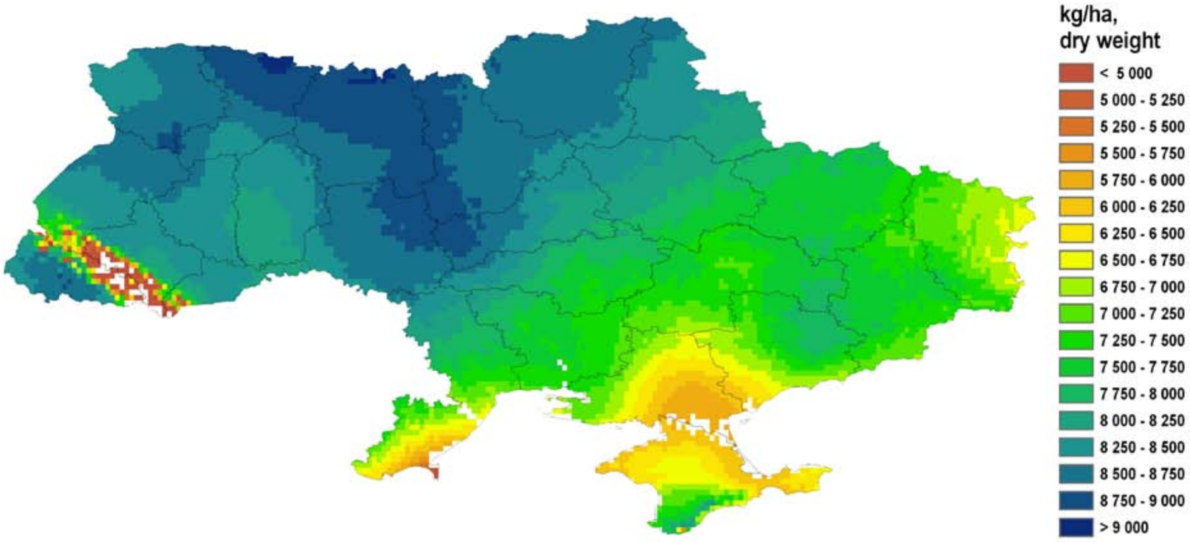

Figure 3.2. Agro-climatic attainable yields for rain-fed winter wheat in 1971-2000 (high level of input and management)

3.4. Growing period suitability for water-collecting sites

In water-collecting sites substantially more water can be available to plants as compared to upland situations. Water-collecting sites are difficult to locate but can be approximately determined on the basis of (i) the delineation of depressions in the landscape with the help of GIS applications of a detailed digital elevation model and (2) prevalence of specific soil types. Fluvisols[13] and to a lesser extent Gleysols[14] are typically representing the flat terrain of alluvial valleys and other water-collecting sites.

The cultivation of Fluvisols (under unprotected natural conditions) is determined by frequency, duration and depth of inundation. The inundation attributes are generally controlled by external factors such as a river's flood regime which in turn is influenced by hydrological features of the catchment area and catchment/site relations, and not necessarily by the amount of 'on site' precipitation.

In Ukraine flooding/inundation occurrence and intensity typically varies widely from year to year. On the basis of historical inundation events and rainfall-runoff relationships, risk of flooding/inundation may be inventoried and incorporated as an additional constraint in the crop suitability assessment.

Gleysols are not directly affected by river flooding. These soils are however frequently situated in low-lying water-collecting sites and when not artificially drained, the Gleysols may be subject to water-logging or even inundation as a result from combinations of high groundwater tables and ponding rainwater. Gleysols without artificial drainage often remain waterlogged for extensive periods, rendering them unsuitable for cultivation of dryland crops.

On both, Fluvisols and Gleysols, crops of short duration, which are tolerant to flooding, water-logging and high groundwater tables, can be found producing satisfactorily. Therefore, a separate crop suitability classification for water-collecting sites is used. The classification accounts for crop-specific tolerances to excess moisture (high groundwater, water-logging and flooding/inundation) and the use of available estimates of flooding regimes of the Fluvisols. Gleysols are mostly, but not necessarily, subjected to water-logging and inundation. Therefore only the Gleysols with terrain-slopes of less than 2% are considered in the classification.

In many parts of Ukraine the flooding of Fluvisols is being controlled with dikes and other protection means. Fluvisols, in protected conditions, are assumed not to suffer from flooding. The moisture regime of Fluvisols under these protected conditions is similar to other soils and therefore protected Fluvisols are treated according to the procedures used for crops in upland conditions.

In a similar way, Gleysols may be artificially drained, thereby diminishing a major limitation for the cultivation of these soils. For areas where the Gleysols have been drained, a revised (i.e., less severe) set of soil ratings is used and the rules for natural Fluvisols are not applied.

Since spatial details of the occurrence of protected Fluvisols and artificial drainage of Gleysols are not yet available these factors are assumed to be linked to the level of inputs/management. The application of Fluvisol suitability ratings and soil unit suitability ratings of artificially drained Gleysols are presented below:

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[13]Fluvisols are by definition flooded by rivers. Fluvisols are young soils where sedimentary history are clearly recognizable in the soil profile.

[14]Gleysols are generally not flooded by rivers. However, the soil profiles indicate regular occurrence of high groundwater tables through reduction (gley) features. Low-lying Gleysols may be ponded/water-logged by high groundwater and rainfall during the rainy season.

	Fluvisols		Gleysols	
	natural	protected	natural	artificially drained
Rain-fed				
High level inputs	no	yes	no	yes
Intermediate level inputs	50%	50%	50%	50%
Low level inputs	yes	no	yes	no
Irrigation				
High level inputs	no	yes	no	yes
Intermediate level inputs	50%	50%	50%	50%

The moisture suitability ratings[15] devised for unprotected Fluvisols and Gleysols without artificial drainage are organized in groups of crops with comparable growth cycle lengths and similar tolerances to high groundwater levels, water-logging and flooding. The rating tables are presented in Annex VII.

3.5. Agro-edaphic suitability analysis

Adequate agricultural exploitation of the climatic potentials and maintenance of land productivity largely depend on soil fertility and the management of soils on an ecologically sustained basis. Soil fertility is concerned with the ability of the soil to retain and supply nutrients and water in order to enable crops to maximally utilize the climatic resources of a given location. The fertility of a soil is determined by both its physical and chemical properties. An understanding of these factors and insight in their interrelations is essential to the effective utilization of climate, terrain and crop resources for optimum use and production.

From the basic soil requirements of crops, a number of soil characteristics have been established related to crop yield response. For most crops and cultivars, optimal, sub-optimal, marginal and unsuitable levels of these soil characteristics are known and have been quantified. Beyond critical ranges, crops cannot be expected to yield satisfactorily unless special precautionary management measures are taken. Soil suitability classifications are based on knowledge of crop requirements, of prevailing soil conditions, and of applied soil management. In other words, soil suitability classifications quantify in broad terms to what extent soil conditions match crop requirements under defined input and management circumstances. This necessitates expert judgement and a semi-quantitative approach.

Soil suitability evaluation for rain-fed crop production

The AEZ agro-edaphic suitability classification is to a large extent based on documented experience. The classification has been intensively used by FAO and other organizations, at various scales in many countries and regions; it passed through several international expert consultations, and hence it constitutes the most recent consolidation of expert knowledge. In this system a suitability rating is proposed for each soil unit, by individual crops at three defined levels of inputs and management circumstances. The agro-edaphic suitability rating is based on a comparison of soil requirements of crops and prevailing edaphic conditions. Data available from various sources have been summarized by Sys et al. (1993).

For Ukraine this original expert-based approach has been combined with a parameterization based on one hand on detailed soil attribute data for soil texture, bulk density, drainage, organic matter, pH (H_2O), calcium carbonate, total exchangeable bases, base saturation, salinity, sodicity and occurrence of gravel (see Annex VIII)[16], and on the

[15] The rating system described above has been taken from the global version of AEZ and will be replaced, as soon systematic data on flooding and inundation depth, duration and timing for Ukraine is available in a detailed spatial manner
[16] This data is available in the soil attribute file linked to each of the soil units by soil mapping units, represented in the 1:1,500,000 scale soil map of Ukraine.

other hand on known crop soil attribute requirements. (Details of this parameterization is being documented and will be part of the final write-up of the agro-edaphic suitability classification methodology).

The results of this suitability classification are shown in a database. This database contains for each crop/LUT/input level combination, appropriate soil unit suitability ratings (see example in Table 3.6).

Table 3.6. Extract of Suitability Ratings of a particular *Cambic Arenosol* (FAO '90 classification) for individual cereals for (i) rain-fed production of respectively high, intermediate and low level inputs and (ii) gravity and sprinkler irrigation (high level of input and management)

Rain-fed (R)/ Irrigated (I)	Input Level	FAO'90 Soil Unit	winter wheat	spring wheat	wetland rice	grain maize	silage maize	winter barley	spring barley	winter rye	oat
R	**High Inputs**	**ARb**	2	2	4	2	2	6	6	3	3
R	**Intermediate Inputs**	**ARb**	6	6	4	6	6	4	4	6	6
R	**Low inputs**	**ARb**	6	6	4	6	6	4	4	6	6
I	**Gravity (High inputs)**	**ARb**	4	4	4	4	4	4	4	4	4
I	**Sprinkler (High inputs)**	**ARb**	2	2	4	2	2	6	6	3	3

Suitability rating **1**: refers to very suitable; **2**: to suitable; **3**: to 50% very suitable and 50% suitable; **4**: to not suitable; **5**: to 50% very suitable and 50% not suitable, and **6**: to 50% suitable and 50% not suitable.

Terrain suitability evaluation for rain-fed crop production

The influence of topography on agricultural land use is manifold. Farming practices are by necessity adapted to terrain slope, slope aspect, slope configuration and micro-relief. For instance, steep irregular slopes are not practical for mechanized cultivation, while these slopes might very well be cultivated with adapted machinery and hand tools.

Sustainable agricultural production on sloping land is foremost concerned with the prevention of erosion of topsoil and decline of fertility. Usually this is achieved by combining special crop management and soil conservation measures. Slopes cultivated with crop/LUTs providing inadequate soil protection and without sufficient soil conservation measures, cause a considerable risk of accelerated soil erosion. In the short term, cultivation of slopes might lead to yield reductions due to loss of applied fertilizer and fertile topsoil. In the long term, this will result in losses of land productivity due to truncation of the soil profile and consequently reduction of natural soil fertility and of available soil moisture.

Rain-fed annual crops are the most critical to cause topsoil erosion, because of their particular cover dynamics and management. The terrain-slope suitability rating used in the AEZ study captures the factors described above which influence production and sustainability. This is achieved through: (i) defining for the various crop/LUTs permissible slope ranges for cultivation, by setting maximum slope limits; (ii) for slopes within the permissible limits, accounting for likely yield reduction due to loss of fertilizer and topsoil, and (iii) distinguishing among farming practices ranging from manual cultivation to fully mechanized cultivation.

Ceteris paribus, i.e., under similar crop cover, soil erodibility and crop and soil management conditions, soil erosion hazards largely depend on amount and intensity of rainfall. Data on rainfall amount is available on a monthly basis in the 0.5 degree latitude/longitude climate databases. Rainfall intensity or energy, as is relevant for soil erosion, is not estimated in these data sets.

To account for clearly existing differences in both amount and within-year distribution of rainfall, use has been made of the modified Fournier index (Fm), which reflects the combined effect of rainfall amount and distribution (Fischer et al., 2002), as follows:

$$F_m = 12 \sum_{i=1}^{12} \frac{p_i^2}{P_{ann}}$$

where:

p_i = precipitation of month i
P_{ann} = total annual precipitation

When precipitation is equally distributed during the year, i.e., in each month one-twelfth of the annual amount is received, then the value of F_m is equal to P_{ann}. On the other extreme, when all precipitation is received within one month, the value of Fm amounts to twelve times P_{ann}. Hence, F_m is sensitive to both total amount and distribution of rainfall and is limited to the range of $P_{ann} \leq F_m \leq 12\ P_{ann}$. The Fm index has been calculated for all 5 arc-min grid-cells of the climatic inventory. The results have been grouped in six classes, namely: $F_m < 1300$, 1300-1800, 1800-2200, 2200-2500, 2500-2700, and $F_m > 2700$. These classes were determined on the basis of regression analysis, correlating different ranges of length of growing period zones with levels of the Fournier index F_m. This was done to incorporate the improved climatic information on within year rainfall distribution while keeping consistency with earlier procedures of the methodology, which were defined by LGP classes.

Slope ratings are defined for slope range classes used in the land resources database, namely: 0-0.5, very flat; 0.5-2%, flat; 2-5%, gently sloping; 5-8 %, undulating; 8-16% rolling, 16-30%, hilly; 30-45%, steep; and > 45% very steep. The following suitability ratings have been used:

S1	Optimal conditions
S2	Sub-optimal conditions
S1/S2	50% optimal and 50% sub-optimal conditions
S2/N	50% sub-optimal and 50% not suitable conditions
N	Not suitable conditions

Table 3.7 presents terrain-slope ratings for rain-fed conditions for four crop groups at three levels of inputs and management by Fournier index, class 1, $F_m < 1300$. Ratings for $F_m >$ 1300 are presented in Annex IX.

Table 3.7. Terrain-slope ratings for rain-fed conditions (F_m <1300)

High Inputs

Slope Gradient Classes	0-0.5%	0.5-2%	2-5%	5-8%	8-16%	16-30%	30-45%	> 45%
Annuals 1	S1	S1	S1	S1	S1/S2	N	N	N
Annuals 2	S1	S1	S1	S1	S1/S2	N	N	N
Pasture	S1	S1	S1	S1	S1	S2	N	N
Forage legumes	S1	S1	S1	S1	S1/S2	N	N	N

Intermediate Inputs

Slope Gradient Classes	0-0.5%	0.5-2%	2-5%	5-8%	8-16%	16-30%	30-45%	> 45%
Annuals 1	S1	S1	S1	S1	S1	S2	N	N
Annuals 2	S1	S1	S1	S1	S1/S2	S2	N	N
Pasture	S1	S1	S1	S1	S1	S1/S2	S2/N	N
Forage legumes	S1	S1	S1	S1	S1	S1/S2	S2/N	N

Low Inputs

Slope Gradient Classes	0-0.5%	0.5-2%	2-5%	5-8%	8-16%	16-30%	30-45%	> 45%
Annuals 1	S1	S1	S1	S1	S1	S1/S2	N	N
Annuals 2	S1	S1	S1	S1	S1	S1/S2	N	N
Pasture	S1	S1	S1	S1	S1	S1	S1/N	N
Forage legumes	S1	S1	S1	S1	S1	S1/S2	S2/N	N

Crop Groups: Annuals 1: wheat, barley, rye, oat, buckwheat
Annuals 2: maize, foxtail millet, white potato, phaseolus bean, pea, soybean, rape, flax, sunflower, sugar beet, cabbage, tomato and onion

Figure 3.3 below presents a spatial representation of edaphic suitability (soil and terrain slope combined) for rain-fed winter wheat as expressed by the suitability index SI[17].

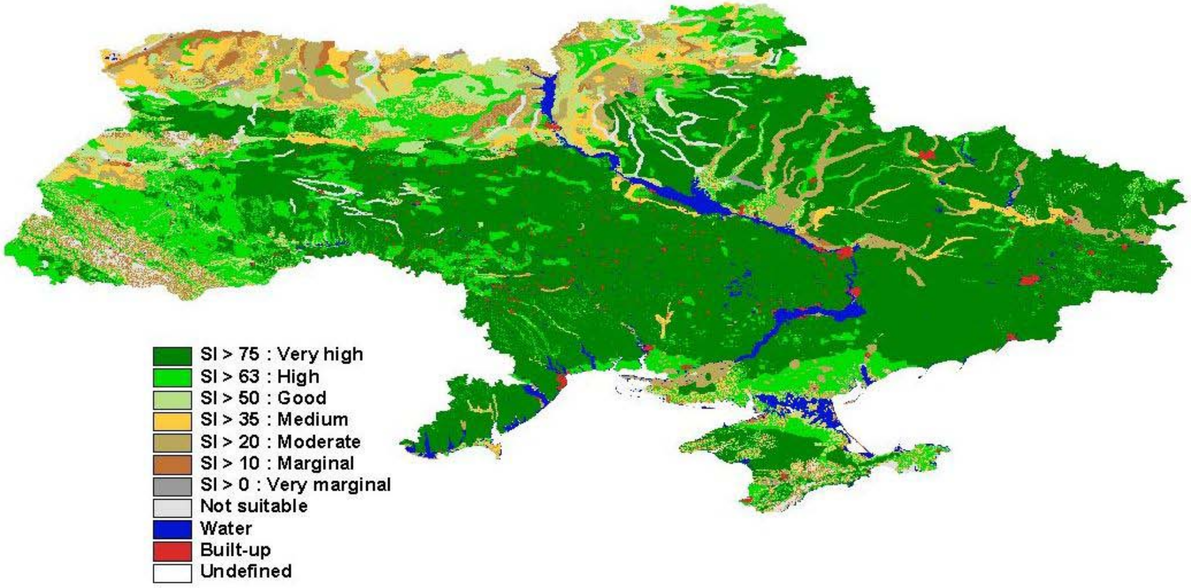


Figure 3.3. Edahpic suitability index classes for winter wheat in 1971-2000 (high level of input and management)

Soil and terrain suitability evaluation for irrigated crop production

The evaluation procedures for gravity irrigation suitability cover intermediate and high levels of management and input circumstances. The following land and soil characteristics have been interpreted specifically for the irrigation suitability classification: topography; soil drainage; soil texture; surface and sub-surface stoniness; calcium carbonate levels; gypsum status; and salinity and alkalinity conditions. (see Fischer et al., 2002)

Topography

The dominant topographic factor governing the suitability of an area for gravity or sprinkler irrigation is the terrain slope. Other topographic factors, such as micro-relief, have partly been accounted for in the soil unit and soil phase suitability classifications. Permissible slopes for irrigation depend on type of irrigation system and level of inputs and management.

[17] The suitability index (SI) is described in six classes: very suitable (VS), suitable (S), moderately suitable (MS), marginally suitable (mS), very marginally suitable (vmS), and not suitable (N) and reflects the suitability make-up of a grid-cell in accordance with the definition of suitability classes in AEZ, namely:

$$SI = VS*0.9 + S*0.7 + MS*0.5 + mS*0.3 + vmS*0.15$$

Gravity irrigation (basin, border, and furrow systems) is used for a large range of crops for terrain slopes of up to 5 %. For 'non-row crops' such as wheat, barley, pasture and forage legumes, slopes of up to 10 % can be used with special systems such as corrugations. On these steeper slopes irrigation efficiency is diminished due to poor uniformity of the water distribution, leading to irregular stands of crops. Therefore, slopes between 5 and 10 % are classified as sub-optimal for all types of gravity irrigation.

Sprinkler irrigation systems are generally more efficient than gravity systems but also much more expensive, and they require special management skills. Sprinklers can be used on somewhat steeper slopes than the gravity systems. However, some of the larger central pivot systems can only be used on flat or almost flat terrain. For pastures adapted systems may be used on slopes of up to 24 %. For annual crops, serious erosion risk starts at about 10-12 % slopes, depending on soil erodibility, ground cover, and management.

Tables 3.8 and 3.9 present terrain-slope suitability ratings, respectively for gravity and sprinkler irrigation systems, for eight groups of crops at high and intermediate levels of inputs. The suitability rating classes are the same as for rain-fed conditions.

Table 3.8. Terrain-slope ratings for gravity irrigation

High Inputs

Slope Gradient Classes	0-0.5%	0.5-2%	2-5%	5-8%	8-16%	16-30%	30-45%	> 45%
Annuals 1	S1	S1	S1	S1/S2	S2/N	N	N	N
Annuals 2	S1	S1	S1	S1/S2	S2/N	N	N	N
Pasture	S1	S1	S1	S1/S2	S2/N	N	N	N
Forage legumes	S1	S1	S1	S1/S2	S2/N	N	N	N

Intermediate Inputs

Slope Gradient Classes	0-0.5%	0.5-2%	2-5%	5-8%	8-16%	16-30%	30-45%	> 45%
Annuals 1	S1	S1	S1	S1/S2	S2/N	N	N	N
Annuals 2	S1	S1	S1	S1/S2	S2/N	N	N	N
Pasture	S1	S1	S1	S1/S2	S2/N	N	N	N
Forage legumes	S1	S1	S1	S1/S2	S2/N	N	N	N

Crop Groups: Annuals 1: wheat, barley, rye, oat, buckwheat
Annuals 2: maize, foxtail millet, white potato, phaseolus bean, pea, soybean, rape, flax, sunflower, sugar beet, cabbage, tomato and onion

Table 3.9. Terrain-slope ratings for sprinkler irrigation

High Inputs

Slope Gradient Classes	0-0.5%	0.5-2%	2-5%	5-8%	8-16%	16-30%	30-45%	> 45%
Annuals 1	S1	S1	S1	S1/S2	S2/N	N	N	N
Annuals 2	S1	S1	S1	S1/S2	S2/N	N	N	N
Pasture	S1	S1	S1	S1	S1/S2	S2/N	N	N
Forage legumes	S1	S1	S1	S1/S2	S2/N	N	N	N

Intermediate Inputs

Slope Gradient Classes	0-0.5%	0.5-2%	2-5%	5-8%	8-16%	16-30%	30-45%	> 45%
Annuals 1	S1	S1	S1	S1/S2	S2/N	N	N	N
Annuals 2	S1	S1	S1	S1/S2	S2/N	N	N	N
Pasture	S1	S1	S1	S1	S1/S2	S2/N	N	N
Forage legumes	S1	S1	S1	S1/S2	S2/N	N	N	N

Crop Groups: Annuals 1: wheat, barley, rye, oat, buckwheat
Annuals 2: maize, foxtail millet, white potato, phaseolus bean, pea, soybean, rape, flax, sunflower, sugar beet, cabbage, tomato and onion

Soil texture

Soil texture provides a measure for permeability and to some extent, for water retention capacity. Soils with potentially high percolation losses and soils with low water retention capacity, and all soils with coarse textures have been considered not suited for gravity irrigation. For medium and fine textured soils excessive percolation and low water-retention capacities are less relevant. The modifications related to texture/clay mineralogy are summarized in Table 3.9.

Table 3.10. Soil texture/clay mineralogy limitations for irrigation

Major Soil Unit		Suitability	
FAO '90	**Soil Unit**	Dryland Crops	Wetland Rice
Podzols (PZ)	all units	N	N
Arenosols (AR)	all units	N	N

Soil drainage

Irrigation crops requires well drained soils to assure aeration and to avoid the possible risk of secondary salinization. Drainage conditions depend on depth and quality of groundwater. Crop drainage requirements under irrigation are quite different as compared to rain-fed conditions. Therefore, the following modifications to rain-fed suitability ratings were applied (see Table 3.10).

Table 3.11. Soil drainage limitations for irrigation

Soil Drainage Class	Suitability
W	S1
MW	S1/S2
I, P	S2
VP, SE, E	N

Drainage Classes: VP - very poor; P – poor; I – imperfectly; MW - moderately well; W – well; SE - somewhat excessively; E – excessively.

Soil depth and soil stoniness

Under irrigated conditions soil depth affects drainage, aeration and water retention properties. Deep soils favor drainage and are therefore optimal for irrigation. Shallow soils such as Rendzic Leptosols and Umbric Leptosols and soils with phases implying a reduction in soil depth have been reviewed and adjusted for irrigated conditions.

Surface stoniness affects soil workability. In addition, subsurface stoniness reduces water-holding capacity and increases infiltration rates. It is assumed that high volume percentage of coarse materials will markedly influence the water-balance in the soil profile. To cater for these constraints specifically affecting irrigation suitability, the soil phase suitability ratings for petric phases have been adjusted from the rain-fed ratings.

Calcium carbonate

Calcium carbonate in the form of free lime in the soil profile affects soil structure and interferes with infiltration and evapotranspiration processes. It influences both the soil moisture regime and availability of nutrients. This, however, applies equally to rain-fed and irrigated cropping. Therefore, no changes are required to the crop-specific limitations as established for rain-fed cropping.

Salinity and alkalinity

Irrigation in dry regions requires careful soil drainage (natural and/or artificial) to avoid irrigation-induced secondary salinization. It is assumed that, where so required, appropriate drainage systems are in place and that irrigation water is non-saline. In this case no changes are necessary to the crop-specific suitability ratings as used for rain-fed cropping.

Alkalinity, expressed as sodium saturation, influences the structure stability of soils, which in turn affects infiltration rates and aeration of soils. The alkalinity (sodicity) constraints are equally important for rain-fed and irrigated conditions. Therefore, the crop-specific soil unit and soil phase ratings evaluated for rain-fed conditions remain unchanged for irrigated cropping.

Crop rotation requirements

In their natural state, many soils cannot be continuously cultivated without undergoing degradation. Such degradation is marked by a decrease in crop yields and a deterioration of soil structure, nutrient status and other physical, chemical and biological attributes. Under traditional low input farming systems, this deterioration is kept in check by proper crop rotations and alternating years of cultivation with years of fallow. The length of the necessary rest period is dependent on inputs applied, soil and climate conditions, and crops. Hence, the main reason for incorporating fallow into crop rotations is to enhance sustainability of production through maintenance of soil fertility.

Fallow factors have been established by main crop groups and environmental conditions. The crop groups include cereals, legumes, roots and tubers, and a miscellaneous group consisting of long term annuals/perennials. The environmental frame consists of individual soil units, thermal regimes and moisture regimes.

Annex X presents fallow requirements. The fallow factor is expressed as percentage of time during the fallow-cropping cycle the land must be under fallow. For Fluvisols and Gleysols fallow factors are lower because of their special moisture and fertility conditions. At high levels of inputs and management, fallow requirements are uniformly set at 10%. At intermediate level of inputs, the fallow requirements are set at one third of the levels required under low level of inputs.

3.6. Summarizing stepwise review of the AEZ procedures

Crop suitability is a result of both agro-climatic and agro-edaphic evaluation. The combination of the agro-climatic suitability with the agro-edaphic suitability is based on the fact that the former results assume ideal soil and terrain conditions, while the latter evaluation assumes ideal agro-climates. Therefore, the results of the agro-climatic suitabilities are successively modified, according to edaphic suitabilities, to provide overall crop suitability.

The calculation procedures have been grouped into five steps:

(1) Climate data analysis
(2) Crop-specific agro-climatic assessment and potential biomass calculation
(3) Application of agro-climatic constraints
(4) Edaphic assessments
(5) Various applications (e.g., calculation of land with cultivation potential)

Step 1 calculates and organizes climate-related parameters for each grid-cell, i.e.

- Altitude
- Latitudinal climate
- Presence of cold break
- Thermal growing periods: temperature sum of days with mean temperature >0ºC, >5ºC, >10ºC
- Begins and ends of period with mean temperature >0ºC, >5ºC, >10ºC
- Accumulated temperature during thermal growing periods
- Actual evapotranspiration
- Annual precipitation
- Annual potential evapotranspiration.
- Total number of growing period days (LGP)
- Total number of wet-days, i.e., growing period days with excess moisture
- Total number days with moisture deficit
- Number of growing periods per year
- Begin and end of dormancy period
- Length of individual growing period
- Number of days in each growing period when crop water requirements can be fully met.
- Number of days in each growing period with excess moisture
- Begin and end dates of each growing period

In **Step 2**, all the 79 LUTs (61 crop/LUTs and 8 grass/pasture fodder LUTs) are assessed. The LUTs are tested starting successively each day during the permissible window of time (separately determined for irrigated and rain-fed conditions). The highest obtained yield defines the optimal crop calendar of each LUT in each grid-cell. The CROPWAT methodology (FAO, 1992) is used to run crop-specific water balances and to account for yield losses due to water deficits. Calculations are repeated seven times: once for irrigation conditions, and six times for rain-fed conditions assuming in the soil moisture balance calculations an available water-holding capacity of respectively 150, 125, 100, 75, 50 and 15 mm/m. This provides an understanding of the sensitivity of LGP and crop yield to soil conditions, and permits in the subsequent steps to select results corresponding to soil types as specified for a grid cell in the Soil map of Ukraine.

In **Step 3,** specific multipliers are used to reduce yields for agro-climatic constraints. This step is carried out separately to make the effect of the workability, pest and diseases, and other constraints transparent. The results of Step 3, agro-climatically attainable yields, are stored by crop/LUT for each grid-cell. The intermediate results of agro-climatic suitabilities, therefore, can be mapped for spatial verification.

Step 4 performs the edaphic assessment and combines the agro-climatic results in accordance with the soil information. As a result, for each 30 arc-sec grid-cell and each crop/LUT an expected yield and suitability distribution (6 classes VS, S, MS, mS, VmS and NS) regarding rain-fed and irrigation conditions are obtained. The results can be for single-crop/LUTs or as aggregations for crop groups (e.g., cereals, pulses, root crops, oil crops, fiber crops, vegetables).

Step 5. The databases created in steps 1 to 4 have been used to derive additional characterizations and aggregations, by, for example climatic zones, oblasts, rayons. Such as:

- Calculation of land with cultivation potential is involving an aggregation over individual crop/LUTs to estimate how much land is potentially suitable for crop cultivation.
- Tabulation of results by land cover type.
- Quantification of climatic production risks by using historical time series of suitability results. For each crop/LUT and grid-cell information on average crop yield, number of crop failures, standard deviation of expected yields, ratio of average yield versus yield of average climate will to be assessed. In this way, spatial distribution of climatic production risk can be assessed.

The structure of the suitability analysis procedures allows step-wise review of results. The results, obtained after completion of each of the above steps, are to be used in the process of checking and validating the proper functioning of the various procedures. The intermediate and final results are helpful for the verification against research data, crop statistics, expert knowledge, etc.

Results of the crop suitability analysis have been summarized in tabular and map form. Map of average potential yields based on year-by-year assessment of average yields and suitability map for rain-fed winter wheat under high level of input and management for the period of 1971-2000 are presented in Figures 3.4 and 3.5 respectively.

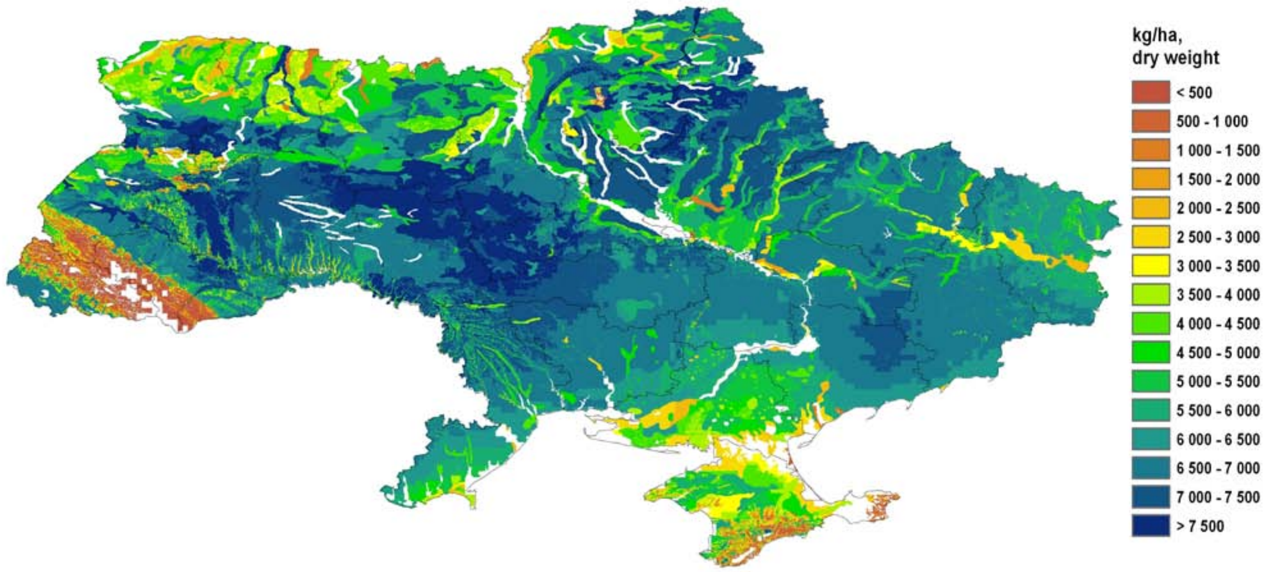


Figure 3.4. Average potential yields of rain-fed winter wheat in 1971-2000 (high level of input and management)

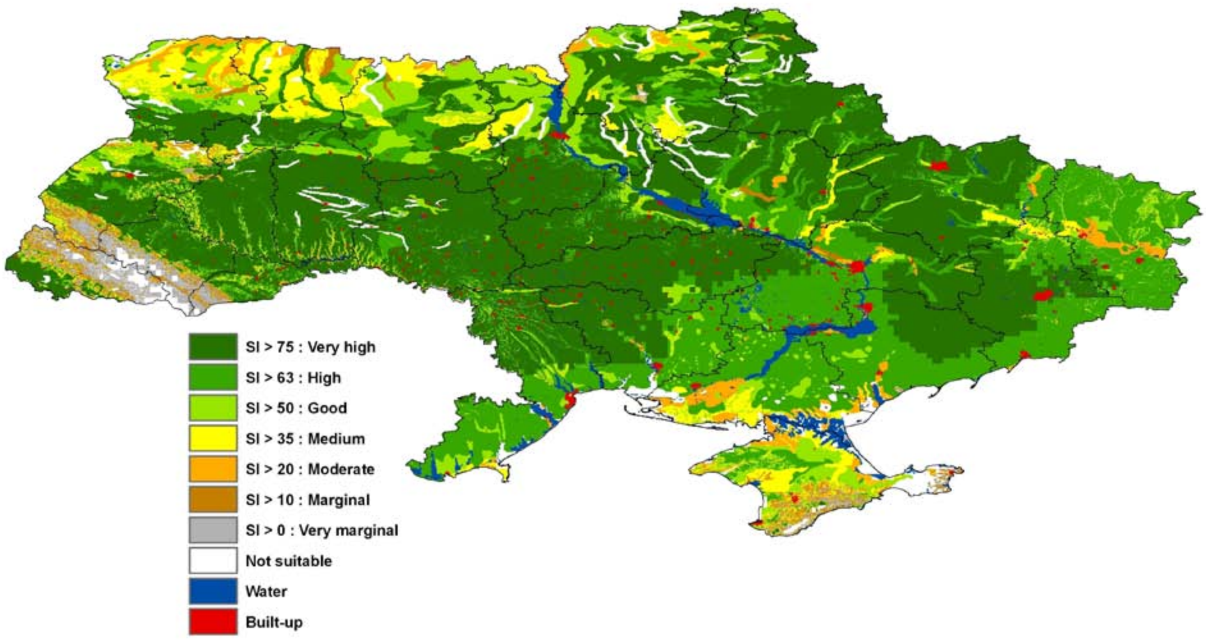


Figure 3.5. Suitability for rain-fed winter wheat in 1971-2000 (high level of input and management)

4. Results

4.1. Introduction

The AEZ assessment of Ukraine provides a comprehensive and spatially explicit database of crop production potential and related factors. The results are a valuable source of information that can be input to various applications and give basis for both rational agricultural planning and sustainable management of natural resources.

Section 4.2 presents estimates of the crop suitability and production potential for rain-fed cropping of major crops in Ukraine such as maize (grain), spring barley, sunflower, spring rape, flax , potato and sugar beet under high level of inputs aggregated at the three main agro-ecological regions of Ukraine, i.e., Steppe, Forest-steppe, and Pollisia and Carpathians.

Section 4.3 provides estimates of productivity potential for winter wheat under high, intermediate and low levels of input and management including land with cultivation potential, yields and production potential, as well as the assessment of the potential impact of irrigation for the period 1971–2000. Section 4.4 highlights the trends in winter wheat yields over the period 1971–2000. Section 4.5 examines differences between potentially attainable yields and observed yields for winter wheat at national and oblast level, and yield variability for the periods 1971–1980, 1981–1990, and 1991–2000 and 1971–2000.

Observed yields at oblast level represent the average farmers' yields (actual yields). The data on oblast yields for the past 30 years were collected from the reports published by the State Statistic Committee of Ukraine. Potential yields were calculated for individual years over the period 1971-2000 by grid cell and were aggregated to respectively Rayon and Oblast levels.

Average yields and coefficients of variation (CV) for the periods 1971–1980, 1981–1990, 1991–2000 and 1971–2000 were calculated based on the time series observed and potential yields, whereby:

- Land assessed for cultivation potential excludes forest, protected land, built-up areas, water bodies and the Chernobyl exclusion zone.
- Individual years very suitable, suitable and moderately suitable crop yields have been used in comparisons with observed yields.

Note: Results of the production potential for major crops under high, intermediate and low input levels at oblast level are given in the Annex XII. Suitability and yield maps for major crops under high level of input and management are presented in the Annex XIII. Annex XVI gives examples of results for winter wheat at high level of input and management tabulated at rayon level for Odes'ka, Cherkas'ka, Kharkivs'ka and L'vivs'ka oblasts for the periods 1981-1990, 1991-2000.

4.2. Suitability and estimated potential yields for major crops

The Ukraine AEZ study considers a total of 79 crop/LUTs, each at three defined levels of inputs and management. They cover 20 crops, two pasture types and two fodder crops. On the basis of historical time-series of climate data for the period 1971 – 2000, for each individual year potential yields, suitable extents and potential production of crops under high, intermediate and low level of inputs were calculated based on a 'best' LUT logic (Box 4.1). Then results were averaged over 30-year period and the grid-cell data was subsequently aggregated at oblast and rayon levels, as well as main agro-ecological regions of Ukraine.

Box 4.1. Defining 'best' LUT.

On the basis of historical time-series of climate data for the period 1971 – 2000, for each of the 79 crop/LUTs individual year yields were calculated. The 'best' LUT type for each crop was selected according to the following criteria:

(i) - crop failure less than 50 % of years;
(ii) - if crop failure occurrences were between 10% to 50%, the LUT with lowest number of years with crop failure was selected;
(iii) - if failure rates < 10%, the LUT with highest average output was selected..

By looking at all crop types, the useful extent of land with cultivation potential was estimated. In total, very suitable, suitable and moderately suitable land accounts for 93% of the country' area, percentages are respectively 46, 38 and 16. When excluding forests, protected areas, built up areas, non-vegetated areas, up to 26 million hectares (54 %) were assessed as very suitable for rain-fed crop production; almost another 20 millionn hectares are suitable with slight constraints. Of the very suitable agricultural land, 55% is located in the Forest-steppe zone, 26 % in the Steppe zone and 19 % in the zone of Polissia and Carpathians. Average potential yields are highest in the Forest-steppe zone, followed by arable land in Polissia and Carpathians. Due to higher incidents of dry conditions, average rain-fed yields in the Steppe zone were somewhat lower.

Table 4.1 presents examples of the results in terms of extents of land with cultivation potential, potential production and potential yields for rain-fed production of winter wheat, maize for grain, spring barley, sunflower, flax, spring rape, sugar beet and potato at assumed high level of input and management.

Table 4. 1. Extents of suitable land, potential production and potential yields of rain-fed crops by main agro-ecological zones under high level of input and management.

Zone	Suitable Extents (10^3 ha)				Potential Production (10^3 t)		Potential Yield (t/ha)	
	VS	VS+S+MS[a]	% VS	% VS+S+MS	VS	VS+S+MS	VS	VS+S+MS
Winter wheat								
Steppe	6468	19728	30,3	92,6	44790	124269	6,9	6,2
Forest-steppe	12246	16550	69,9	94,5	91796	116383	7,5	7,0
Polissia and Carpathians	2753	7019	33,4	85,2	21258	44988	7,7	6,4
Ukraine	21467	43297	35,9	72,4	157844	285640	7,4	6,6
Maize								
Steppe	0	15022	0,0	70,5	0	68243	0,0	4,5
Forest-steppe	1589	15228	9,1	87,0	9952	74323	6,3	4,9
Polissia and Carpathians	273	3515	3,3	42,7	1527	14342	5,6	4,1
Ukraine	1862	33765	3,1	56,4	11479	156908	6,2	4,6
Spring barley								
Steppe	2971	19777	13,9	92,8	10254	60848	3,5	3,1
Forest-steppe	10320	16575	58,9	94,7	39657	58318	3,8	3,5
Polissia and Carpathians	1480	7029	18,0	85,3	6106	22516	4,1	3,2
Ukraine	14771	43381	24,7	72,5	56017	141682	3,8	3,3
Sunflower								
Steppe	0	17436	0,0	81,8	0	36872	0,0	2,1
Forest-steppe	1413	15448	8,1	88,2	3334	32145	2,4	2,1
Polissia and Carpathians	196	3738	2,4	45,4	476	6206	2,4	1,7
Ukraine	1609	36622	2,7	61,2	3810	75223	2,4	2,1
Flax								
Steppe	14431	19302	67,7	90,6	8418	10735	0,6	0,6
Forest-steppe	12162	16517	69,5	94,3	11713	14852	1,0	0,9
Polissia and Carpathians	2866	6996	34,8	84,9	3109	6326	1,1	0,9
Ukraine	29459	42815	49,2	71,6	23240	31913	0,8	0,7
Spring rape								
Steppe	101	19007	0,5	89,2	293	44625	2,9	2,3
Forest-steppe	12527	16428	71,6	93,8	38244	47757	3,1	2,9
Polissia and Carpathians	3910	7020	47,5	85,2	12238	19193	3,1	2,7
Ukraine	16538	42455	27,6	71,0	50775	111575	3,1	2,6
Sugar beet								
Steppe	0	17220	0,0	80,8	0	448566	0,0	26,0
Forest-steppe	9520	16173	54,4	92,4	345063	538074	36,2	33,3
Polissia and Carpathians	3392	6391	41,2	77,6	127126	203446	37,5	31,8
Ukraine	12912	39784	21,6	66,5	472189	1190086	36,6	29,9
Potato								
Steppe	2309	17305	10,8	81,2	53429	349669	23,1	20,2
Forest-steppe	11387	16320	65,0	93,2	318556	426291	28,0	26,1
Polissia and Carpathians	4312	6428	52,3	78,0	124422	171265	28,9	26,6
Ukraine	18008	40053	30,1	67,0	496407	947225	27,6	23,6

[a] VS = very suitable; S = suitable; MS = moderately suitable

4.3. Rain-fed and irrigated estimated potentials for winter wheat

Especially favourable climatic and soil conditions over the most territory of Ukraine occur for winter wheat production. Table 4.2 presents land extents with cultivation potential for winter wheat under high level of input and management by oblast. Results at the national level show that about 43 million hectares i.e., 72 % of Ukraine's total land area is suitable for winter wheat cultivation, and about 36 % of this land is very suitable.

Table 4.2. Extents with cultivation potential for rain-fed winter wheat by oblast under high level of input and management.

	Total land	Extents of land with/without cultivation potential, 10^3ha					%			
		VS[a]	S	MS	mS+ VmS	NS	VS	VS+S+ MS	mS+ VmS	NS
Southern and Eastern										
AR Krym	2641	11	716	607	88	629	0,4	50,5	3,3	23,8
Odes'ka	3321	1074	1478	179	16	96	32,3	82,2	0,5	2,9
Mykolaivs'ka	2385	1068	917	192	9	14	44,8	91,3	0,4	0,6
Khersons'ka	2682	0	1319	520	140	239	0,0	68,6	5,2	8,9
Zaporiz'ka	2718	864	1342	157	21	50	31,8	86,9	0,8	1,8
Dnipropetrovs'ka	3173	1016	1623	90	39	43	32,0	86,0	1,2	1,4
Donets'ka	2639	1103	1202	71	11	21	41,8	90,0	0,4	0,8
Luhans'ka	2655	70	1989	179	102	45	2,6	84,3	3,8	1,7
Kharkivs'ka	3129	2024	587	59	38	28	64,7	85,3	1,2	0,9
Central										
Vinnyts'ka	2637	1542	586	43	1	85	58,5	82,3	0,0	3,2
Cherkas'ka	2084	1257	293	46	1	57	60,3	76,6	0,0	2,7
Poltavs'ka	2858	1396	820	64	16	184	48,8	79,8	0,6	6,4
Kirovohrads'ka	2447	1781	382	38	4	13	72,8	89,9	0,2	0,5
Northern										
Sums'ka	2370	1332	394	57	0	88	56,2	75,2	0,0	3,7
Chernihivs'ka	3174	978	906	239	7	323	30,8	66,9	0,2	10,2
Kyivs'ka	2880	1014	642	182	4	150	35,2	63,8	0,1	5,2
Zhytomyrs'ka	2968	732	822	207	0	90	24,7	59,3	0,0	3,0
Volyns'ka	2003	346	402	256	0	268	17,3	50,1	0,0	13,4
Rivnens'ka	1994	455	333	180	0	189	22,8	48,5	0,0	9,5
Western										
Ivano-Frankivs'ka	1387	391	212	14	4	77	28,2	44,5	0,3	5,6
Zakarpats'ka	1271	161	172	13	3	126	12,7	27,2	0,2	9,9
L'vivs'ka	2172	636	458	121	5	224	29,3	55,9	0,2	10,3
Ternopil's'ka	1375	869	177	7	0	56	63,2	76,6	0,0	4,1
Khmel'nyts'ka	2054	1073	313	36	0	114	52,2	69,2	0,0	5,6
Chernivets'ka	805	274	174	14	1	40	34,0	57,4	0,1	5,0
Ukraine	**59822**	**21467**	**18259**	**3571**	**510**	**3249**	**35,9**	**72,4**	**0,9**	**5,4**

[a] VS = very suitable; S = suitable; MS = moderately suitable; mS = marginally suitable; VmS = very marginally suitable; NS = not suitable

Results for winter wheat under different levels of input and management are represented in Table 4.3. The differences between extents with cultivation potential under high, intermediate and low levels of input and management are minor; reduction is 3 % and 6 % for intermediate and low levels correspondingly. However, potential yields under intermediate and low input levels are on average 35 % and 45 % lower than those under high input level.

Table 4.3. Extents of suitable land, production potential and attainable yields of rain-fed winter wheat by oblast for high, intermediate and low levels of input and management.

Oblast	Total Area (10^3 ha)	High Input Level						Intermediate Input Level (VS+S+MS)			Low Input Level (VS+S+MS)		
		Suitable Extents (10^3 ha)		Potential Production (10^3 t)		Potential Yield (t/ha)		Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)
		VS[a]	VS+S+MS	VS	VS+S+MS	VS	VS+S+MS						
Southern and Eastern													
AR Krym	2641	11	1334	77	6776	7,0	5,1	1161	3986	3,4	1031	3331	3,2
Odes'ka	3321	1074	2731	7703	17524	7,2	6,4	2743	11436	4,2	2729	10092	3,7
Mykolaivs'ka	2385	1068	2177	7439	14425	7,0	6,6	2178	9359	4,3	2179	8298	3,8
Khersons'ka	2682	0	1839	0	9919	0,0	5,4	1776	6322	3,6	1776	5777	3,3
Zaporiz'ka	2718	864	2363	6018	15159	7,0	6,4	2344	9769	4,2	2346	8699	3,7
Dnipropetrovs'ka	3173	1016	2729	7025	17982	6,9	6,6	2679	11438	4,3	2631	9932	3,8
Donets'ka	2639	1103	2376	7588	15826	6,9	6,7	2368	10206	4,3	2361	8931	3,8
Luhans'ka	2655	70	2238	481	13947	6,9	6,2	2261	9142	4,0	2262	8096	3,6
Kharkivs'ka	3129	2024	2670	14045	17804	6,9	6,7	2655	11369	4,3	2613	9688	3,7
Central													
Vinnyts'ka	2637	1542	2171	12033	15758	7,8	7,3	2200	9964	4,5	2199	7791	3,5
Cherkas'ka	2084	1257	1596	9578	11495	7,6	7,2	1599	7266	4,5	1590	5950	3,7
Poltavs'ka	2858	1396	2280	10115	14975	7,2	6,6	1926	8221	4,3	1647	6158	3,7
Kirovohrads'ka	2447	1781	2201	12700	15318	7,1	7,0	2209	9829	4,4	2202	8483	3,9
Northern													
Sums'ka	2370	1332	1783	9926	12463	7,5	7,0	1709	7520	4,4	1625	5894	3,6
Chernihivs'ka	3174	978	2123	7558	14039	7,7	6,6	1798	7207	4,0	1329	4461	3,4
Kyivs'ka	2880	1014	1838	7928	12616	7,8	6,9	1700	7141	4,2	1476	5187	3,5
Zhytomyrs'ka	2968	732	1761	5771	11734	7,9	6,7	1630	6615	4,1	1319	4309	3,3
Volyns'ka	2003	346	1004	2700	6194	7,8	6,2	946	3601	3,8	816	2410	3,0
Rivnens'ka	1994	455	968	3523	6328	7,7	6,5	885	3620	4,1	784	2544	3,2
Western													
Ivano-Frankivs'ka	1387	391	617	2942	4233	7,5	6,9	570	2298	4,0	525	1670	3,2
Zakarpats'ka	1271	161	346	1232	2316	7,7	6,7	409	1513	3,7	295	838	2,8
L'vivs'ka	2172	636	1215	4852	8086	7,6	6,7	1131	4398	3,9	981	3023	3,1
Ternopil's'ka	1375	869	1053	6549	7614	7,5	7,2	1080	4811	4,5	1081	3787	3,5
Khmel'nyts'ka	2054	1073	1422	8021	10005	7,5	7,0	1425	6213	4,4	1389	4820	3,5
Chernivets'ka	805	274	462	2040	3104	7,4	6,7	444	1823	4,1	429	1356	3,2
Ukraine	**59822**	**21467**	**43297**	**157844**	**285640**	**7,4**	**6,6**	**41826**	**175067**	**4,2**	**39615**	**141525**	**3,6**

[a] VS = very suitable; S = suitable; MS = moderately suitable

Irrigated agriculture is concentrated in the south and east of Ukraine. In 1990, land equipped with irrigation infrastructure covered about three million hectares, i.e., about 7% of the total arable land. After 1992, the construction of new irrigation systems was virtually stopped and several of the existing schemes went out of operation. In 2004, land equipped for irrigation had declined to 1.5 million hectares, of which only about 370 thousand hectares were actually irrigated. Existing main and secondary level irrigation systems may provide water supply for an area up to 2.4 million hectares. Figure 4.1 shows the area equipped for irrigation around the year 2000, as the percentage of the total area on a raster with a resolution of 5 arc-min (FAO/University of Frankfurt, 2007).

In 2004, about 72 % of the then irrigated land was used for growing cereals (50%) and industrial crops, e.g., sunflower and soybean (22 %%). About 10 % of the irrigated land was used for growing vegetables, and the remaining 18 % for fodder crops.

The assessment of the potential impact of irrigation was done for 3 crops, namely winter wheat, maize and sunflower for the areas equipped with irrigation (Figure 4.1). The detailed results by oblast are presented in the Annex XII. Aggregated results presented in Table 4.4 show that there is almost no or little benefit from irrigation to the production potential in the Northern and Western regions. In the Southern, Eastern and Central regions irrigation provides leads to increased on grain yields. For instance, yields of wheat, maize and sunflower under irrigation in the Southern and Eastern parts of Ukraine have been assessed respectively 36%, 140% and 110% higher than rain-fed yields. Consequently, full exploitation of the area equipped for irrigation would increase the potential production capacities respectively by 35% for winter wheat, almost 120% for maize and more than 100% for sunflower.

Table 4.4. Agronomicaly attainable high input yields of winter wheat, maize and sunflower under irrigation and rain-fed conditions.

	Area equipped for irrigation, (10^3 ha)	Yield (t/ha)	
		Irrigated Production	Rain-fed Production
Winter wheat			
Southern and Eastern	1995	7,9	5,8
Central	178	7,8	6,8
Northern	161	6,8	6,4
Western	44	7,4	7,0
Ukraine	**2378**	**7,8**	**6,0**
Maize			
Southern and Eastern	1995	8,2	3,4
Central	178	8,2	4,7
Northern	161	6,5	4,2
Western	44	6,4	4,8
Ukraine	**2378**	**8,1**	**3,7**
Sunflower			
Southern and Eastern	1995	3,8	1,8
Central	178	4,0	2,1
Northern	161	3,1	1,7
Western	44	2,8	1,9
Ukraine	**2378**	**3,8**	**1,9**

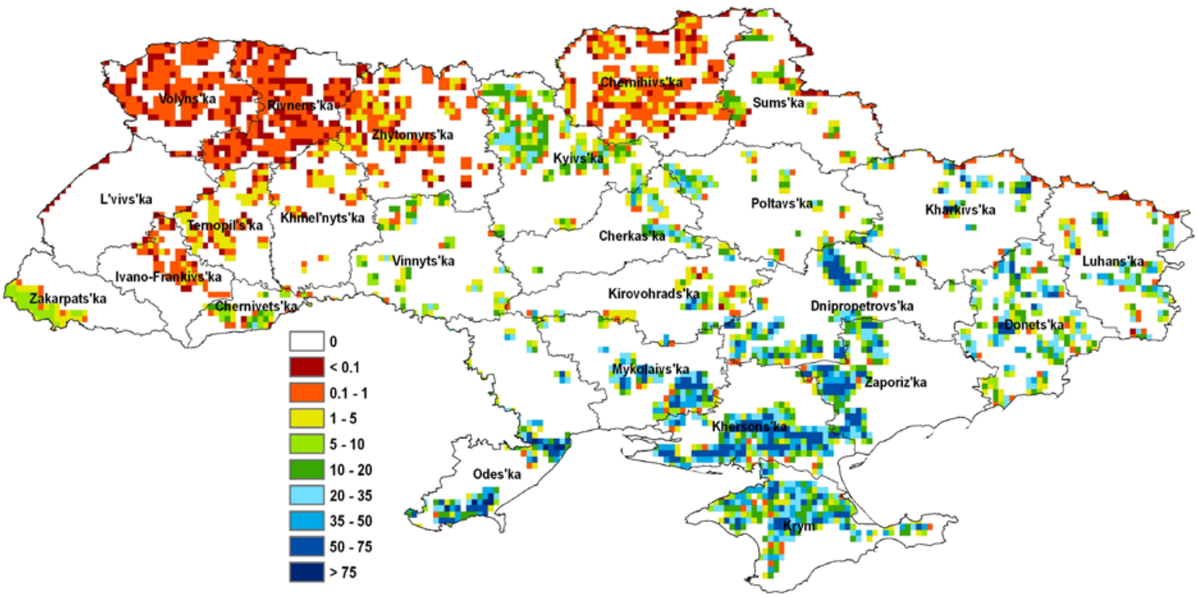


Figure 4.1. Area equipped for irrigation in Ukraine.

4.4. Trends in actual and estimated potential rain-fed winter wheat yields

Figure 4.2 depicts estimated potential and observed yields for winter wheat and their trends for the 30-year period of 1971–2000 at the national level. The general conclusions can be drawn that: (a) the trend of the potential winter wheat yields for 1971-2000 shows a slight decline, (b) estimated potential yields substantially exceed observation; and (c) potential yields are more variable and have a greater spread in values than observed yields.

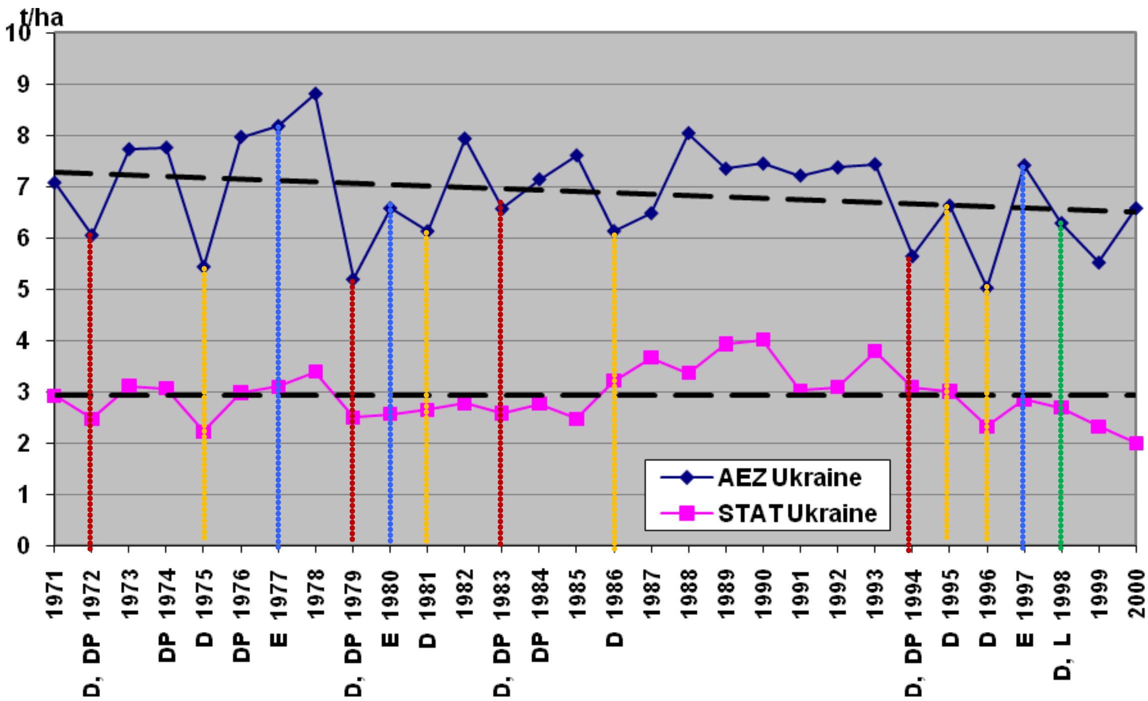


Figure 4.2. Estimated potential yields vs. observed yields for rain-fed winter wheat at the national level in 1971 – 2000.

Estimated potentials follow the annual fluctuations of the observed data and are in correspondence with the meteorological observations and records of weather anomalies that have been affecting actual crop yields (Table 4.5). The most sizable effect on the yields (Figure 4.2) had drought during the growing period (D) and the combination of drought during the growing period (D) and unfavorable weather conditions during the dormancy period (DP). Such unfavorable weather conditions resulted in the reduction in both estimated potentials and observed yields in nearly all years when it occurred. Yet the excess of moisture during ripening (E) did not affect negatively winter wheat yields.

Table 4.5. Unfavorable weather conditions for winter wheat in Ukraine in 1971-2000.

Condition	Year
Drought during the growing period (D)	1972, 1975, 1979, 1981, 1983, 1986, 1994, 1995, 1996, 1999
Excess of moisture during ripening (E)	1977, 1980, 1997
Low temperatures in spring (L)	1999
Unfavorable weather conditions during the dormancy period (DP)	1972, 1974, 1976, 1979, 1983, 1984, 1994
Source: Adamenko T. Changes in agro-climatic conditions and their influence on the grain production in Ukraine (www.apk-inform.com)	

Fitting trends to longer time series reduces the sensitivity of results to the short or midterm impacts of new varieties or changes in agricultural practices, it is likely that fitting trends to shorter time series helps capture these effects. Hence, yield trends were estimated for consecutive sequences of 10-year periods between 1971 and 2000 (Figure 4.3). In the AEZ assessment cultivars, management and inputs are assumed to be constant over the whole 30-year period which makes the estimated potential yields to be sensitive to the specific weather conditions. However, the corresponding linear trends for the periods 1971–1980, 1981–1990, and 1991–2000 for the estimated potential and observed yields are markedly similar, and only in the 1980-s the positive trend of the observed yields is stipper which indicates some improvement in agricultural practices over that period. These reflect that Ukrainian agricultural performance was mainly dependent on environmental conditions, e.g. climate, rather than on agricultural management, inputs and technology.

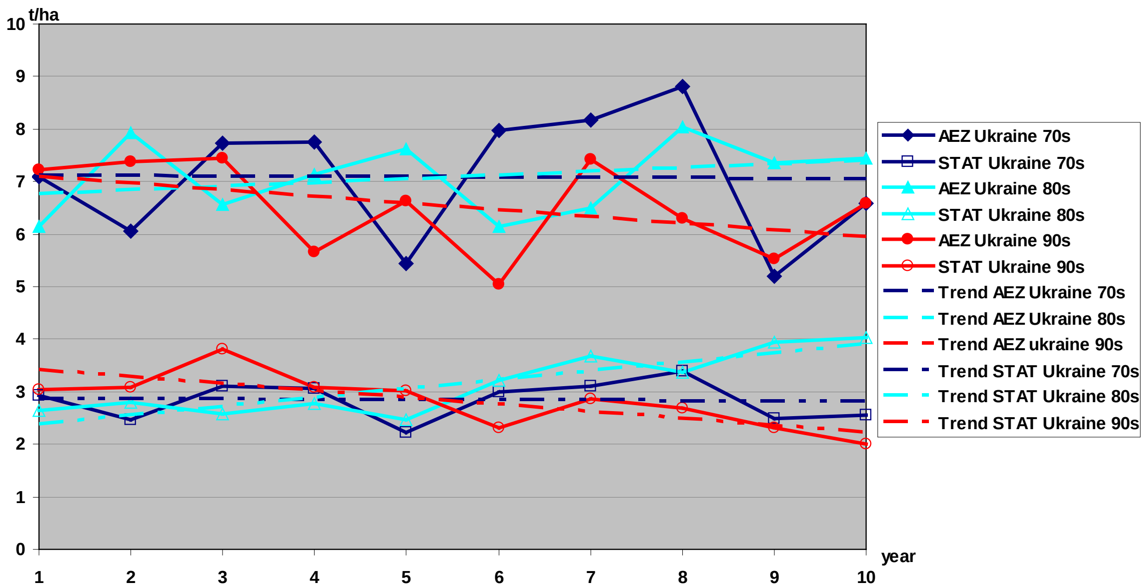


Figure 4.3. Estimated potential yields vs. observed yields for rain-fed winter wheat at the national level for the periods 1971–1980, 1981–1990, and 1991–2000.

The national yields are averages of those of the oblast's ones and it is expected that they may highlight similarities or mask differences between oblasts. Figure 4.4 and Annex XIV show that the declining trends for estimated potential rain-fed winter wheat yields are evident in all oblasts except AR Krym. However, for the observed yield trends for the main winter wheat growing regions of Southern and Central parts of Ukraine show a slight decrease, while in Northern and Western regions they are positive.

Inter-annual fluctuations in estimated potential yields are especially in sympathy with the observed yields across Ukraine, but differ spatially. Results for southern, eastern and central regions of Ukraine, which are characterized by low and highly variable rainfall regimes, show wide and continual temporal fluctuations over the 30-years period of 1971–2000, in some years up to 50%. Regions with reliable and ample precipitation in western and northern part of Ukraine, with the exception of Sums'ka, Chernihivs'ka and Kyivs'ka oblasts, show quite modest inter-annual fluctuations over 1971–1990, with the increase in variation during the 1990's.

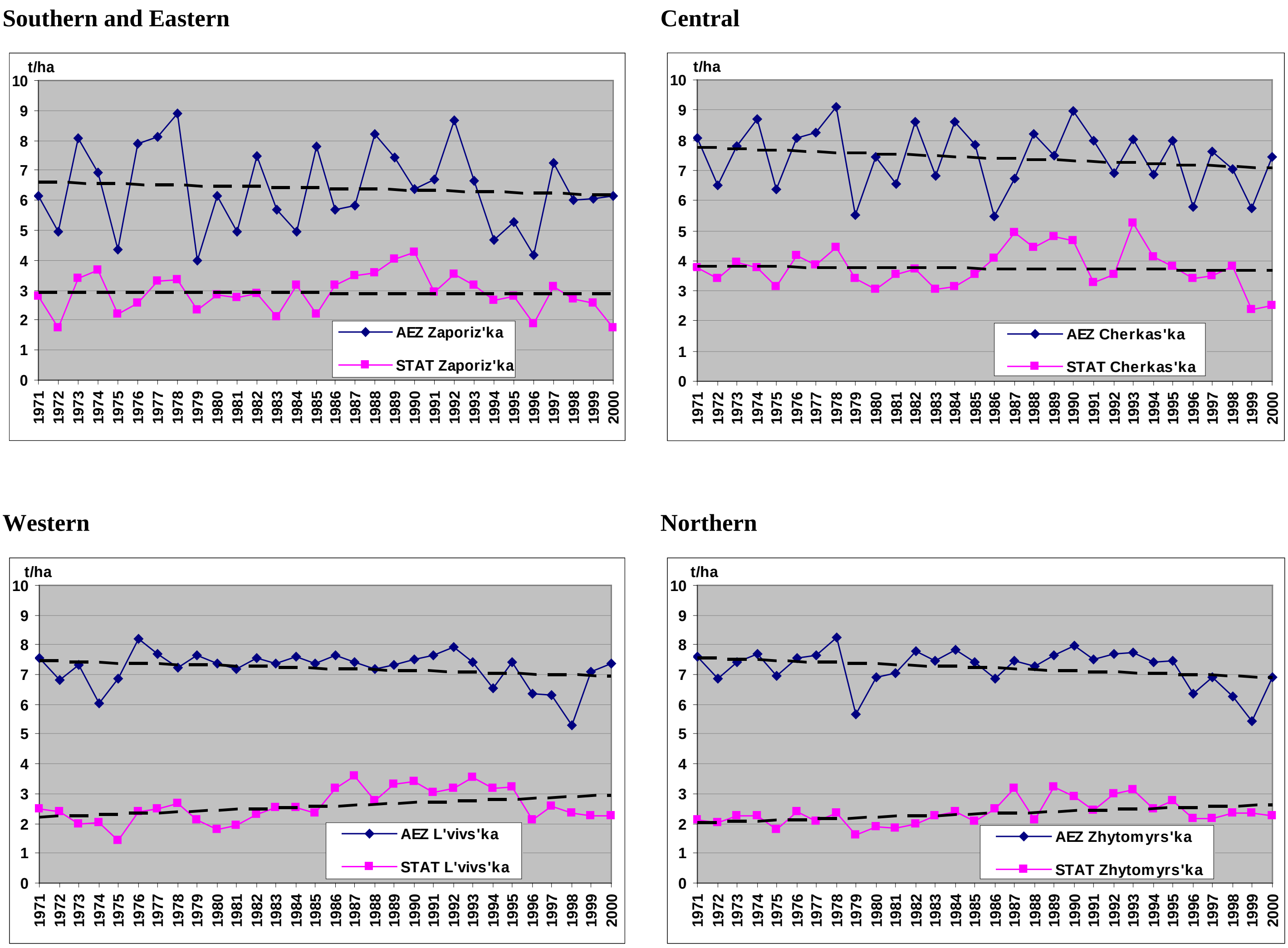


Figure 4.4. Estimated potential yields vs. observed yields and their trends for winter wheat for selected oblasts in 1971 – 2000.

4.5. Yield gap and variability of estimated potential yields and observed winter wheat yields

In the context of AEZ, estimated yields are potentially attainable yields, limited to a realistically obtainable yield by considering different levels of input and management, and naturally occurring yield reductions due to pest and disease incidence, water stress, extreme temperature events, and climatic factors that directly or indirectly affect yield. The comparison between estimated potential yields and observed yields provide relevant information regarding identification of the yield gap and its major causes (e.g., lack of agricultural inputs, inappropriate cropping systems, inadequate crop management, year-to-year variations in climatic conditions, occurrence of natural hazards such as floods and droughts). Such yield gaps may vary widely and understanding their causes is at the heart of improving crop management.

Figure 4.5 depicts the gap between estimated potential and observed yields which reflects the differences between observed average yields and aggregated potential yields assuming high level of input and management at the national level. The estimated potential winter wheat yields at the national level range from 5 to almost 9 t/ha over the period of 1971-2000 and national observed yields were in the range of 2.5–4 t/ha, with the yield gap varying from 2.6 to 5.4 t/ha over the years.

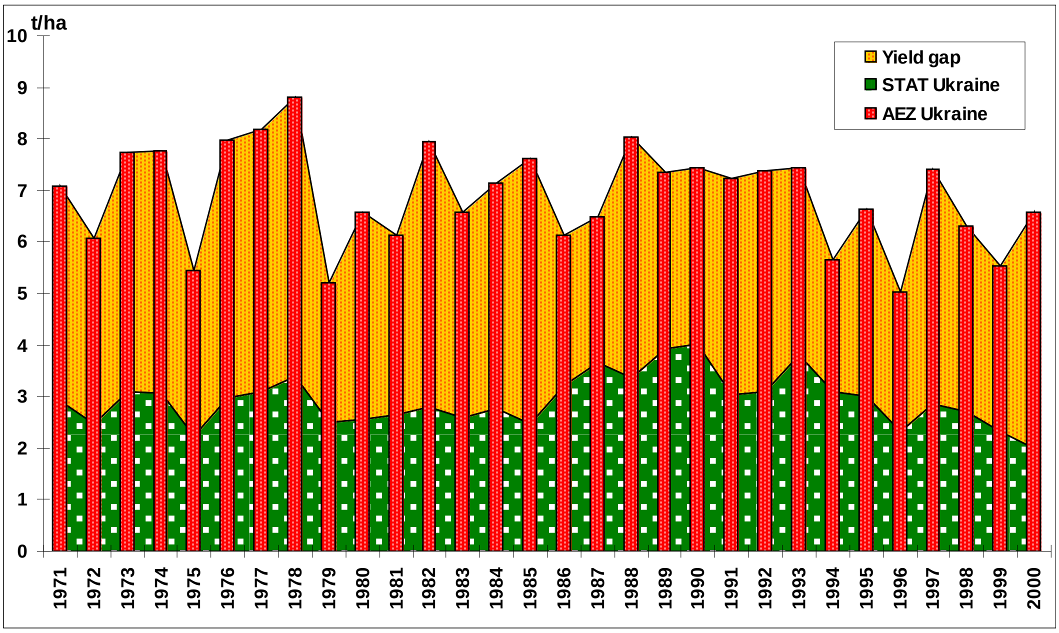


Figure 4.5. Yield gap winter wheat at the national level in 1971 – 2000.

Across the oblasts of Ukraine average observed yields of winter wheat over the period 1971-2000 were varying between 2 and 4 t/ha (Table 4.6), reaching their most in the 1980-s. However, the estimated potential rain-fed yields for the same period range from 5 up to almost 8t/ha, indicating a much higher yield potential of the crops than currently being realized by the average farmer all over the country. At the same time, winter wheat yields on local experimental stations across the country under minimal stress and adequate management commonly surpass in the range of 7–10 t/ha, depending on the region (www.agroua.net). Despite of a gap of 10–20 % which is generally considered to be difficult to abridge because of nontransferability of some technologies from experiment stations to on-farm situations, there are certain losses in yields due to heterogeneity of environmental resources between and within fields, differences in the management practices and extent of input use in a given environment.

Table 4.6. Yield gap between potential and observed winter wheat yields , 1971–1980, 1981–1990, 1991–2000 compared to 1971–2000

Oblast'	Average yield calculated on year-by-year basis (t/ha)								Yield gap (t/ha)*			
	National statistics				AEZ							
	1971-1980	**1981-1990**	**1991-2000**	***1971-2000***	**1971-1980**	**1981-1990**	**1991-2000**	***1971-2000***	**1971-1980**	**1981-1990**	**1991-2000**	***1971-2000***
Southern and Eastern												
AR Krym	2,6	2,9	2,4	*2,6*	4,6	4,8	4,9	*4,8*	1,9	1,9	2,4	*2,1*
Odes'ka	2,8	2,8	2,6	*2,7*	6,9	6,5	6,1	*6,5*	4,1	3,8	3,5	*3,8*
Mykolaivs'ka	2,8	2,9	2,4	*2,7*	7,0	6,8	6,1	*6,6*	4,2	3,8	3,7	*3,9*
Khersons'ka	2,9	3,0	2,6	*2,8*	5,2	5,1	4,9	*5,1*	2,3	2,1	2,3	*2,2*
Zaporiz'ka	2,8	3,2	2,7	*2,9*	6,6	6,4	6,2	*6,4*	3,7	3,3	3,5	*3,5*
Dnipropetrovs'ka	2,8	3,1	2,8	*2,9*	6,7	6,6	6,0	*6,4*	4,0	3,5	3,2	*3,6*
Donets'ka	2,8	3,3	2,7	*2,9*	6,6	6,6	6,2	*6,5*	3,8	3,3	3,5	*3,6*
Luhans'ka	2,3	2,7	2,2	*2,4*	6,1	6,3	5,9	*6,1*	3,8	3,6	3,8	*3,7*
Kharkivs'ka	2,9	3,2	2,8	*3,0*	6,9	6,9	6,1	*6,6*	4,0	3,7	3,2	*3,6*
Central												
Vinnyts'ka	3,2	3,6	3,2	*3,3*	7,6	7,8	7,1	*7,5*	4,5	4,2	3,8	*4,2*
Cherkas'ka	3,7	4,0	3,6	*3,8*	7,6	7,5	7,1	*7,4*	3,9	3,5	3,6	*3,7*
Poltavs'ka	3,0	3,6	2,9	*3,2*	6,8	6,9	6,1	*6,6*	3,8	3,3	3,2	*3,4*
Kirovohrads'ka	3,1	3,1	2,8	*3,0*	7,1	7,1	6,5	*6,9*	4,0	4,0	3,7	*3,9*
Northern												
Sums'ka	2,7	3,1	2,7	*2,8*	7,4	7,4	6,8	*7,2*	4,7	4,3	4,1	*4,4*
Chernihivs'ka	2,4	2,8	2,2	*2,5*	7,1	7,2	6,8	*7,1*	4,7	4,5	4,6	*4,6*
Kyivs'ka	3,1	3,5	3,3	*3,3*	7,3	7,5	7,0	*7,3*	4,1	4,0	3,7	*4,0*
Zhytomyrs'ka	2,1	2,4	2,5	*2,3*	7,3	7,5	7,0	*7,2*	5,2	5,0	4,5	*4,9*
Volyns'ka	2,3	3,1	2,8	*2,7*	6,7	6,8	6,3	*6,6*	4,4	3,7	3,6	*3,9*
Rivnens'ka	2,6	3,1	2,8	*2,8*	7,2	7,3	6,7	*7,1*	4,6	4,2	3,9	*4,3*
Western												
Ivano-Frankivs'ka	2,1	3,0	2,7	*2,6*	7,5	7,8	7,2	*7,5*	5,3	4,8	4,5	*4,9*
Zakarpats'ka	2,7	3,5	3,1	*3,1*	7,3	7,6	6,9	*7,3*	4,6	4,1	3,8	*4,2*
L'vivs'ka	2,2	2,8	2,8	*2,6*	7,3	7,4	6,9	*7,2*	5,1	4,6	4,2	*4,6*
Ternopil's'ka	2,9	3,5	3,2	*3,2*	7,6	7,7	7,0	*7,4*	4,8	4,2	3,8	*4,3*
Khmel'nyts'ka	2,8	3,2	3,3	*3,1*	7,3	7,4	6,7	*7,2*	4,6	4,2	3,5	*4,1*
Chernivets'ka	3,1	3,6	3,2	*3,3*	7,3	7,3	6,7	*7,1*	4,2	3,7	3,5	*3,8*
Ukraine	**2,8**	**3,1**	**2,8**	***2,9***	**7,1**	**7,1**	**6,5**	***6,9***	**4,2**	**3,9**	**3,7**	***4,0***

* discrepancies are coursed by rounding

The yield gap shows a tendency to a slight decline over the period 1971–2000 (Table 4.6). However, oblasts in southern and southeastern part of Ukraine show slight increase in yield gap during 1990's, while oblasts in northern and western parts of Ukraine still had the tendency of reducing the gap. In general, yield gap is greater in the northern and northwestern oblasts of Ukraine and range from 4 up to 5 t/ha, while in central and southern regions, yield gap ranges between 2 and 4 t/ha.

Table 4.7. Changes in potential and observed average winter wheat yields

Oblast'	AEZ				National statistics			
	1981-1990 to 1971-1980		1991-2000 to 1981-1990		1981-1990 to 1971-1980		1991-2000 to 1981-1990	
	%	t/ha	%	t/ha	%	t/ha	%	t/ha
Southern and Eastern								
AR Krym	5,4	0,26	-0,9	-0,04	6,1	0,29	2,1	0,10
Odes'ka	-5,9	-0,39	-7,8	-0,47	-0,7	-0,02	-8,2	-0,21
Mykolaivs'ka	-3,0	-0,20	-10,4	-0,64	5,3	0,15	-22,0	-0,53
Khersons'ka	-2,8	-0,14	-3,2	-0,16	2,1	0,06	-13,4	-0,35
Zaporiz'ka	-1,8	-0,12	-4,4	-0,27	11,0	0,35	-17,0	-0,46
Dnipropetrovs'ka	-2,4	-0,16	-9,6	-0,58	9,4	0,29	-10,2	-0,29
Donets'ka	0,4	0,03	-7,0	-0,43	15,7	0,52	-21,8	-0,59
Luhans'ka	3,3	0,21	-5,8	-0,34	12,6	0,34	-23,3	-0,50
Kharkivs'ka	-0,4	-0,03	-13,1	-0,80	8,2	0,26	-10,9	-0,31
Central								
Vinnyts'ka	1,5	0,12	-9,9	-0,70	11,4	0,41	-10,3	-0,33
Cherkas'ka	-0,8	-0,06	-5,6	-0,40	7,4	0,29	-12,0	-0,43
Poltavs'ka	0,5	0,03	-11,6	-0,71	16,7	0,60	-22,9	-0,67
Kirovohrads'ka	0,1	0,00	-9,0	-0,58	0,0	0,00	-11,8	-0,33
Northern								
Sums'ka	0,9	0,07	-8,9	-0,61	13,4	0,42	-13,4	-0,36
Chernihivs'ka	1,3	0,09	-7,0	-0,48	12,4	0,34	-25,8	-0,57
Kyivs'ka	3,1	0,24	-6,5	-0,46	10,1	0,36	-6,3	-0,21
Zhytomyrs'ka	2,9	0,22	-7,3	-0,51	15,3	0,37	2,4	0,06
Volyns'ka	0,5	0,03	-7,1	-0,45	24,0	0,74	-11,6	-0,32
Rivnens'ka	1,2	0,08	-8,9	-0,60	16,5	0,51	-10,6	-0,30
Western								
Ivano-Frankivs'ka	4,5	0,35	-8,9	-0,64	27,6	0,82	-9,3	-0,25
Zakarpats'ka	4,0	0,30	-9,2	-0,63	22,4	0,78	-12,5	-0,39
L'vivs'ka	2,0	0,15	-6,9	-0,48	21,5	0,60	-0,4	-0,01
Ternopil's'ka	0,5	0,04	-9,7	-0,68	16,4	0,57	-6,4	-0,21
Khmel'nyts'ka	1,3	0,09	-10,4	-0,70	14,1	0,46	1,3	0,04
Chernivets'ka	0,1	0,01	-8,5	-0,57	14,9	0,54	-13,0	-0,42
Ukraine	**0,1**	**0,01**	**-8,7**	**-0,57**	**10,0**	**0,32**	**-11,6**	**-0,33**

National statistics have shown improvements in winter wheat yields during the 1980's. During that period, observed yields increased on average by 10 % (Table 4.7). The estimated potential yields for most of the oblasts show a positive trend for the corresponding period also. In the 1990's, recorded yields on average were almost 12% lower compare to the previous period. Yet, the corresponding AEZ negative changes in yields due to climatic trends were almost 9 % on average, affecting among all the main wheat growing regions in southern, eastern and central parts of Ukraine. Thus, in the 1990's the decrease in winter wheat yields was most likely not only determined by deterioration of management and technology. Adverse weather conditions had significant impact on winter wheat yields all over Ukraine.

Year-to-year variation in estimated potential yields of rain-fed winter wheat expressed as coefficient of variation (CV), ranges between 8 to 33 % across the country. The variation in yields could be classified as low, medium, and high when the CV is <10, 10–20, and >20 %, respectively. Locations with high CV >20 % are mainly southern, eastern and partly central regions of Ukraine. The estimated potential yields fluctuate widely from year to year, with standard deviations (SD) of about 1.6 to 2.2 t/ha among years. Hence these locations are prone to relatively high climatic risk. Regions with CV <20 % are more stable and the year-to-year magnitude in yields comprises less than 1.6 t/ha, lowering in the northern and western parts up to 0.6–0.8 t/ha. Figures 4.6 and 4.7 show respectively CV and SD of rain-fed winter wheat yields of each grid-cell aggregated into six classes for the period 1971–2000.

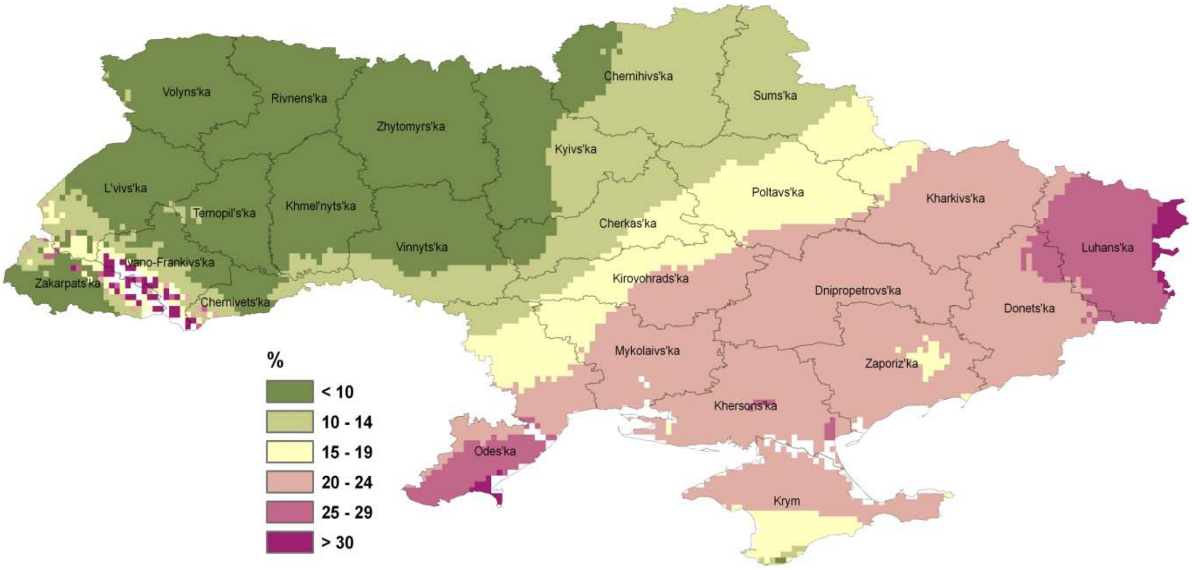


Figure 4.6. Coefficient of variation of rain-feed winter wheat yields for the period 1971-2000 (high level of input and management).

Coefficients of variations (CV in %) and standard deviations (SD in t/ha) of estimated potential and observed winter wheat yields for the periods 1971–1980, 1981–1990, 1991–2000 and 1971–2000, aggregated at the oblast' level are presented in Table 4.8. CV of both estimated potential and observed yields in the southern and eastern parts are corresponding. However, the larger spatial and temporal variations are seen in observed yields as compared to estimated potential among the oblasts of northern and western parts of Ukraine.

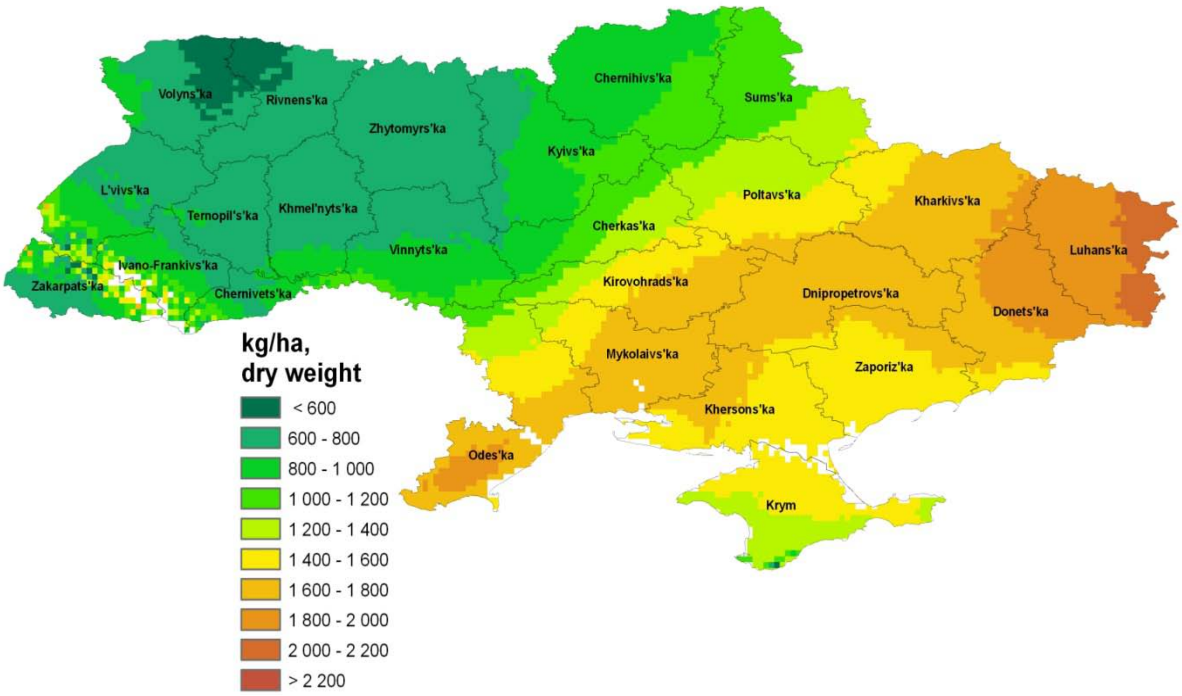


Figure 4.7. Standard deviation of rain-fed winter wheat yields for the period 1971-2000 (high level of input and management).

Table 4.8. CV and SD of potential and observed winter wheat yields , 1971-1980, 1981-1990, and 1991-2000 compared to 1971-2000

Oblast	National statistic (calculated on year-by-year basis)								AEZ (calculated on year-by-year basis)							
	Standard Deviation (t/ha)				Coefficient of variation (%)				Standard Deviation (t/ha)				Coefficient of variation (%)			
	1971-1980	1981-1990	1991-2000	*1971-2000*	1971-1980	1981-1990	1991-2000	*1971-2000*	1971-1980	1981-1990	1991-2000	*1971-2000*	1971-1980	1981-1990	1991-2000	*1971-2000*
Southern and Eastern																
AR Krym	0,5	0,5	0,5	0,5	19,2	18,7	21,0	*20,3*	1,8	1,1	1,3	1,4	40,9	22,3	25,6	*29,3*
Odes'ka	0,4	0,6	0,7	0,6	13,8	20,2	27,5	*20,5*	1,3	1,2	1,6	1,4	18,3	19,0	26,5	*21,2*
Mykolaivs'ka	0,4	0,8	0,6	0,6	14,5	25,9	24,9	*23,1*	1,5	1,2	1,4	1,4	21,2	18,1	23,7	*21,0*
Khersons'ka	0,5	0,7	0,5	0,6	18,4	23,5	20,1	*20,9*	1,7	1,5	1,3	1,5	33,2	29,5	26,1	*28,9*
Zaporiz'ka	0,6	0,7	0,6	0,6	22,0	22,4	20,5	*22,1*	1,7	1,2	1,3	1,4	26,3	18,7	21,0	*21,7*
Dnipropetrovs'ka	0,6	0,8	0,6	0,7	22,2	26,8	20,7	*23,3*	2,0	1,1	1,2	1,5	29,4	16,3	19,8	*22,6*
Donets'ka	0,6	0,5	0,6	0,6	23,1	16,0	22,5	*21,6*	1,9	1,4	1,7	1,6	28,3	20,6	26,7	*24,7*
Luhans'ka	0,6	0,7	0,8	0,7	26,0	26,2	38,2	*30,3*	2,2	1,6	1,6	1,8	36,7	25,2	27,6	*29,2*
Kharkivs'ka	0,6	0,8	0,8	0,7	19,4	27,0	28,7	*25,0*	2,0	1,3	1,3	1,6	29,2	19,3	20,8	*23,7*
Central																
Vinnyts'ka	0,4	0,6	0,5	0,5	13,4	17,3	16,6	*16,4*	0,8	0,6	0,9	0,8	10,3	7,2	12,8	*10,7*
Cherkas'ka	0,4	0,7	0,8	0,7	12,0	17,4	22,8	*17,8*	1,1	1,1	0,8	1,0	15,0	14,9	11,8	*13,8*
Poltavs'ka	0,6	0,8	0,8	0,8	19,0	22,4	29,0	*24,8*	1,8	1,1	0,9	1,3	25,9	15,9	15,4	*19,9*
Kirovohrads'ka	0,4	0,7	0,6	0,6	13,9	23,7	21,4	*20,0*	1,5	1,4	1,2	1,3	21,2	19,6	18,1	*19,5*
Northern																
Sums'ka	0,4	0,6	0,7	0,6	15,5	18,9	24,9	*20,5*	1,5	1,0	0,8	1,1	20,0	13,9	12,3	*15,8*
Chernihivs'ka	0,5	0,5	0,5	0,5	19,6	16,5	23,4	*21,2*	1,1	0,8	0,8	0,9	15,6	11,2	12,3	*13,1*
Kyivs'ka	0,4	0,6	0,6	0,6	12,1	17,8	18,7	*16,7*	1,0	0,7	0,8	0,8	13,6	9,0	10,8	*11,2*
Zhytomyrs'ka	0,3	0,5	0,3	0,4	12,2	20,1	13,6	*17,6*	0,7	0,3	0,8	0,6	9,8	4,6	10,8	*8,9*
Volyns'ka	0,4	0,6	0,5	0,6	15,8	20,6	17,9	*21,3*	0,4	0,2	0,7	0,5	5,2	2,6	10,8	*7,4*
Rivnens'ka	0,4	0,5	0,5	0,5	13,6	15,3	17,0	*16,7*	0,4	0,2	0,7	0,6	5,8	3,2	10,7	*7,8*
Western																
Ivano-Frankivs'ka	0,3	0,5	0,6	0,6	15,5	17,2	23,9	*23,2*	0,7	0,2	0,8	0,6	9,4	2,7	10,7	*8,7*
Zakarpats'ka	0,5	0,9	0,8	0,8	18,3	26,5	24,7	*25,6*	0,6	0,2	0,8	0,6	8,6	3,0	11,3	*8,7*
L'vivs'ka	0,4	0,6	0,5	0,6	17,2	20,0	18,6	*21,4*	0,6	0,2	0,8	0,6	8,2	2,2	11,4	*8,3*
Ternopil's'ka	0,5	0,6	0,8	0,7	18,2	17,4	23,3	*20,5*	0,5	0,2	0,9	0,6	6,5	2,5	12,2	*8,6*
Khmel'nyts'ka	0,5	0,5	0,5	0,5	16,5	16,6	16,3	*17,6*	0,6	0,2	0,9	0,7	7,6	3,3	12,8	*9,3*
Chernivets'ka	0,6	0,6	0,9	0,7	18,5	16,5	28,6	*22,0*	0,6	0,4	0,8	0,7	8,7	6,2	12,3	*9,7*
Ukraine	**0,4**	**0,6**	**0,5**	**0,5**	**13,1**	**18,4**	**18,2**	***17,1***	**1,2**	**0,7**	**0,9**	**1,0**	**17,2**	**10,0**	**13,4**	***14,0***

5. Concluding remarks

5.1. Summary

The present study was undertaken: (i) to assess the suitability of each crop in different regions across Ukraine; (ii) to estimate the rain-fed potential yields and compare these with current average yields and (iii) to quantify the yield gaps between average farmer's yields and rain-fed potential yields. AEZ provides the methodology to analyze and quantify the yield potentials, which allows evaluation of the extent of the constraints to crop production in different agro-environments.

Three main conclusions can be derived from this analysis. First, Ukraine has vast resources for agricultural production, including climate conditions, soils and moisture regimes. It was assessed that up to 26 million hectares (54 %) are very suitable for rain-fed crop production and almost another 20 million hectares are suitable with slight constraints. Full exploitation of the area equipped for irrigation in Ukraine increases the potential production for the same area by a third for winter crops and almost double for summer crops.

Results obtained from AEZ runs follow the annual fluctuations of the observed data and are in correspondence with the meteorological observations and records of weather anomalies that have been affecting actual crop yields. Inter-annual fluctuations in estimated potential yields especially are in good agreement with the observed yields across Ukraine, but differ spatially.

The extent of yield gap (2-5 t/ha) and a high degree of spatial and temporal variability up to 25 %, indicate good potentials for increasing winter wheat productivity with improved management and input use under rain-fed conditions by enhancing yield stability and raising productivity levels. The year-to-year variability in weather influences the productivity as well as the resource use in a given location. Despite the average estimated potential rain-fed winter wheat yields are similar all over Ukraine, the variability associated with winter wheat yields in southern and eastern parts is about double that in the center and three times as much as in northern and western parts of Ukraine. Unfortunately, current agricultural technology in Ukraine is far from optimal and spatial and annual variability of already low yields lead to uncertainty in agricultural production, income losses and rural depreciation.Variability due to the weather conditions in Ukraine appears to be a major factor. Such dependency makes agricultural production very sensitive to the climate change.

Rain-fed agriculture suffers from a number of biophysical and socioeconomic constraints, which limit crop production. These constraints include excess and deficit moisture, land degradation, low level of input use, low level of technology adoption and resources. Therefore, sustainable agricultural land use must be based on sound agronomic principles and adaptation of the modern technologies. Besides, it must also embrace an understanding of the constraints and interactions of other dimensions of agricultural production, including the flexibility to diversify and develop a broad genetic base to ensure the possibility of rapid response to changing conditions and climate change. Land management practices, in principal control processes of land degradation and their efficiency in this respect, should largely govern the sustainability of land use. Furthermore, sustainability depends on institutional, political, social, and economic pressures and structures that can exacerbate environmental problems. These considerations must be integral to ensure sustainability of agricultural development in Ukraine.

5.2. Limitations of the study

The use of crop models in agricultural research and development, in general, and in yield gap analysis, in particular, involves different levels of details and associated data needs and information requirements. The systems approach of AEZ model to assess the agricultural production systems requires datasets and databases on the different components, namely: (a) crops, (b) weather, (c) soil and soil degradation, (d) management and land use.

Although, the agronomic data, such as the data on environmental requirements for crops, were adjusted to the Ukrainian conditions, assumptions on water requirements and occurrence and severity of some agro-climate-related constraints to crop production would, no doubt, benefit from detailed information from field experiments.

The current status of land degradation cannot be inferred from the soil map which was used in the present study. At the same time, a number of studies on land degradation in Ukraine indicate that the state and rate of various types of land degradation might locally have a negative effect on land productivity.

The use of information on management was limited to the more general definition of modes of production and the quantification of “input–output packages”, which is referred to as LUTs, taking to some extent into account the socioeconomic context of production decisions and conditions and would benefit from more detailed specifications based on Ukrainian data and knowledge. In addition, the detailed land use coverage for Ukraine was not available; therefore, the assessment was done for all land excluding land under forest, protected and built-up areas, water bodies and Chernobyl Exclusion zone.

References

CGIAR-CSI (2006): NASA Shuttle Radar Topographic Mission (SRTM). The SRTM data is available as 3 arc-second (approx. 90m resolution) DEMs. The dataset is available for download at: http://srtm.csi.cgiar.org/

EROS Data Center, 1998. *Global 30 arc-second Digital Elevation Model* (http://edcwww.cr.usgs.gov). Anonymous ftp access at edcftp.cr.usgs.gov

Evans, L.T., 1993. *Crop Evolution, Adaptation, and Yield.* Cambridge University Press, Cambridge, UK.

FAO, 1978-81. *Report on the Agro-Ecological Zones Project*. World Soil Resources Report 48, FAO, Rome, Italy.

FAO, 1988. *Land Resources Appraisal of Bangladesh.* Report 6, FAO, Rome, Italy.

FAO, 1990. *Guidelines for Soil Description*. FAO, Rome, Italy.

FAO, 1992a. *CROPWAT: A Computer Program for Irrigation Planning and Management*. FAO Irrigation and Drainage Paper 46, Land and Water Development Division, FAO, Rome, Italy.

FAO, 1992b. *Report on the Expert Consultation on Revision of FAO Methodologies for Crop Water Requirements*. Land and Water Development Division, FAO, Rome, Italy.

FAO/UNESCO/ISRIC, 1990. *Revised Legend of the Soil Map of the World.* World Soil Resources Report 60, FAO, Rome, Italy.

Fischer, G., van Velthuizen, H., Shah, M. and Nachtergaele, F.O., 2002, *Global Agroecological Assessment for Agriculture in the 21st Century: Methodology and Results*, RR-02-02, FAO and IIASA, Laxenburg, Austria.

Fuchs, T., Schneider, U., Rudolf, B. *Precipitation Analysis Products of the GPCC.* Global Precipitation Climatology Centre (GPCC), Deutscher Wetterdienst, Offenbach a. M., Germany, March 2007: http://www.dwd.de/en/FundE/Klima/KLIS/int/GPCC/GPCC.htm

http://ngm.nationalgeographic.com/ngm/0604/feature1/images/mp_download.1.pdf (exclusion zone)

Medvedev, V., Lisovyj, M., eds. 2001. *State of soils fertility in Ukraine and forecast of its changes under conditions of present-day farming*. Shtrih Press, Kharkiv, Ukraine.

Mishchenko N, Gumeniuk K ., 2006. *Agro-Ecological Assessment for the Transition of the Agricultural Sector in Ukraine. Part I: Socio-Economic Aspects.* IR-06-052, IIASA, Laxenburg, Austria.

Mitchell T. D. and P. D. Jones. 2005. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *International Journal of Climatology* 25, 693-712: http://cru.csi.cgiar.org

Monteith, J.L., 1965. Evapotranspiration and the environment. In: *The State and Movement of Water in Living Organisms*, XIXth Symposium, Society for Xp. Biology, Swansea. Cambridge University Press, Cambridge, UK, pp. 205–234.

Monteith, J.L., 1981. Evapotranspiration and surface temperature. *Quarterly Journal Royal Meteorological Society*, 107:1–27.

New, M.G., M. Hulme, and P.D. Jones, 1998. Representing 20th century space-time climate variability. I: Development of a 1961–1990 mean monthly terrestrial climatology. *Climate* (Web access via http://www.cru.uea.ac.uk/link).

Siebert, S., Döll, P., Hoogeveen, J., Frenken, K., 2007. *Global Map of Irrigation Areas version 4.0.1.* Johann Wolfgang Goethe University, Frankfurt am Main, Germany / Food and Agriculture

Organization of the United Nations, Rome, Italy. Information on Ukraine : http://www.fao.org/nr/water/aquastat/irrigationmap/ua/index.stm

Sys, C., E. van Ranst, J. Debaveye, and F. Beernaart, 1993. *Land Evaluation – Parts I, II and III*. International Training Centre for Post-Graduate Soil Scientists (ITC), University of Ghent, Agricultural Publications No. 7, General Administration for Development Cooperation, Brussels, Belgium.

Sys, C., E. van Ranst, J. Debaveye, and F. Beernaart, 1993. *Land Evaluation – Parts I, II and III*. International Training Centre for Post-Graduate Soil Scientists (ITC), University of Ghent, Agricultural Publications No. 7, General Administration for Development Cooperation, Brussels, Belgium.

USGS (2002): GTOPO30 – Global 30 arc-second elevation data. U.S. Geological Survey, National Mapping Division, EROS Data Center; for download available at: http://edcdaac.usgs.gov/gtopo30/gtopo30.html

ANNEX I. Biomass and yield calculation

The AEZ methodology for the calculation of potential net biomass and yields is based on eco-physiological principles, is outlined below:

To calculate the net biomass production (B_n) of a crop, an estimation of the gross biomass production (B_g) and respiration loss (R) is required:

$$B_n = B_g - R \tag{1}$$

The equation relating the rate of net biomass production (b_n) to the rate of gross biomass production (b_g) and the respiration rate (r) is:

$$b_n = b_g - r \tag{2}$$

The maximum rate of net biomass production (b_{nm}) is reached when the crop fully covers the ground surface. The period of maximum net crop growth, i.e., the point in time when maximum net biomass increments occur, is indicated by the inflection point of the cumulative growth curve. When the first derivative of net biomass growth is plotted against time the resulting graph resembles a normal distribution curve. The model assumes that the average rate of net production (b_{na}) over the entire growth cycle is half the maximum growth rate, i.e., b_{na} = 0.5 b_{nm}. The net biomass production for a crop of N days (B_n) is then:

$$B_n = 0.5\ b_{nm}\ x\ N \tag{3}$$

The maximum rate of gross biomass production (b_{gm}) is related to the maximum net rate of CO_2 exchange of leaves (P_m) which is dependent on temperature, the photosynthesis pathway of the crop, and the level of atmospheric CO_2 concentration.

For a standard crop, i.e., a crop in adaptability group I with P_m = 20 kg ha^{-1} hr^{-1} and a leaf area index of LAI = 5, the rate of gross biomass production b_{gm} is calculated from the equation:

$$b_{gm} = F\ x\ b_o + (1 - F)\ b_c \tag{4}$$

where:

- F = the fraction of the daytime the sky is clouded, $F = (A_c - 0.5\ R_g) / (0.8\ A_c)$, where A_c (or PAR) is the maximum active incoming short-wave radiation on clear days (de Wit, 1965), and R_g is incoming short-wave radiation (both are measured in cal cm^{-2} day^{-1})
- b_o = gross dry mater production rate of a standard crop for a given location and time of the year on a completely overcast day, (kg ha^{-1} day^{-1}) (de Wit, 1965)
- b_c = gross dry mater production rate of a standard crop for a given location and time of the year on a perfectly clear day, (kg ha^{-1} day^{-1}) (de Wit, 1965)

When P_m is greater than 20 kg ha^{-1} hr^{-1}, b_{gm} is given by the equation:

$$b_{gm} = F\ (0.8 + 0.01 P_m)\ b_o + (1 - F)\ (0.5 + 0.025\ P_m)\ b_c \tag{5}$$

When P_m is less than 20 kg ha^{-1} hr^{-1}, b_{gm} is calculated according to:

$$b_{gm} = F\ (0.5 + 0.025\ P_m)\ b_o + (1 - F)\ (0.05\ P_m)\ b_c \tag{6}$$

To calculate the maximum rate of net biomass production (b_{nm}), the maximum rate of gross biomass production (b_{gm}) and the rate of respiration (r_m) are required. Here, growth respiration is considered a linear function of the rate of gross biomass production (McCree, 1974), and maintenance respiration a linear function of net biomass that has already been accumulated (B_m) When the rate of gross biomass production is b_{gm}, the respiration rate r_m is:

$$r_m = k\, b_{gm} + c\, B_m \quad (7)$$

where k and c are the proportionality constants for growth respiration and maintenance respiration respectively, and B_m is the net biomass accumulated at the time of maximum rate of net biomass production. For both legume and non legume crops k equals 0.28. However, c is temperature dependent and differs for the two crop groups. At 30 ^oC, factor c_{30} for a legume crop equals 0.0283 and for a non-legume crop 0.0108. The temperature dependence of c_t for both crop groups is modelled with a quadratic function:

$$c_t = c_{30}\, (0.0044+0.0019\, T+0.0010\, T^2). \quad (8)$$

It is assumed that the cumulative net biomass B_m of the crop (i.e., biomass at the inflection point of the cumulative growth curve) equals half the net biomass that would be accumulated at the end of the crop's growth cycle. Therefore, we set B_m = 0.5 B_n, and using (3), B_m for a crop of N days is determined according to:

$$B_m = 0.25\, b_{nm} \times N \quad (9)$$

By combining the respiration equation with the equation for the rate of gross photosynthesis, the maximum rate of net biomass production (b_{nm}) or the rate of net dry matter production at full cover for a crop of N days becomes:

$$b_{nm} = 0.72\, b_{gm} / (1 + 0.25\, c_t\, N) \quad (10)$$

Finally, the net biomass production (B_n) for a crop of N days, where 0.5 b_{nm} is the seasonal average rate of net biomass production, can be derived as:

$$B_n = (0.36\, b_{gm} \times L) / (1/N + 0.25\, c_t\,) \quad (11)$$

where:

- b_{gm} = maximum rate of gross biomass production at leaf area index (LAI) of 5
- L = growth ratio, equal to the ratio of b_{gm} at actual LAI to b_{gm} at LAI of 5
- N = length of normal growth cycle
- c_t = maintenance respiration, dependent on both crop and temperature according to equation (8)

Potential yield (Y_p) is estimated from net biomass (B_n) using the equation:

$$Y_p = H_i \times B_n \quad (12)$$

where:

- H_i = harvest index, i.e., proportion of the net biomass of a crop that is economically useful

Thus, climate and crop characteristics that apply in the computation of net biomass and yield are: (a) heat and radiation regime over the crop cycle, (b) crop adaptability group to determine applicable rate of photosynthesis P_m, (c) length of growth cycle (from emergence to physiological maturity), (d) length of yield formation period,.(e) leaf area index at maximum growth rate, and (f) harvest index.

ANNEX II. Calculation of reference evapotranspiration according to Penman-Monteith combination equation

The calculation of reference evapotranspiration (ET_o), i.e., the rate of evapotranspiration from a hypothetic reference crop with an assumed crop height of 12 cm, a fixed canopy resistance of 70ms^{-1} and an albedo of 0.23 (closely resembling the evapotranspiration from an extensive surface of green grass), is done according to the Penman-Monteith equation (Monteith, 1965, 1981; FAO, 1992b). The calculation procedure uses a standardized set of input parameters, as follows:

T_{max} ... maximum daily temperature (ºC)
T_{min} ... minimum daily temperature (ºC)
RH ... mean daily relative humidity (%)
$U2$ ... wind speed measurement (ms^{-1})
SD ... bright sunshine hours per day (hours)
A ... elevation (m)
L ... latitude (deg)
J ... Julian date, i.e., number of day in year

The *Penman-Monteith combination equation* can be written in terms of an aerodynamic and a radiation term (FAO, 1992b):

$$ET_o = ET_{ar} + ET_{ra} \tag{1}$$

where the *aerodynamic term* can be approximated by

$$ET_{ar} = \frac{\gamma}{\vartheta + \gamma *} \cdot \frac{900}{T_a + 273} \cdot U2 \cdot (e_a - e_d) \tag{2}$$

and the *radiation term* by

$$ET_{ra} = \frac{\vartheta}{\vartheta + \gamma *} \cdot (R_n - G) \cdot \frac{1}{\lambda} \tag{3}$$

where variables in (2) and (3) are as follows:

γ ... psychrometric constant (kPa ºC^{-1})
$\gamma*$ .. modified psychrometric constant (kPa ºC^{-1})
ϑ ... slope of vapor pressure curve (kPa ºC^{-1})
T_a ... average daily temperature (ºC)
e_a ... saturation vapor pressure (kPa)
e_d ... vapor pressure at dew point (kPa)
$(e_a - e_d)$ vapor pressure deficit (kPa)
$U2$ ... wind speed measurement (ms^{-1})
R_n ... net radiation flux at surface (MJ m^{-2} d^{-1})
G ... soil heat flux (MJ m^{-2} d^{-1})
λ ... latent heat of vaporization (MJ kg^{-1})

In the calculation procedure for the reference crop we use the following relationships to define terms in (2):

Average daily temperature:

$$T_a = 0.5(T_{max} + T_{min}) \tag{4}$$

Latent heat of vaporization:

$$\lambda = 2.501 - 0.002361\, T_a \tag{5}$$

Atmospheric pressure (kPa) at elevation A:

$$P = 101.3\left(\frac{293 - 0.0065\, A}{293}\right)^{5.256} \tag{6}$$

Psychrometric constant:

$$\gamma = 0.0016286 \cdot \frac{P}{\lambda} \tag{7}$$

Aerodynamic resistance:

$$r_a = \frac{208}{U2} \tag{8}$$

Crop canopy resistance:

$$r_c = \frac{R_l}{0.5\, LAI} \tag{9}$$

where under ambient CO_2 concentrations the average daily stomata resistance of a single leaf, R_l (sm^{-1}), is set to R_l = 100, and leaf area index of the reference crop is assumed as $LAI = 24 \cdot 0.12 = 2.88$.

Modified psychrometric constant:

$$\gamma * = \gamma \left(1 + \frac{r_c}{r_a}\right) \tag{10}$$

Saturation vapor pressure e_a for given temperatures $T_{\min}$ and $T_{\max}$

$$e_{ax} = 0.6108 \exp\left(\frac{17.27\, T_{\max}}{237.3 + T_{\max}}\right) \tag{11}$$

$$e_{an} = 0.6108 \exp\left(\frac{17.27\, T_{\min}}{237.3 + T_{\min}}\right) \tag{12}$$

$$e_a = 0.5\,(e_{ax} + e_{an}) \tag{13}$$

Vapor pressure at dew point, e_d:

$$e_d = \frac{RH}{100} \cdot \frac{0.5}{\left(\frac{1}{e_{ax}} + \frac{1}{e_{an}}\right)} \tag{14}$$

Slope of vapor pressure curve, ϑ, for given temperatures $T_{\max}$ and $T_{\min}$:

$$\vartheta_x = \frac{4096\, e_{ax}}{(237.3 + T_{\max})^2} \tag{15}$$

$$\vartheta_n = \frac{4096\, e_{an}}{(237.3 + T_{\min})^2} \tag{16}$$

$$\vartheta = \left(\vartheta_x + \vartheta_n\right) \tag{17}$$

Using (4)-(17) all variables in (2) can be calculated from the input parameters of the ET_o computer subroutine. To determine the remaining variables R_n and G used in the radiation term ET_{ra} of equation (3), we proceed with the following calculation steps:

Latitude expressed in rad:

$$\varphi = \frac{L\pi}{180} \tag{18}$$

Solar declination (rad):

$$\delta = 0.4093 \cdot \sin\left(\frac{2\pi}{365} J - 1.405\right) \tag{19}$$

Relative distance Earth to Sun:

$$d = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right) \tag{20}$$

Sunset hour angle (rad):

$$\psi = arc\cos(-\tan\varphi \tan\delta) \tag{21}$$

Extraterrestrial radiation (MJ m^{-2} d^{-1}):

$$R_a = 37.586\, d\, (\psi \sin\varphi \sin\delta + \cos\varphi \cos\delta \sin\psi) \tag{22}$$

Maximum daylight hours:

$$DL = \frac{24}{\pi}\psi \tag{23}$$

Short-wave radiation R_s (MJ m^{-2} d^{-1})

$$R_s = \left(0.25 + 0.5\frac{SD}{DL}\right) R_a \tag{24}$$

For a reference crop with an assumed albedo coefficient $\alpha = 0.23$ *net incoming short-wave radiation* R_{ns} (MJ m^{-2} d^{-1}) is:

$$R_{ns} = 0.77\, R_s \tag{25}$$

Net outgoing long-wave radiation R_{nl} (MJ m^{-2} d^{-1}) is estimated using:

$$R_{nl} = 4.903 \cdot 10^{-9}\left(0.1 + 0.9\frac{SD}{DL}\right)\left(0.34 - 0.139\sqrt{e_d}\right)\frac{(273.16 + T_{max})^4 + (273.16 + T_{min})^4}{2} \tag{26}$$

Using (25) and (26), *net radiation flux* at surface, R_n, becomes

$$R_n = R_{ns} - R_{nl} \tag{27}$$

Finally, *soil heat flux* is approximated using

$$G = 0.14\,(T_{a,n} - T_{a,n-1}) \tag{28}$$

where $T_{a,n}$ and $T_{a,n-1}$ are average monthly temperatures of current and previous month, respectively. With equations (5), (10), (17), (27) and (28) all variables in (3) are defined and can be calculated from the input parameters described at the beginning of this Appendix.

ANNEX III. Soil moisture storage capacity for the soil units of the FAO'90 legend

The growing period for most crops continues beyond the rainy season and, to a greater or lesser extent, crops mature on moisture stored in the soil profile. However, the amount of soil moisture stored in the soil profile, and available to a crop, varies, e.g., with depth of the soil profile, the soil physical characteristics, and the rooting pattern of the crop. Depletion of soil moisture reserves causes the actual evapotranspiration to fall short of the potential rate. Soil moisture storage capacity of soils (*Smax*) depends on soil physical and chemical characteristics, but above all on effective soil depth or volume. For the soil units of the Legend of the Soil Map of the World, FAO has developed procedures for the estimation of Smax, which are used to generate the classification presented in the Table below.

Soil moisture storage capacity classes derived for FAO soil units of Revised Legend '90

FAO Legend '90	**SLU**	**coarse**		**medium**		**fine**		**FAO Legend '90**	**SLU**	**coarse**		**medium**		**fine**	
Soil Unit		mm	CL	mm	CL	mm	CL	**Soil Unit**		mm	CL	mm	CL	mm	CL
Ferric Acrisols	ACf	146	1	162	1	157	1	Eutric Gleysols	GLe	n.a.	1	n.a.	1	n.a.	1
Gleyic Acrisols	ACg	146	1	162	1	157	1	Gelic Gleysols	GLi	n.a.	1	n.a.	1	n.a.	1
Haplic Acrisols	ACh	146	1	162	1	157	1	Calcic Gleysols	GLk	n.a.	1	n.a.	1	n.a.	1
Plinthic Acrisols	ACp	146	1	162	1	157	1	Mollic Gleysols	GLm	n.a.	1	n.a.	1	n.a.	1
Humic Acrisols	ACu	146	1	162	1	157	1	Thionic Gleysols	GLt	n.a.	1	n.a.	1	n.a.	1
Ferric Alisols	ALf	146	1	162	1	157	1	Umbric Gleysols	GLu	n.a.	1	n.a.	1	n.a.	1
Gleyic Alisols	ALg	146	1	162	1	157	1	Gleyic Greyzems	GRg	106	3	180	1	165	1
Haplic Alisols	ALh	146	1	162	1	157	1	Haplic Greyzems	GRh	106	3	180	1	165	1
Stagnic Alisols	ALj	146	1	162	1	157	1	Haplic Gypsisols	GYh	106	3	180	1	165	1
Plinthic Alisols	ALp	146	1	162	1	157	1	Calcic Gypsisols	GYk	106	3	180	1	165	1
Humic Alisols	ALu	146	1	162	1	157	1	Luvic Gypsisols	GYl	162	1	180	1	175	1
Gleyic Andosols	ANg	200	1	200	1	200	1	Petric Gypsisols	GYp	79	4	135	2	123	2
Haplic Andosols	ANh	200	1	200	1	200	1	Fibric Histosols	HSf	n.a.	1	n.a.	1	n.a.	1
Gelic Andosols	ANi	200	1	200	1	200	1	Gelic Histosols	HSi	n.a.	1	n.a.	1	n.a.	1
Mollic Andosols	ANm	200	1	200	1	200	1	Folic Histosols	HSl	n.a.	1	n.a.	1	n.a.	1
Umbric Andosols	ANu	200	1	200	1	200	1	Terric Histosols	HSs	n.a.	1	n.a.	1	n.a.	1
Vitric Andosols	ANz	200	1	200	1	200	1	Thionic Histosols	HSt	n.a.	1	n.a.	1	n.a.	1
Albic Arenosols	ARa	106	3	180	1	165	1	Haplic Kastanozems	KSh	106	3	180	1	165	1
Cambic Arenosols	ARb	106	3	180	1	165	1	Calcic Kastanozems	KSk	106	3	180	1	165	1
Calcaric Arenosols	ARc	106	3	180	1	165	1	Luvic Kastanozems	KSl	162	1	180	1	175	1
Gleyic Arenosols	ARf	106	3	180	1	165	1	Gypsic Kastanozems	KSy	106	3	180	1	165	1
Haplic Arenosols	ARg	106	3	180	1	165	1	Dystric Leptosols	LPd	13	6	19	6	18	6
Luvic Arenosols	ARl	106	3	180	1	165	1	Eutric Leptosols	LPe	13	6	19	6	18	6
Ferralic Arenosols	ARo	106	3	180	1	165	1	Gelic Leptosols	LPi	13	6	19	6	18	6
Aric Anthrosols	ATa	200	1	200	1	200	1	Rendzic Leptosols	LPk	39	5	57	5	53	5
Cumulic Anthrosols	ATc	250	1	250	1	250	1	Mollic Leptosols	LPm	13	6	19	6	18	6
Fimic Anthrosols	ATf	200	1	200	1	200	1	Lithic Leptosols	LPq	13	6	19	6	18	6
Urbic Anthrosols	ATu	200	1	200	1	200	1	Umbric Leptosols	LPu	13	6	19	6	18	6
Gleyic Chernozems	CHg	106	3	180	1	165	1	Albic Luvsiols	LVa	162	1	180	1	175	1
Haplic Chernozems	CHh	106	3	180	1	165	1	Ferric Luvisols	LVf	146	1	162	1	157	1
Calcic Chernozems	CHk	106	3	180	1	165	1	Gleyic Luvisols	LVg	162	1	180	1	175	1
Luvic Chernozems	CHl	162	1	180	1	175	1	Haplic Luvisols	LVh	162	1	180	1	175	1
Glossic Chernozems	CHw	106	3	180	1	165	1	Stagnic Luvisols	LVj	162	1	180	1	175	1
Haplic Calcisols	CLh	106	3	180	1	165	1	Calcic Luvisols	LVk	162	1	180	1	175	1
Luvic Calcisols	CLl	162	1	180	1	175	1	Vertic Luvisols	LVv	162	1	180	1	175	1
Petric Calcisols	CLp	79	4	135	2	123	2	Chromic Luvisols	LVx	162	1	180	1	175	1
Calcaric Cambisols	CMc	106	3	180	1	165	1	Albic Lixisols	LXa	146	1	162	1	157	1
Dystric Cambisols	CMd	106	3	180	1	165	1	Ferric Lixisols	LXf	146	1	162	1	157	1
Eutric Cambisols	CMe	106	3	180	1	165	1	Gleyic Lixisols	LXg	146	1	162	1	157	1
Gleyic Cambisols	CMg	106	3	180	1	165	1	Haplic Lixisols	LXh	146	1	162	1	157	1
Gelic Cambisols	CMi	106	3	180	1	165	1	Stagnic Lixisols	LXj	146	1	162	1	157	1
Ferralic Cambisols	CMo	95	3	162	1	148	1	Plinthic Lixisols	LXp	146	1	162	1	157	1

FAO Legend '90 Soil Unit	SLU	coarse		medium		fine	
		mm	CL	mm	CL	mm	CL
Humic Cambisols	CMu	106	3	180	1	165	1
Vertic Cambisols	CMv	106	3	180	1	165	1
Chromic Cambisols	CMx	106	3	180	1	165	1
Calcaric Fluvisols	FLc	n.a.	1	n.a.	1	n.a.	1
Dystric Fluvisols	FLd	n.a.	1	n.a.	1	n.a.	1
Eutric Fluvisols	FLe	n.a.	1	n.a.	1	n.a.	1
Mollic Fluvisols	FLm	n.a.	1	n.a.	1	n.a.	1
Salic Fluviosls	FLs	n.a.	1	n.a.	1	n.a.	1
Thionic Fluvisols	FLt	n.a.	1	n.a.	1	n.a.	1
Umbric Fluvisols	FLu	n.a.	1	n.a.	1	n.a.	1
Geric Ferralsols	FRg	146	1	162	1	148	1
Haplic Ferralsols	FRh	146	1	162	1	148	1
Plinthic Ferralsols	FRp	146	1	162	1	148	1
Rhodic Ferralsols	FRr	146	1	162	1	148	1
Humic Ferralsols	FRu	146	1	162	1	148	1
Xanthic Ferralsols	FRx	146	1	162	1	148	1
Andic Gleysols	GLa	n.a.	1	n.a.	1	n.a.	1
Dystric Gleysols	GLd	n.a.	1	n.a.	1	n.a.	1
Albic Plinthosols	PTa	95	3	162	1	148	1
Dystric Plinthosols	PTd	95	3	162	1	148	1
Eutric Plinthosols	PTe	95	3	162	1	148	1
Humic Plinthosols	PTu	95	3	162	1	148	1
Cambic Podzols	PZb	106	3	180	1	165	1
Carbic Podzols	PZc	106	3	180	1	165	1
Ferric Podzols	PZf	106	3	180	1	165	1
Gleyic Podzols	PZg	106	3	180	1	165	1
Haplic Podzols	PZh	106	3	180	1	165	1
Gelic Podzols	PZi	106	3	180	1	165	1
Calcaric Regosols	RGc	106	3	180	1	165	1
Dystric Regosols	RGd	106	3	180	1	165	1
Eutric Regosols	RGe	106	3	180	1	165	1
Gelic Regosols	RGi	106	3	180	1	165	1
Umbric Regosols	RGu	106	3	180	1	165	1
Gypsic Regosols	RGy	106	3	180	1	165	1

FAO Legend '90 Soil Unit	SLU	coarse		medium		fine	
		mm	CL	mm	CL	mm	CL
Haplic Nitisols	NTh	146	1	162	1	157	1
Rhodic Nitisols	NTr	146	1	162	1	157	1
Humic Nitisols	NTu	146	1	162	1	157	1
Dystric Podzoluvisol	PDd	162	1	180	1	175	1
Eutric Podzoluvisols	PDe	162	1	180	1	175	1
Gleyic Podzoluvisols	PDg	162	1	180	1	175	1
Gelic Podzoluvisols	PDi	162	1	180	1	175	1
Stagnic Podzoluvisol	PDj	162	1	180	1	175	1
Calcaric Phaeozems	PHc	106	3	180	1	165	1
Gleyic Phaeozems	PHg	106	3	180	1	165	1
Haplic Phaeozems	PHh	106	3	180	1	165	1
Stagnic Phaeozems	PHj	106	3	180	1	165	1
Luvic Phaeozems	PHl	162	1	180	1	175	1
Dystric Planosols	PLd	152	1	169	1	165	1
Eutric Planosols	PLe	152	1	169	1	165	1
Gelic Planosols	PLi	152	1	169	1	165	1
Mollic Planosols	PLm	152	1	169	1	165	1
Umbric Planosols	PLu	152	1	169	1	165	1
Gleyic Solonchaks	SCg	106	3	180	1	165	1
Haplic Solonchaks	SCh	106	3	180	1	165	1
Gelic Solonchaks	SCi	106	3	180	1	165	1
Calcic Solonchaks	SCk	106	3	180	1	165	1
Mollic Solonchaks	SCm	106	3	180	1	165	1
Sodic Solonchaks	SCn	106	3	180	1	165	1
Gypsic Solonchaks	SCy	106	3	180	1	165	1
Gleyic Solonetz	SNg	106	3	180	1	165	1
Haplic Solonetz	SNh	106	3	180	1	165	1
Stagnic Solonetz	SNj	106	3	180	1	165	1
Calcic Solonetz	SNk	106	3	180	1	165	1
Mollic Solonetz	SNm	106	3	180	1	165	1
Gypsic Solonetz	SNy	106	3	180	1	165	1
Dystric Vertisols	VRd	135	2	135	2	135	2
Eutric Vertisols	VRe	135	2	135	2	135	2
Calcic Vertisols	VRk	135	2	135	2	135	2
Gypsic Vertisols	VRy	135	2	135	2	135	2

ANNEX IV. Temperature regime requirements of crop/LUTs in Ukraine

Crop	Sub-optimal Conditions	Optimal Conditions
Winter Wheat, **Winter Rye** *L = 30 + 90, L = 40 + 120* **Winter Barley** *L = 30 + 90, L = 35 + 105*	*Climates: B, Te, STr (WR+SR)* *L6a < 0.667*Lb* *L6a+L5a > 0.167*Lb* *L2a+L2b < 0.333*Lb* *L1 = 0* *L2b+L3b+L4b+L5b < 0.500*Lb* *L3b+L4b+L5b+L6b > La* *TSgc>1300 ** *no permafrost* *LGP* $_{t=5}$ *< 365* *dormancy required* *vernalization required*	*Climates: B, Te, STr (WR+SR)* *L6a < 0.500*Lb* *L6a+L5a > 0.167*Lb* *L2a+L2b < 0.333*Lb* *L1 = 0* *L2b+L3b+L4b+L5b < 0.500*Lb* *L3b+L4b+L5b+L6b > La* *TSgc> 1400 ** *no permafrost* *LGP t=5 < 365* *dormancy required* *vernalization required*
Spring Wheat *L =90/105/120/* **Spring Barley** *L = 90/105*	*Climates: B, Te, STr (WR+SR)* *L6a < 0.500*L* *L6b = 0* *L6a+L5a > 0.0835*L* *L2 < 0.333*L* *L1 = 0* *L2b+L3b+L4b+L5b < 0.500*L* *TSgc> 1200* *no permafrost* *LGP t=5 < 365*	*Climates: B, Te, STr (WR+SR)* *L6a < 0.375*L* *L6b = 0* *L6a+L5a > 0.167*L* *L2 < 0.333*L* *L1 = 0* *L2b+L3b+L4b+L5b < 0.500*L* *TSgc > 1300* *no permafrost* *LGP t=5 < 365*
Spring Oat *L = 90/105/120*	*Climates: B, Te, STr (WR+SR)* *L6a < 0.500*L* *L6b = 0* *L6a+L5a > 0.167*L* *L2 < 0.333*L* *L1 = 0* *L2b+L3b+L4b+L5b < 0.500*Lb* *TSgc> 1200* *no permafrost* *LGP t=5 < 365*	*Climates: B, Te, STr (WR+SR)* *L6a < 0.375*L* *L6b = 0* *L6a+L5a > 0.167*L* *L2b < 0.333*L* *L1 = 0* *L2b+L3b+L4b+L5b < 0.500*Lb* *TSgc > 1300* *no permafrost* *LGP t=5 < 365*
Japonica Rice *L 120/135*	*Climates: Tr, STR (SR+WR), Te* *L5a+L4a < 0.400*L* *L4 >0 (min 5 days)* *L2b < 0.667*L* *L1 < 0.200*L* *L4b+L5b < 0.250*L* *L6=0* *TSgc > 1900*	*Climates: Tr, STR (SR+WR), Te* *L5a+L4a < 0.400*L* *L4 >0 (min 5 days)* *L2 < 0.667*L* *L1 < 0.200*L* *L4b+L5b < 0.250*L* *L6=0* *TSgc> 2050*
Maize (grain) **L = 90/105/120/135**	*Climates: STr (SR+WR), Te* *L5 < 0.250*L* *L6=0* *TSgc>1750* *no permafrost*	*Climates: STr (SR+WR), Te* *L5 = <0.200*L* *L6=0* *TSgc>1800* *no permafrost*
Maize (temperate, silage) **L = 120/135/150/165**	*Climates: STr (SR+WR), Te* *L5 < 0.200*L* *L2 < 0.333*L* *L6=0* *TSgc>1700* *no permafrost*	*Climates: STr (SR+WR), Te* *L5 < 0.500*L* *L2 < 0.333*L* *L6=0* *TSgc > 1850* *no permafrost*
Foxtail Millet (Setaria) ***L = 75/90/105/120***	*Climates: STr (SR+WR), Te* *L6=L5=0* *L3 > 0 (min 5 days)* *LGPT10 > L* *L2 < 0.500*L* *L1=0* *TSgc > 1600*	*Climates: STr (SR+WR), Te* *L6=L5=0* *L3 > 0 (min 5 days)* *LGPT10 > L* *L2 < 0.500*L* *L1=0* *TSgc > 1800*

Irish Potato ***L = 75/90/120/150***	*Climates: B, Te, STr, Tr* *L6a < 0.33 *L; L6b <0.167*L* *L2 < 0.167*L* *L1 = 0* *L6+L5+L4 > 0.500*L* *LGPT10 > L* *TSgc >1200* *no permafrost*	*Climates: B, Te, STr, Tr* *L6a < 0.333 * L; L6b <0.167 * L* *L2 = L1 = 0* *L6+L5+L4 > 0.66767*L* *LGPT10 > L* *TSgc>1350* *no permafrost*
Sugar beet *L = 120/135/150/165*	*Climates: Te, STr (SR+WR)* *L6a < 0.333*L; L6b <0.167*L* *L6+L5 > 0.167*L* *L2 < 0.333*L* *L1 = 0* *TSgc > 1600* *no permafrost*	*Climates: Te, STr (SR+WR)* *L6a < 0.333 * L; L6b <0.167 * L* *L6+L5 > 0.167*L* *L2 < 0.167*L* *L1 = 0* *TSgc> 1750* *no permafrost*
Phaseolus Bean (temperate) *L = 90/120/150*	*Climates: Te, STr (SR+WR)* *L5< 0.667*L* *L5+L4+L3 > 0.500*L* *L1 =L2 = L6=0* *TSgc > 1050*	*Climates: Te, STr (SR+WR)* *L5 < 0.667*L* *L5+L4+L3 > 0.500*L* *L1 = L6=0* *TSgc > 1125*
Soybean *L 105/120/135*	*Climates: STr(SR+WR), Te* *L6 = 0* *L5 <0.300*L* *L3 + L4 > 0.333*L* *L1 < 0.333*L* *LGPT10 > L* *TSgc > 2200* *no permafrost*	*Climates: STr(SR+WR), Te* *L5 = L6=0* *L3 + L4 > 0.333*L* *L1 <0.333*L* *LGPT10 > L* *TSgc > 2300* *no permafrost*
Sunflower *L = 105/120/135/150*	*Climates: STr (SR+WR), Te* *L1 = L6 = 0* *L2a+L2b < 0.200*L* *L5a+L5b < 0.200*L* *L5+L4+L3 > 0.667*L* *TSgc > 1800* *no permafrost*	*Climates: STr (SR+WR), Te* *L1 = L6 = 0* *L2a+L2b < 0.300*L* *L5a+L5b < 0.250*L* *L5+L4+L3 > 0.400*L* *TSgc > 2000* *no permafrost*
Winter Rape *L = 35 + 105, L = 45 + 120*	*Climates: Te, STr (SR+TR)* *L6a < 0.667*Lb* *L2a+L2b < 0.333*Lb* *L1a+L1b = 0* *L2b+L3b+L4b+L5b < 0.500*Lb* *L4b+L5b +L6b > La* *TSgc > 1400** *dormancy required* *vernaliztion required* *no permafrost*	*Climates: Te, STr (SR+TR)* *L6a < 0.500*Lb* *L2a+L2b < 0.333*Lb* *L1 = 0* *L2b+L3b+L4b+L5b < 0.500*Lb* *L4b+L5b +L6b > La* *TSgc > 1500** *dormancy required* *vernaliztion required* *no permafrost*
Spring Rape *L = 105/120/135*	*Climates: Te, STr (SR+WR)* *L6a < 0.333*Lb* *L2a+L2b < 0.333*Lb* *L1 = 0* *L2b+L3b+L4b+L5b < 0.500*Lb* *TSgc > 1500* *LGP t=5 < 365* *no permafrost*	*Climates: Te, STr (SR+WR)* *L6a < 0.333*Lb* *L2a+L2b < 0.333*Lb* *L1 = 0* *L2b+L3b+L4b+L5b < 0.500*Lb* *TSgc > 1400* *LGP t=5 < 365* *no permafrost*
Olive *L = 12 months*	*Climates: STr (SR+WR), Te* *L8 = L9 = 0* *L7 + L6 + L5 + L4 > 0.400*L* *L4 + L3+ L2 > 0.333*L* *L1 = 0* *TSgc > 4000*	*Climates: STr (SR+WR), Te* *L8 = L9 = 0* *L7 + L6 + L5 + L4 > 0.400*L* *L4 + L3+ L2 > 0.333*L* *L1 = 0* *TSgc > 5000*

Alfalfa (Lucerne) $L = LGP_{t=5}$	*Climates: Te, STR (SR+WR)* *L6 < 0.167*L* *L2 < 0.500*L* *L1 < 0.167*L* *TSgc > 1250*	*Climates: Te, STR (SR+WR)* *L6 < 0.500*L* *L1 < 0.333*L* *TSgc > 1750*
Grasses $L= LGP_{t=5}$	*Climates:Te, B* *TSgc > 500* *Gc (L) = (LGP t=5) >30 days*	*Climates:Te* *TSgc > 625* *Gc (L) = (LGP t=5) >60 days*
Tobacco *L=150/165*	*Climates: STr (WR), Te* *L6 = L5 =L1 = 0* *L4+L3 > 0.667*L* *Tsgc > 1750* *25% < avgRH < 90%*	*Climates: STr (WR), Te* *L6 = L5 =L1 = 0* *L4+L3 > 0.500*L* *Tsgc > 2000* *30% < avgRH < 75%*
Cabbage *L= 90/105/120/165*	*Climates: Te, STr, Tr* *L6 < 0.333*L* *L5 < 0.667 *L* *L4 + L5 > 0.500*L* *L2 + L3 < 0.500*L* *L1=0* *Tsgc > 1400*	*Climates: Te, STr, Tr* *L6 < 0.167*L* *L5 < 0.500*L* *L4 + L5 > 0.667*L* *L2 + L3 < 0.333*L* *L1=0* *Tsgc > 1600*
Tomato *L=90/105/120/135*	*Climates: Te, STr (WR+SR)* *L6 =0* *L5 <0.333*L* *L2 <0.333*L* *L1=0* *Tsgc > 1600*	*Climates: Te, STr (SR+WR)* *L6 =0* *L5 <0.200*L* *L2 <0.167*L* *L1=0* *Tsgc > 1800*
Onion *L=90/105/120/135*	*Climates: Te, STr (WR+SR)* *L6 < 0.167*L* *L5+L6 <0.667*L* *L4+L3 > 0.333*L* *L2 <0.333*L* *L1=0* *Tsgc > 1500*	*Climates: Te, STr (WR)* *L5 <0.667*L* *L4+L3 > 0.500*L* *L2 < 0.167*L* *L1= L6 = 0* *Tsgc > 1350*
Buckwheat *75/90*	*Climates: Te, STr (SR+WR)* *L2b = L2a= L1=0* *L6b < 0.333*L* *L6a < 0.167*L* *L3 < 0.333*L* *TSgc> 1100*	*Climates: Te, STr (SR+WR)* *L6a = L2= L1=0* *L6b < 0.333*L* *L3 < 0.167*L* *TSgc > 1200*
Dry Pea *90/105/120*	*Climates: Te, STr (SR+WR)* *L5 < 0.667*L* *L5+L4+L3 > 0.500*L* *L1 = L6=0* *TSgc > 1200*	*Climates: Te, STr (SR+WR)* *L5 < 0.667*L* *L5+L4+L3 > 0.500*L* *L1 = L6=0* *TSgc > 1300*
Flax *75/90/105/120*	*Climates: Te* *0.083*Lb<L6a < 0.333*Lb* *L3= L2 = L1 = L0 = 0* *L4b+L5b+l6b = 0* *TSgc > 950*	*Climates: Te* *0.083*Lb<L6a < 0.167*Lb* *L3= L2 = L1 = L0 = 0* *L4b+L5b+l6b = 0* *TSgc > 1050*

Notes:

Climates: B = Boreal; Te = Temperate; STR = Sub-tropics; WR = Winter Rainfall; SR = Summer Rainfall; Tr = Tropics

Growth cycle: L/Gc = Total; La = Pre-dormancy; Lb = Post-dormancy

Temperature profile interval symbols:

Temperature intervals (^{o}C)	<-5	-5-0	0-5	5-10	10-15	15-20	20-25	25-30	>30
Totals	L9	L8	L7	L6	L5	L4	L3	L2	L1
Increasing temperatures (winter to summer)	L9a	L8a	L7a	L6a	L5a	L4a	L3a	L2a	L1a
Decreasing temperatures (summer to winter)	L9b	L8b	L7b	L6b	L5b	L4b	L3b	L2b	L1b

Heat Units: TSgc = Temperature Sum during growth cycle

Temperature Growing Period: $LGP_{t=5}$ = Number of days with mean daily temperatures above 5^{o}C

*- **applicable to post-dormancy period only**

ANNEX V. Parameters for biomass and yield calculations

CROPS		Growth cycle (days)	Growth cycle Ukraine (days)	Adaptability group	High Inputs		Intermediate Inputs		Low Inputs		Dependence of Rate of Leaf Photosynthesis (Pm) on Temperature (oC)								
					HI	**Max. LAI**	**HI**	**Max. LAI**	**HI**	**Max. LAI**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
Wheat (winter)	**1**	30-90	90-120	C3/I	0.45	4.5	0.35	3.5	0.25	2.5	5	15	25	25	20	10	0	0	0
Wheat (winter)	**2**	40-120	90-120	C3/I	0.50	5.5	0.35	3.8	0.30	3.5	5	15	25	25	20	10	0	0	0
Wheat (spring)	**3**	90	85-100	C3/1	0.35	3.0	0.30	2.3	0.20	1.6	5	15	20	20	15	5	0	0	0
Wheat (spring)	**4**	105	100-115	C3/I	0.40	3.5	0.30	2.6	0.20	1.8	5	15	20	20	15	5	0	0	0
Wheat (spring)	**5**	120		C3/I	0.40	4.0	0.30	3.0	0.20	2.0	5	15	20	20	15	5	0	0	0
Rice (wetland)	**6**	120	118-125	C3/II	0.40	5.0	0.35	4.0	0.30	2.5	0	5	15	30	35	35	30	5	0
Rice (wetland)	**7**	135		C3/II	0.40	5.5	0.35	4.3	0.30	3.0	0	5	15	30	35	35	30	5	0
Maize (grain)	**8**	90		C4/IV	0.40	3.0	0.30	2.3	0.20	1.8	0	5	40	50	50	50	40	5	0
Maize (grain)	**9**	105		C4/IV	0.40	3.0	0.30	2.3	0.20	1.8	0	5	40	50	50	50	40	5	0
Maize (grain)	**10**	120	120-140	C4/IV	0.40	3.5	0.30	2.5	0.20	2.0	0	5	40	50	50	50	40	5	0
Maize (grain)	**11**	135	120-140	C4/IV	0.45	4.0	0.33	3.0	0.20	2.0	0	5	40	50	50	50	40	5	0
Maize (silage)	**12**	120		C4/IV	0.60	6.0	0.50	4.5	0.40	3.0	0	5	40	50	50	50	40	5	0
Maize (silage)	**13**	135		C4/IV	0.60	6.0	0.50	4.5	0.40	3.0	0	5	40	50	50	50	40	5	0
Maize (silage)	**14**	150		C4/IV	0.65	6.5	0.55	5.0	0.45	3.5	0	5	40	50	50	50	40	5	0
Maize (silage)	**15**	165		C4/IV	0.65	6.5	0.55	5.0	0.45	3.5	0	5	40	50	50	50	40	5	0
Barley (winter)	**16**	30-90	60-80	C3/I	0.45	4.5	0.35	3.5	0.25	2.5	5	15	25	25	20	10	0	0	0
Barley (winter)	**17**	35-105	80-100	C3/I	0.45	5.0	0.35	3.8	0.25	2.5	5	15	25	25	20	10	0	0	0
Barley (spring)	**18**	90	80-110	C3/I	0.40	3.0	0.30	2.8	0.20	2.0	5	15	20	20	15	5	0	0	0
Barley (spring)	**19**	105	80-110	C3/I	0.40	3.5	0.30	2.8	0.20	2.0	5	15	20	20	15	5	0	0	0
Rye (winter)	**20**	30-90	80-100	C3/I	0.35	3.5	0.28	2.8	0.20	2.0	5	15	20	20	15	5	0	0	0
Rye (winter)	**21**	40-120	100-120	C3/I	0.35	4.0	0.28	3.0	0.20	2.0	5	15	20	20	15	5	0	0	0
Oat	**22**	90	80-100	C3/I	0.30	3.5	0.25	2.5	0.20	2.0	5	15	20	20	15	5	0	0	0
Oat	**23**	105		C3/I	0.35	3.7	0.27	2.7	0.22	2.2	5	15	20	20	15	5	0	0	0
Oat	**24**	120		C3/I	0.40	4.0	0.30	3.0	0.25	2.5	5	15	20	20	15	5	0	0	0

CROPS		Growth cycle (days)	Growth cycle Ukraine (days)	Adaptability group	High Inputs		Intermediate Inputs		Low Inputs		Dependence of Rate of Leaf Photosynthesis (Pm) on Temperature (oC)								
					HI	**Max. LAI**	**HI**	**Max. LAI**	**HI**	**Max. LAI**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
Foxtail millet	**25**	75		C4/VI	0.30	3.5	0.23	2.5	0.18	2.0	0	5	40	50	50	50	40	5	0
Foxtail millet	**26**	90		C4/VI	0.30	4.0	0.23	3.0	0.18	2.5	0	5	40	50	50	50	40	5	0
Foxtail millet	**27**	105		C4/VI	0.35	4.5	0.25	3.0	0.20	2.5	0	5	40	50	50	50	40	5	0
Foxtail millet	**28**	120		C4/VI	0.35	5.0	0.25	3.0	0.20	2.5	0	5	40	50	50	50	40	5	0
Buckwheat	**29**	75	70-90	C3/1	0.20	4.0	0.15	25	0.13	20	5	15	20	20	15	5	0	0	0
Buckwheat	**30**	90		C3/1	0.22	4.5	0.20	2.7	0.18	2.2	5	15	20	20	15	5	0	0	0
Potato	**31**	75		C3/I	0.55	3.0	0.45	2.8	0.30	2.0	5	15	25	25	20	15	5	0	0
Potato	**32**	90	70-80	C3/I	0.60	3.5	0.45	2.8	0.30	2.0	5	15	25	25	20	15	5	0	0
Potato	**33**	120	90-110	C3/I	0.60	4.5	0.45	3.2	0.30	2.0	5	15	25	25	20	15	5	0	0
Potato	**34**	150	130-150	C3/I	0.60	5.0	0.45	3.7	0.30	2.5	5	15	25	25	20	15	5	0	0
Sugarbeet	**35**	120		C3/1	0.45	4.0	0.25	3.0	0.20	2.0	5	15	20	25	25	25	25	5	0
Sugarbeet	**36**	135	120-140	C3/1	0.45	4.5	0.25	3.5	0.20	2.5	5	15	20	25	25	25	25	5	0
Sugarbeet	**37**	150	140-160	C3/I	0.45	4.5	0.25	3.5	0.20	2.5	5	15	20	25	25	25	25	5	0
Sugarbeet	**38**	165		C3/I	0.45	5.5	0.25	4.0	0.20	3.0	5	15	20	25	25	25	25	5	0
Rape (winter)	**39**	35+105	290-320	C3/I	0.20	3.5	0.18	2.5	0.12	1.5	5	15	25	25	20	15	5	0	0
Rape (winter)	**40**	45+120		C3/I	0.25	4.0	0.18	3.0	0.12	2.0	5	15	25	25	20	15	5	0	0
Rape (spring) - colza	**41**	105		C3/I	0.20	2.5	0.18	2.5	0.12	1.5	5	15	25	25	20	15	5	0	0
Rape (spring) - colza	**42**	120	80-110	C3/I	0.20	3.0	0.18	3.0	0.12	2.0	5	15	25	25	20	15	5	0	0
Rape (spring) - colza	**43**	135	80-110	C3/I	0.25	3.5	0.18	3.0	0.12	2.0	5	15	25	25	20	15	5	0	0
Soybean	**44**	105	110-120	C3/II	0.30	3.0	0.20	2.3	0.15	1.5	0	5	15	30	35	35	30	5	0
Soybean	**45**	120	110-120	C3/II	0.35	3.5	0.20	2.7	0.15	1.8	0	5	15	30	35	35	30	5	0
Soybean	**46**	135	120-140	C3/II	0.35	4.0	0.20	3.0	0.15	2.0	0	5	15	30	35	35	30	5	0

CROPS		Growth cycle (days)	Growth cycle Ukraine (days)	Adaptability group	High Inputs		Intermediate Inputs		Low Inputs		Dependence of Rate of Leaf Photosynthesis (Pm) on Temperature (oC)								
					HI	**Max. LAI**	**HI**	**Max. LAI**	**HI**	**Max. LAI**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
Dry Peas	**47**	90	90-100	C3/I	0.20	3.0	0.23	2.6	0.15	1.8	5	15	25	25	20	15	5	0	0
Dry Peas	**48**	105		C3/1	0.22	3.5	0.23	2.8	0.15	1.8	5	15	25	25	20	15	5	0	0
Dry Peas	**49**	120		C3/I	0.25	4.0	0.23	3.0	0.15	2.0	5	15	25	25	20	15	5	0	0
Phaseolus bean	**50**	90		C3/I	0.30	3.0	0.23	2.3	0.15	1.5	5	15	25	25	20	15	5	0	0
Phaseolus bean	**51**	120		C3/I	0.30	4.0	0.23	3.0	0.15	2.0	5	15	25	25	20	15	5	0	0
Phaseolus bean	**52**	150		C3/I	0.30	4.0	0.23	3.0	0.15	2.0	5	15	25	25	20	15	5	0	0
Sunflower	**53**	105	120-140	C3/I	0.20	3.5	0.15	2.7	0.15	1.8	5	15	25	25	20	15	5	0	0
Sunflower	**54**	120	140-160	C3/I	0.20	4.0	0.15	3.0	0.15	2.0	5	15	25	25	20	15	5	0	0
Sunflower	**55**	135	120-140	C3/I	0.25	4.0	0.20	3.0	0.15	2.0	5	15	25	25	20	15	5	0	0
Sunflower	**56**	150	140-160	C3/I	0.25	4.5	0.20	3.5	0.15	2.5	5	15	25	25	20	15	5	0	0
Tobacco	**57**	150		C3/II	0.07	4.0	0.07	3.0	0.07	3.0	0	0	15	30	35	35	30	5	0
Tobacco	**58**	165		C3/II	0.09	4.0	0.09	3.5	0.09	3.5	0	0	15	30	35	35	30	5	0
Flax (for fibre)	**59**	75		C3/1	0.09	3.0	0.06	2.0	0.04	1.5	5	15	20	20	15	5	0	0	0
Flax (for fibre)	**60**	90	80-90	C3/I	0.10	3.0	0.07	2.2	0.05	1.7	5	15	20	20	15	5	0	0	0
Flax (for fibre)	**61**	105		C3/1	0.10	3.5	0.07	2.5	0.05	2.0	5	15	20	20	15	5	0	0	0
Flax (for fibre)	**62**	120	60-110	C3/1	0.10	3.5	0.09	2.5	0.06	2.0	5	15	20	20	15	5	0	0	0
Olive	**63**	365		C3/I	0.20	3.5	0.15	2.5	0.10	1.5	5	15	25	25	25	25	20	5	0
Cabbage	**64**	90		C3/I	0.40	4.0	0.30	3.3	0.20	2.5	5	15	20	25	20	10	0	0	0
Cabbage	**65**	105	70-110	C3/I	0.40	4.5	0.30	3.6	0.20	2.8	5	15	20	25	20	10	0	0	0
Cabbage	**66**	120	120-140	C3/I	0.40	4.5	0.30	3.6	0.20	2.8	5	15	20	25	20	10	0	0	0
Cabbage	**67**	165	150-170	C3/I	0.40	5.0	0.30	4.0	0.20	3.0	5	15	20	25	20	10	0	0	0
Tomato	**68**	105		C3/I	0.40	3.5	0.23	2.5	0.18	1.8	0	10	20	25	20	10	5	0	0
Tomato	**69**	105	95-115	C3/I	0.40	4.0	0.28	2.8	0.20	2.0	0	10	20	25	20	10	5	0	0
Tomato	**70**	120		C3/I	0.40	4.0	0.30	3.0	0.23	0.23	0	10	20	25	20	10	5	0	0
Tomato	**71**	135	115-135	C3/I	0.40	4.5	0.30	3.3	0.25	2.5	0	10	20	25	20	10	5	0	0

CROPS		Growth cycle (days)	Growth cycle Ukraine (days)	Adaptability group	High Inputs		Intermediate Inputs		Low Inputs		Dependence of Rate of Leaf Photosynthesis (Pm) on Temperature (oC)								
					HI	**Max. LAI**	**HI**	**Max. LAI**	**HI**	**Max. LAI**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
Onion	**72**	90	70-85	C3/I	0.40	3.5	0.28	2.0	0.20	1.5	0	10	20	25	20	10	5	0	0
Onion	**73**	105		C3/I	0.40	3.5	0.30	2.3	0.20	1.8	0	10	20	25	20	10	5	0	0
Onion	**74**	120	90-120	C3/I	0.40	3.5	0.30	2.3	0.23	1.8	0	10	20	25	20	10	5	0	0
Onion	**75**	135	120-140	C3/I	0.40	3.5	0.30	2.3	0.23	1.8	0	10	20	25	20	10	5	0	0
Alfalfa	**76**	365		C3/I	0.65	6.0	0.40	3.5	0.30	3.0	5	15	20	25	25	25	25	5	0
Grass + Legume	**77**	365		C3/I	0.65	4.0	0.40	3.5	0.30	3.0	5	15	20	20	15	5	0	0	0
Grasses	**78**	365		C3/I	0.65	4.0	0.40	3.5	0.30	3.0	5	15	20	20	15	5	0	0	0
Grasses	**79**	365		C4/IV	0.65	4.0	0.40	3.5	0.30	3.0	2.5	15	37.5	50	50	37.5	25	10	0

HI - harvest index
Max. LAI – maximum leaf area index
Notes:
When the growth cycle is curtailed due to the growing period being shorter. both harvest index *and* maximum leaf area index are to be reduced proportionately relative to the normal yield formation period. It is assumed that yield formation periods relate to growth cycles as follows: cereals 33%; roots and tubers 66%; legumes 50%; oil crops except for olive and oil palm 50%; fiber crops 50%. sugar crops 66%; and pastures 100%. The yield formation period of winter crops is relative to the post-winter (dormancy) part of the growth cycle.
Group I C3 species adapted to lower temperatures (e.g.. wheat. potatoes);
Group II C3 species adapted to higher temperatures (e.g.. soybean. rice);
Group III C4 species adapted to higher temperatures (e.g.. millet. maize. sugarcane);
Group IV C4 species adapted to lower temperatures (e.g.. sorghum. maize).

Parameters for the calculation of water-limited yields

CROPS	Length of Crop Stage (% of growth cycle)					Crop water requirements relative to reference evapotranspiration				Yield loss factors			
	d1	**d2**	**d3**	**d4**	$k1^c$	$k2^c$	$k3^c$	$k0^c$	k_1^y	k_2^y	k_3^y	k_4^y	k_0^y
Wheat (winter)	10	30	35	25	0.40	1.10	0.40	0.85	0.20	0.60	0.75	0.50	1.05
Wheat (spring)	10	20	45	25	0.40	1.10	0.40	0.85	0.20	0.65	0.80	0.55	1.15
Rice (wetland)	10	30	30	30	1.10	1.20	1.00	1.10	1.00	2.00	2.50	1.00	2.00
Maize /grain)	15	30	35	20	0.40	1.10	0.60	0.85	0.40	0.90	1.50	0.50	1.25
Barley (winter)	10	30	35	25	0.40	1.10	0.40	0.85	0.20	0.60	0.75	0.50	1.05
Barley (spring)	10	20	45	25	0.40	1.10	0.40	0.85	0.20	0.65	0.80	0.55	1.15
Buckwheat	15	20	40	25	0.40	1.05	0.40	0.80	0.20	0.60	0.80	0.50	0.90
Rye (winter)	10	30	35	25	0.40	1.10	0.40	0.85	0.20	0.60	0.75	0.50	1.05
Rye (spring)	10	20	45	25	0.40	1.10	0.40	0.85	0.20	0.65	0.80	0.55	1.15
Oat	10	20	45	25	0.40	1.10	0.40	0.85	0.20	0.65	0.80	0.55	1.15
Foxtail Millet	10	25	40	25	0.40	1.05	0.40	0.85	0.20	0.60	0.80	0.50	1.00
Irish Potato	20	25	35	20	0.50	1.10	0.75	0.85	0.50	0.80	0.80	0.70	1.10
Sugarbeet	15	30	35	20	0.50	1.10	0.70	0.85	1.00	1.00	1.00	0.50	1.10
Ph. Bean	20	33	33	14	0.40	1.10	0.90	0.85	0.20	0.60	1.10	0.75	1.15
Pea (dry)	15	30	40	15	0.50	1.15	0.30	0.80	0.20	0.90	0.70	0.20	1.15
Soybean	15	20	45	20	0.40	1.10	0.50	0.85	0.20	0.80	1.00	0.80	0.85
Sunflower	17	28	35	20	0.40	1.10	0.40	0.80	0.25	0.60	1.00	0.80	0.95
Rape	15	25	40	20	0.50	1.10	0.50	0.80	0.20	0.80	1.00	0.80	0.85
Flax	15	25	35	25	0.50	1.10	0.70	0.95	0.40	0.80	0.80	0.80	1.10

Notes:
The coefficients *d1*. …. *d4* relate to the characteristics of the crop growth cycle. denoting here the relative length (in percent) of four crop development stages. namely. initial stage. vegetative stage. reproductive stage. and maturation stage. Parameters $k1^c$. $k2^c$. and $k3^c$ define crop water requirements respectively for the initial stage. the reproductive phase. and the end of the maturation stage. Coefficient k^{0c} indicates water requirements relative to reference evapotranspiration over the entire growth cycle. Finally. factors k^y quantify the expected yield loss in relation to a crop evapotranspiration deficit. by crop stage and for the entire growth cycle. respectively.

ANNEX VI. Agro-climatic constraint parameters for rain-fed production

Level of input

1 - low

2 - intermidiate

3 - high

Constraints

1 - *(a) yield losses due to water-stress constraints on crop growth (e.g., rainfall variability);*

2 - *(b) yield losses due to the effect of pests, diseases and weed constraints on crop growth;*

3 - *(c) yield losses due to climatic conditions stress, excess wetness and pest and diseases constraints on yield components and yield formation (e.g., affecting quality of produce);*

4 - *(d) yield losses due to workability constraints (e.g., wetness rendering produce handling difficulties), and*

5 - *(e) yield losses due to occurrence of early or late frosts.*

Note: The example for winter wheat is shown. Due to the lagre size of the database, information for all crops is available in electronic format.

Crop	Growth cycle	Input level	Con-straint	Length of Growing Period														
				0	30	60	90	120	150	180	210	240	270	300	330	364	365-	365+
Winter Wheat	30+90	1	1	100	100	100	50	50	25	0	0	0	0	0	0	0	0	0
	30+90	1	2	0	0	0	0	0	0	0	0	0	25	25	25	25	25	25
	30+90	1	3	25	25	25	25	25	0	0	0	0	0	0	25	25	50	50
	30+90	1	4	0	0	0	0	0	0	0	0	0	0	0	0	25	25	50
	30+90	1	5	100	100	100	100	50	0	0	0	0	0	0	0	0	0	0
	30+90	2	1	100	100	100	50	50	25	0	0	0	0	0	0	0	0	0
	30+90	2	2	0	0	0	0	0	0	0	0	0	0	25	25	25	25	25
	30+90	2	3	25	25	25	25	25	0	0	0	0	0	0	25	25	50	50
	30+90	2	4	0	0	0	0	0	0	0	0	0	0	0	0	25	25	50
	30+90	2	5	100	100	100	100	50	0	0	0	0	0	0	0	0	0	0
	30+90	3	1	100	100	100	50	50	25	0	0	0	0	0	0	0	0	0
	30+90	3	2	0	0	0	0	0	0	0	0	0	0	0	25	25	25	25
	30+90	3	3	25	25	25	25	25	0	0	0	0	0	0	0	25	25	50
	30+90	3	4	0	0	0	0	0	0	0	0	0	0	25	25	25	50	50
	30+90	3	5	100	100	100	100	50	0	0	0	0	0	0	0	0	0	0
	40+120	1	1	100	100	100	50	50	25	25	0	0	0	0	0	0	0	0
	40+120	1	2	0	0	0	0	0	0	0	0	0	25	25	25	25	25	25
	40+120	1	3	25	25	25	25	25	0	0	0	0	0	0	25	25	50	50
	40+120	1	4	0	0	0	0	0	0	0	0	0	0	0	0	25	25	50
	40+120	1	5	100	100	100	125	75	25	25	0	0	0	0	0	0	0	0
	40+120	2	1	100	100	100	50	50	25	25	0	0	0	0	0	0	0	0
	40+120	2	2	0	0	0	0	0	0	0	0	0	0	25	25	25	25	25
	40+120	2	3	25	25	25	25	25	0	0	0	0	0	0	25	25	50	50
	40+120	2	4	0	0	0	0	0	0	0	0	0	0	0	0	25	25	50
	40+120	2	5	100	100	100	125	75	25	25	0	0	0	0	0	0	0	0
	40+120	3	1	100	100	100	50	50	25	25	0	0	0	0	0	0	0	0
	40+120	3	2	0	0	0	0	0	0	0	0	0	0	0	25	25	25	25
	40+120	3	3	25	25	25	25	25	0	0	0	0	0	0	0	25	25	50
	40+120	3	4	0	0	0	0	0	0	0	0	0	0	25	25	25	50	50
	40+120	3	5	100	100	100	125	75	25	25	0	0	0	0	0	0	0	0

ANNEX VII. Crop suitability of water collecting sites

Short-term dryland crops (a)

This group includes some short duration crops (wheat, barley, rye, oat, foxtail millet, buckwheat, and forage legumes which are somewhat tolerant to excess moisture. For less than 120 days it is assumed there is on the average slight water stress, especially when the contribution from rainfall is not well distributed. At LGPs longer than 120 days these crops will grow irrespective rainfall during growing period.

Suitability class	**Percentage of water-collecting sites suitable per LGP class**						
	< 120 (days)	120-149 (days)	150-179 (days)	180-209 (days)	210-239 (days)	240-269 (days)	>270 (days)
VS		33	33	33	33	33	33
S	33						
MS		33	33	33	33	33	33
mS	33						
NS	34	34	34	34	34	34	34

Short-term dryland crops (b)

The crops in this group include maize, phaseolus bean, pea, soybean, rape, sunflower and flax. They are sensitive to excess water (especially water-logging). Therefore, they are less suitable in longer LGPs. Their water requirements are similar or somewhat higher than group (a) crops.

Suitability class	**Percentage of water-collecting sites suitable per LGP class**						
	< 120 (days)	120-149 (days)	150-179 (days)	180-209 (days)	210-239 (days)	240-269 (days)	>270 (days)
VS		33	33	33	33		
S	33						
MS		33	33	33	33	33	
mS	33						
NS	34	34	34	34	34	67	100

Short-term dryland crops (c)

Root crops (white potato, sugarbeet), vegetables (onion, tomato and cabbage) and tobacco are all sensitive to high groundwater levels and water-logging. These crops can only be grown on the rarely flooded/inundated parts, provided they are well drained.

Suitability class	**Percentage of water-collecting sites suitable per LGP class**						
	< 120 (days)	120-149 (days)	150-179 (days)	180-209 (days)	210-239 (days)	240-269 (days)	>270 (days)
VS							
S							
MS		33	33	33	33		
mS	33	33	33	33	33	33	
NS	67	34	34	34	34	67	100

Wetland rice

Wetland Rice is difficult to grow under rain-fed conditions. In particular the water management is problematic. For irrigated conditions risk of submerging, flowing water, high water levels during maturing and harvest makes management difficult. Long LGPs are assumed to be associated with high flood risks.

Suitability class	Percentage of water-collecting sites suitable per LGP class						
	< 120 (days)	120-149 (days)	150-179 (days)	180-209 (days)	210-239 (days)	240-269 (days)	>270 (days)
VS							
S				33	33	33	
MS			33				33
mS		33					
NS	100	67	67	67	67	67	67

Pastures

Natural pastures are well adapted to wet conditions. Normally the species mix is fine-tuned to the environmental conditions. Artificial (sown) pastures might grow unevenly depending on both local differences of soil fertility and water supply. The total period of water availability can be considered an adequate measure of the productivity regarding pastures (periods of water-logging, flooding and inundation are to be subtracted).

Suitability class	Percentage of water-collecting sites suitable per LGP class						
	< 120 (days)	120-149 (days)	150-179 (days)	180-209 (days)	210-239 (days)	240-269 (days)	>270 (days)
VS		33	33	33	67	67	67
S	33		33	33	33	33	33
MS	33	33		34			
mS			34				
NS	100	67	67	67	67	67	67

ANNEX VIII. Soil-phase ratings for rain-fed and irrigation conditions

NSO3EL_ID	Soil unit composition by polygon									Soil attributes dominant soil unit																												
	Code FAO 1	**FAO_1**	**Code FAO 2**	**FAO_2**	**Code FAO 3**	**FAO_3**	**FAO_1__**	**FAO_2__**	**FAO_3__**	**GRAN_SOSTA**	**FAO texture class**	**Reference Bulk Density**	**Gropu_by_mean_dens**	**Bulk density (g/cm3)**	**Bulk density problem**	**DRAINAGE**	**DRAINAGE Classes**	**Humus_Content**	**Organic carbon (%)**	**pH_code**	**PH (H2O)**	**Carbon**	**Carbonate**	**Sum_Pogl_Osnovaniy**	**TEB (meq/1 g soil)**	**Cation_capacity**	**CECs (meq/1 g soil)**	**Base_Saturation**	**BS (%)**	**SUM_SALTS**	**Occurrence salts**	**SODA**	**Occurrence Sodium**	**ZASOLENIE**	**Salinity type**	**Skeletic phase**	**Soil Unit Code**	**Soil characteristics**
90	**2**	ARb	**65**	HSs	**88**	PDg	6	2	2	1	1	1,7	3	1,4	ok	1	E	11	0,7	2	5,3	4		12	1,0	11	4	1	25	1	1	1	1				1	acidic,
416	**2**	ARb	**88**	PDg			8	2		1	1	1,7	3	1,4	ok	1	E	11	0,7	2	5,3	4		12	1,0	11	4	1	25	1	1	1	1				1	excessive,
116	**3**	ARb	**65**	HSs	**45**	FLhi	6	2	2	1	1	1,7	3	1,4	ok	1	E	11	0,7	3	5,8	4		12	1,0	11	4	1	25	1	1	1	1				2	slightly acidic,
																																						excessive,
40	**1**	ARb	**88**	PDg			8	2		1	1	1,7	3	1,4	ok	1	E	11	0,7	4	6,5	4		12	1,0	11	4	1	25	1	1	1	1				3	neutral,
47	**1**	ARb	**88**	PDg			8	2		1	1	1,7	3	1,4	ok	1	E	11	0,7	4	6,5	4		12	1,0	11	4	1	25	1	1	1	1				3	excessive,
60	**1**	ARb	**45**	FLhi			8	2		1	1	1,7	3	1,4	ok	1	E	11	0,7	4	6,5	4		12	1,0	11	4	1	25	1	1	1	1				3	coarse
292	**1**	ARb	**47**	GLe	**45**	FLhi	6	2	2	1	1	1,7	3	1,4	ok	1	E	11	0,7	4	6,5	4		12	1,0	11	4	1	25	1	1	1	1				3	
1422	**1**	ARb	**47**	GLe			8	2		1	1	1,7	3	1,4	ok	1	E	11	0,7	4	6,5	4		12	1,0	11	4	1	25	1	1	1	1				3	

Note: Due to the lagre size of the database, information for all soil units is available in electronic format.

(continued)

Rain-fed (R)/Irrigated (I)	Input Level	FAO'9 Soil Unit Symbol and Texture group	Soil Unit Code	winter wheat	spring wheat	bunded rice	grain maize	silage maize	winter barley	spring barley	winter rye	oat	foxtail millet	Buckwheat	white potato	sugar beet	winter rape	rape	soybean	dry pea	phaseolus bean	sunflower	tobacco	flax	olive	cabbage	tomato	onion	alfalfa	gras
R	**High Inputs (H)**	**ARb**	**2**	2	2	4	2	2	2	2	3	3	2	**3**	3	2	2	2	2	**2**	2	2	3	**2**	2	2	2	2	2	3
R	**Intermediate Inputs (I)**	**ARb**	**2**	6	6	4	6	6	4	4	6	6	6	**2**	2	6	6	6	6	**6**	6	6	2	**6**	4	4	4	4	6	2
R	**Low inputs (L)**	**ARb**	**2**	4	4	4	4	4	4	4	4	4	4	**6**	6	4	4	4	4	**4**	4	4	6	**4**	4	4	4	4	4	6
I	**Gravity (High inputs)**	**ARb1**	**2**	4	4	4	4	4	4	4	4	4	4	**4**	4	4	4	4	4	**4**	4	4	4	**4**	4	4	4	4	4	4
I	**Sprinkler (High inputs)**	**ARb1**	**2**	2	2	4	3	3	2	2	3	3	2	**3**	2	6	6	6	6	**6**	6	6	6	**6**	6	4	4	4	3	3
R	**High Inputs (H)**	**ARb**	**3**	2	2	4	2	2	2	2	3	3	2	**3**	3	2	2	2	2	**2**	2	2	3	**2**	3	2	2	3	2	3
R	**Intermediate Inputs (I)**	**ARb**	**3**	6	6	4	6	6	6	6	6	6	6	**2**	2	6	6	6	6	**6**	6	6	2	**6**	2	6	6	2	6	2
R	**Low inputs (L)**	**ARb**	**3**	4	4	4	4	4	4	4	4	4	4	**6**	6	4	4	4	4	**4**	4	4	6	**4**	4	4	4	6	4	6
I	**Gravity (High inputs)**	**ARb1**	**3**	4	4	4	4	4	4	4	4	4	4	**4**	4	4	4	4	4	**4**	4	4	4	**4**	4	4	4	4	4	4
I	**Sprinkler (High inputs)**	**ARb1**	**3**	2	2	4	2	2	2	2	3	3	2	**3**	2	6	6	6	6	**6**	6	6	2	**6**	2	4	4	4	2	3
R	**High Inputs (H)**	**ARb**	**1**	2	2	4	2	2	2	2	3	3	2	**3**	3	2	2	2	2	**2**	2	2	3	**2**	3	2	2	3	2	3
R	**Intermediate Inputs (I)**	**ARb**	**1**	6	6	4	6	6	6	6	6	6	6	**2**	2	6	6	6	6	**6**	6	6	2	**6**	2	6	6	2	6	2
R	**Low inputs (L)**	**ARb**	**1**	4	4	4	4	4	4	4	4	4	4	**6**	6	4	4	4	4	**4**	4	4	6	**4**	4	4	4	6	4	6
I	**Gravity (High inputs)**	**ARb1**	**1**	4	4	4	4	4	4	4	4	4	4	**4**	4	4	4	4	4	**4**	4	4	4	**4**	4	4	4	4	4	4
I	**Sprinkler (High inputs)**	**ARb1**	**1**	2	2	4	2	2	2	2	3	3	2	**3**	2	6	6	6	6	**6**	6	6	6	**6**	2	4	4	6	2	3

ANNEX IX. Terrain-slope ratings for rain-fed conditions

Fm <1300

High Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			100			50	50				100			100			100
Annual 2	100			100			100			50	50				100			100			100
Wetland Rice	100			50	50			50	50			100			100			100			100
Olive	100			100			100			50	50			50	50			100			100
Pasture	100			100			100			100				100				100			100
Forage Legumes	100			100			100			50	50				100			100			100

Intermediate Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			100			100				100				100			100
Annual 2	100			100			100			50	50			100				100			100
Wetland Rice	100			50	50			100				100			100			100			100
Olive	100			100			100			50	50			100				100			100
Pasture	100			100			100			100			50	50			50	50			100
Forage Legumes	100			100			100			100			50	50			50	50			100

Low Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			100			100			50	50				100			100
Annual 2	100			100			100			100			50	50				100			100
Wetland Rice	100			100			50	50			100			50	50			100			100
Olive	100			100			100			100			50	50				100			100
Pasture	100			100			100			100			100			50		50			100
Forage Legumes	100			100			100			100			50	50			50	50			100

Modified Fournier index: $Fm = 12\sum_{i=1}^{12}\frac{p_i^2}{Pann}$ where: p_i = rainfall of month i and Pann = annual rainfall total

Crop Groups: Annual 1: wheat, barley, rye, oat, buckwheat
Annual 2: maize, foxtail millet, white potato, phaseolus bean, dry pea, soybean, flax sunflower, sugar beet, rape, tomato, cabbage, onion and tobacco.

Fm: 1300-1800

High Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			100			50	50				100			100			100
Annual 2	100			100			100			50	50				100			100			100
Wetland Rice	100			50	50			50	50			100			100			100			100
Olive	100			100			100				100				100			100			100
Pasture	100			100			100			100				50	50			100			100
Forage Legumes	100			100			100			50	50				100			100			100

Intermediate Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			100			50	50			50	50			100			100
Annual 2	100			100			100			50	50			50	50			100			100
Wetland Rice	100			50	50			100				100			100			100			100
Olive	100			100			100			50	50			50	50			100			100
Pasture	100			100			100			100			50	50			25	75			100
Forage Legumes	100			100			100			100			25	50	25			100			100

Low Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			100			100				50	50			100			100
Annual 2	100			100			100			50	50			50	50			100			100
Wetland Rice	100			50	50			100				100			100			100			100
Olive	100			100			100			50	50			50	50			100			100
Pasture	100			100			100			100			50	50			25	75			100
Forage Legumes	100			100			100			100			25	50	25			100			100

Modified Fournier index: $Fm = 12\sum_{i=1}^{12}\frac{p_i^2}{Pann}$ where: p_i = rainfall of month i and Pann = annual rainfall total

Crop Groups: Annual 1: wheat, barley, rye, oat, buckwheat

Annual 2: maize, foxtail millet, white potato, phaseolus bean, dry pea, soybean, flax sunflower, sugar beet, rape, tomato, cabbage, onion and tobacco.

Fm: 1800-2200

High Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			100			25	50	25			100			100			100
Annual 2	100			100			100			25	50	25			100			100			100
Wetland Rice	100			50	50			50	50			100			100			100			100
Olive	100			100			100				50	50			100			100			100
Pasture	100			100			100			100				25	75			100			100
Forage Legumes	100			100			100			25	50	25			100			100			100

Intermediate Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			100			25	50	25			100			100			100
Annual 2	100			100			100			25	50	25			100			100			100
Wetland Rice	100			50	50			100				100			100			100			100
Olive	100			100			100			25	50	25			100			100			100
Pasture	100			100			100			100			50	50			25	75			100
Forage Legumes	100			100			100			100				50	50			100			100

Low Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			100			50	50				100			100			100
Annual 2	100			100			100			25	50	25			100			100			100
Wetland Rice	100			50	50			100				100			100			100			100
Olive	100			100			100			25	50	25			100			100			100
Pasture	100			100			100			100			50	50			25	75			100
Forage Legumes	100			100			100			50	50			50	50			100			100

Modified Fournier index: $Fm = 12 \sum_{i=1}^{12} \frac{p_i^2}{Pann}$ where: p_i = rainfall of month i and Pann = annual rainfall total

Crop Groups: Annual 1: wheat, barley, rye, oat, buckwheat
Annual 2: maize, foxtail millet, white potato, phaseolus bean, dry pea, soybean, flax sunflower, sugar beet, rape, tomato, cabbage, onion and tobacco.

Fm: 2200-2500

High Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			100				50	50			100			100			100
Annual 2	100			100			100				50	50			100			100			100
Wetland Rice	100			50	50			50	50			100			100			100			100
Olive	100			100			100					100			100			100			100
Pasture	100			100			100			100					100			100			100
Forage Legumes	100			100			100				50	50			100			100			100

Intermediate Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			100				50	50			100			100			100
Annual 2	100			100			100				50	50			100			100			100
Wetland Rice	100			50	50			100				100			100			100			100
Olive	100			100			100				50	50			100			100			100
Pasture	100			100			100			100			25	50	25			100			100
Forage Legumes	100			100			100				100			25	75			100			100

Low Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			100				100				100			100			100
Annual 2	100			100			100				50	50			100			100			100
Wetland Rice	100			50	50			100				100			100			100			100
Olive	100			100			100				50	50			100			100			100
Pasture	100			100			100			100			25	50	25			100			100
Forage Legumes	100			100			100				100			25	75			100			100

Modified Fournier index: $Fm = 12 \sum_{i=1}^{12} \frac{p_i^2}{Pann}$ where: p_i = rainfall of month i and Pann = annual rainfall total

Crop Groups: Annual 1: wheat, barley, rye, oat, buckwheat
Annual 2: maize, foxtail millet, white potato, phaseolus bean, dry pea, soybean, flax sunflower, sugar beet, rape, tomato, cabbage, onion and tobacco.

Fm: 2500-2700

High Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			100				25	75			100			100			100
Annual 2	100			100			100				25	75			100			100			100
Wetland Rice	100			50	50			50	50			100			100			100			100
Olive	100			100			100					100			100			100			100
Pasture	100			100			100			50	50				100			100			100
Forage Legumes	100			100			100				25	75			100			100			100

Intermediate Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			100				25	75			100			100			100
Annual 2	100			100			100				25	75			100			100			100
Wetland Rice	100			50	50			100				100			100			100			100
Olive	100			100			100				25	75			100			100			100
Pasture	100			100			100			100				25	75			100			100
Forage Legumes	100			100			100				50	50			100			100			100

Low Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			100				50	50			100			100			100
Annual 2	100			100			100				25	75			100			100			100
Wetland Rice	100			50	50			100				100			100			100			100
Olive	100			100			100				25	75			100			100			100
Pasture	100			100			100			100				25	75			100			100
Forage Legumes	100			100			100				50	50			100			100			100

Modified Fournier index: $Fm = 12\sum_{i=1}^{12}\frac{p_i^2}{Pann}$ where: p_i = rainfall of month i and Pann = annual rainfall total

Crop Groups: Annual 1: wheat, barley, rye, oat, buckwheat
Annual 2: maize, foxtail millet, white potato, phaseolus bean, dry pea, soybean, flax sunflower, sugar beet, rape, tomato, cabbage, onion and tobacco.

Fm > 2700

High Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			50	50				100			100			100			100
Annual 2	100			100			50	50				100			100			100			100
Wetland Rice	100			50	50			25	75			100			100			100			100
Olive	100			100			50	50				100			100			100			100
Pasture	100			100			100				50	50			100			100			100
Forage Legumes	100			100			50	50				100			100			100			100

Intermediate Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			50	50			25	75			100			100			100
Annual 2	100			100			50	50			25	75			100			100			100
Wetland Rice	100			50	50			50	50			100			100			100			100
Olive	100			100			50	50			25	75			100			100			100
Pasture	100			100			100			100				50	50			100			100
Forage Legumes	100			100			50	50			50	50			100			100			100

Low Inputs

Slope Gradient Classes	0-2 %			2-5%			5-8%			8-16%			16-30%			30-45%			> 45%		
Crop Groups	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**	**S1**	**S2**	**N**
Annual 1	100			100			50	50			50	50			100			100			100
Annual 2	100			100			50	50			25	75			100			100			100
Wetland Rice	100			50	50			50	50			100			100			100			100
Olive	100			100			50	50			25	75			100			100			100
Pasture	100			100			100			100				50	50			100			100
Forage Legumes	100			100			50	50			50	50			100			100			100

Modified Fournier index: $Fm = 12\sum_{i=1}^{12}\frac{p_i^2}{Pann}$ where: p_i = rainfall of month i and Pann = annual rainfall total

Crop Groups: Annual 1: wheat, barley, rye, oat, buckwheat
Annual 2: maize, foxtail millet, white potato, phaseolus bean, dry pea, soybean, flax sunflower, sugar beet, rape, tomato, cabbage, onion and tobacco.

ANNEX X. Fallow land requirements

	Thermal Regime (July mean temperature)		> 20°C					< 20°C				
	Moisture Regime (LGP, days)		**<90**	**90-120**	**120-180**	**180-270**	**>270**	**<90**	**90-120**	**120-180**	**180-270**	**>270**
	FAO’90 Soil Units	**Crop Groups**										
I	FLe1, FLe2, Flhi1, Flhi2	Cereals	30	30	30	30	30	30	30	30	30	30
		Legumes	30	30	30	30	30	30	30	30	30	30
		Roots/Tubers	30	30	30	30	30	30	30	30	30	30
		Long term Annuals and Perennials	30	30	30	30	30	30	30	30	30	30
II	GLe1, GLe2, GLe3, GLe4, GLe5, GLm1, GLm2, GLm3, GLm4, GLm5, GLm6, GLm7	Cereals	40	40	40	40	40	40	40	40	40	40
		Legumes	40	40	40	40	40	40	40	40	40	40
		Roots/Tubers	40	40	40	40	40	40	40	40	40	40
		Long term Annuals and Perennials	40	40	40	40	40	40	40	40	40	40
III	CHh1, CHh2, CHh3, CHh6, CHh7, CHh8, CHh9, CHh10, CHh11, CHh12, CHk1, CHk2, CHk5, CHk6, CHl1, CHl4, CHl5, CHl7, CMc1, CMc2, CMe1, GRh6, KSl1, KSl2, LPk1, LPk2, LPm1, PDg3, PDg4, PDg5, PHh1, PHh3, PHh5, PHh6, PHl1, PHl3, PHl5, PLe4	Cereals	70	65	60	60	70	75	70	65	65	75
		Legumes	70	65	60	60	70	75	70	65	65	75
		Roots/Tubers	70	65	60	60	70	75	70	65	65	75
		Long term Annuals and Perennials	70	65	60	60	70	75	70	65	65	75
IV	CHh4, CHh5, CHh13, CHk3, CHk4, CHk7, CHk8, CHl2, CHl3, CHl6, CHl8, GRg4, GRh5, KSh1, KSh2, KSh3, PHh2, PHh4, PHh7, PHl2, PHl4, PLe1, PLe2, PLe3, PLe5, PLe6, PLe7, PLe8, SCh1, SCh2, SCh3, SCh4, SNg1	Cereals	75	70	65	65	75	80	75	70	70	80
		Legumes	75	70	65	65	75	80	75	70	70	80
		Roots/Tubers	75	70	65	65	75	80	75	70	70	80
		Long term Annuals and Perennials	75	70	65	65	75	80	75	70	70	80

V		Cereals	75	70	65	65	75	80	75	70	70	80
		Legumes	75	70	65	65	75	80	75	70	70	80
		Roots/Tubers	80	75	70	70	80	85	80	75	75	85
		Long term Annuals and Perennials	85	80	75	75	85	90	85	80	80	90
VI	CMd1, CMd2, CMg1, FLd1, GRg1, GRg2, GRg3, GRh1, GRh2, GRh3, GRh4, HSs2, HSs3, HSs4, HSs5, HSs6, LPd1, LPd2, PDe1, PDe2, PDe3, PDe4, PDe5, PDe6, PDe7, PDg1, PDg2, PDg6, PDg7, PDj1, PDj2, PLe1, PLe2, PLe3, PLe5, PLe6	Cereals	80	75	70	70	80	85	80	75	75	85
		Legumes	80	75	70	70	80	85	80	75	75	85
		Roots/Tubers	80	75	70	70	80	85	80	75	75	85
		Long term Annuals and Perennials	80	75	70	70	80	85	80	75	75	85
VII	ARb2	Cereals	80	75	70	70	80	85	80	75	75	85
		Legumes	80	75	70	70	80	85	80	75	75	85
		Roots/Tubers	85	80	75	75	85	90	85	80	80	90
		Long term Annuals and Perennials	85	80	75	75	85	90	85	80	80	90
VIII	ARb1, ARb3, ARb4, ARb5, ARb6, ARb7, ARb8, ARb9, ARb10, ARb11, HSs1, LPu1	Cereals	85	80	75	75	85	90	85	80	80	90
		Legumes	85	80	75	75	85	90	85	80	80	90
		Roots/Tubers	85	80	75	75	85	90	85	80	80	90
		Long term Annuals and Perennials	85	80	75	75	85	90	85	80	80	90

ANNEX XI. Vernalization requirements for the AEZ applications

Vernalization response is important for matching the plant growth cycle to the environment in which it is grown, so it can make the best use of the seasonal opportunities for growth and avoid adverse climatic factors (Levitt, 1948; Aitken, 1961; Tottman, 1977).

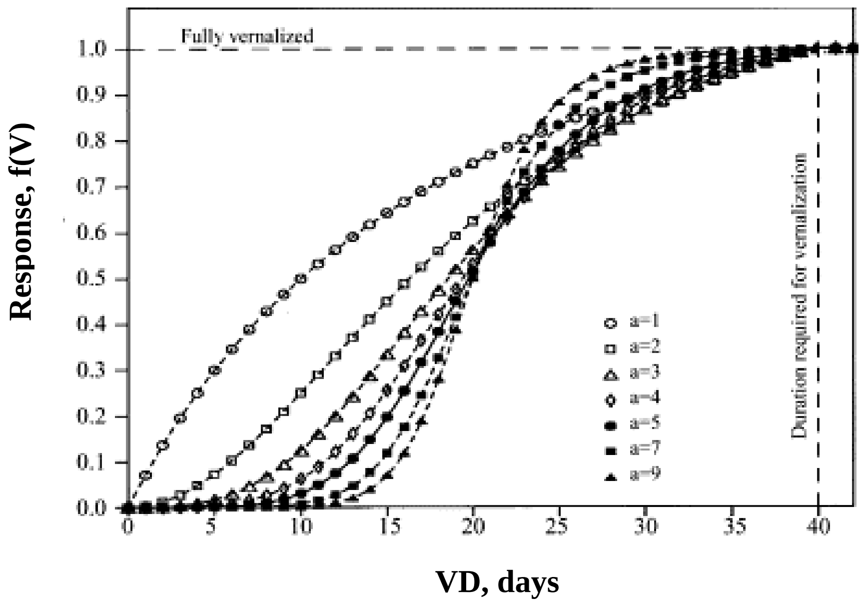
The major effect of vernalization is to shorten the duration of the phase of leaf primordia production (Griffiths, Lyndon and Bennett, 1985). It does this by bringing forward the time of initiation of the collar primordium and as a consequence reduces the number of leaves initiated on the main shoot (e.g. Gott, Gregory and Purvis, 1955). Hence final leaf number is reduced, given the assumption that the rate of leaf primordia production is dependent on temperature only (Baker and Gallagher, 1983*b*; Kirby *et al*. 1987; Delecolle *et al*., 1989). Vernalization thus affects not only the timing of floral initiation but also through its effect on leaf number, the timing of other stages up to the emergence of the flag leaf, and the number of potential tiller sites on the main shoot (e.g. Levy and Peterson, 1972). (M. J. Robertson, I. R. Brooking. and J. T. Ritchie. Temperature Response of Vernalization in Wheat: Modelling the Effect on the Final Number of Mainstem Leaves, *Annals of Botany* 78: 371-381, 1996).

Crop	**Mean daily temperature, ° C**			**Source**	**Number of vernalization days (VD)**[1]
	min	**opt**	**max**		
Winter genotypes					
wheat	-1.3	4.9	15.7	Streck et al. (2002)	30 - 70
	-1	2	15	Wang and Engel (1998)	
	-1	5	14	Robertson (1996)	
	0	3 - 6	12 - 19	H.M.Rawnson et al. (1998)	
S. European	-1	0 - 3	12	Porter and Gawith. (1999)	
rye	-4	1 - 7	15	Devlin and Witham (1983)	30 - 50
	-1	5	12	W.Mirschel et al. (2005)	
barley	0	3.5-4	10	W.Mirschel et al. (2005)	20 - 40
rape		0 - 5		Sovero (1993)	20 - 30
Spring genotypes					
short duration	7 - 18			Acevedo et al. (2002)	5 - 10
long duration	7 - 18			Acevedo et al. (2002)	10 - 15

De-vernalization effect for winter wheat after 40VD starts with T > 18°C for 10 days (Baloch *et al*., 2002)

	Start response, days	**Half response, days**	**Full response, days**
Winter wheat	8-10 (Streck *et al*, 2003)	20-25 (Streck et al, 2003) (Wang and Engel, 1998 – ½ of full VD)	45 (Streck et al, 2003) (Wang and Engel, 1998 – 46 days)

[1] Number of VD is average from different sources.



Vernalization function [f(V)] calculated by the modified equations [Eq. (2)] for various values of n, as indicated, and $VD_{0,5}$ = 20.

The Morgan–Mercer–Flodin (MMF) function (Morgan *et al*., 1975):

$$Y = \frac{ab + cX^n}{b + X^n} \tag{1}$$

For the vernalization response function [*f(V)]*, *X* is VD and *Y* is the vernalization response that varies from 0 to 1, with 0 corresponding to unvernalized plants and 1 corresponding to fully vernalized plants. Because the response function varies from 0 to 1, the coefficients a and c in Eq. [1] have values of 0 and 1, respectively. Then, *f(V)* is calculated by a function of

$$f(V) = \frac{VD^n}{VD_{0.5}^n + VD^n} \tag{2}$$

The daily vernalization rate [fvn(T), VD units per day] was calculated using a ß function (Wang and Engel, 1998):

$$fvn(T) = \frac{2(T - T_{\min})^{\alpha}(T_{opt} - T_{\min})^{2\alpha} - (T - T_{\min})^{2\alpha}}{(T_{opt} - T_{\min})^{2\alpha}}, \text{ for } T_{\min} \le T \le T_{\max}$$

$$fvn(T) = 0, \text{ for } T < T_{\min},\ T > T_{\max} \tag{3}$$

$$\alpha = \frac{\ln 2}{\ln(T_{\max} - T_{\min}) - \ln(T_{opt} - T_{\min})} \tag{4}$$

where $T_{\min}$, T_{opt}, and $T_{\max}$ are the cardinal temperatures for vernalization (minimum, optimum, and maximum) and T is the temperature at which the experiment was conducted. The VD treatments were calculated by:

$$VD = \sum_j fvn(T_j) \tag{5}$$

Proposed vernalization requirement parameterization

Crop	Start response, days	Half response, days	Full response, days
W. wheat	10	22.5	45
W. rye	10	22.5	45
W. barley	8	17.5	35
W. rape	8	15	30

Crop	Mean daily temperature, ° C		
	min	opt	max
W. wheat	-1	5	15
W. rye	-2	5	15
W. barley	0	4	12
W. rape	0	3	10

References

ACEVEDO E., SILVA P., SILVA H. Wheat growth and physiology, FAO, Rome, 2002.

DEVLIN R., WITHAM F. Plant Physiology. 4th Edition. Willard Grant, Boston, 1983.

MIRSCHEL W., WENKEL K., SCHULTZ A. Dynamic phenological model for winter rye and winter barley, *Europ. J. Agronomy* 23: 123–135, 2005.

PORTER J.R., GAWITH M. Temperatures and the growth anddevelopment of wheat: a review. *Eur J Agron* 10: 23–361, 999.

RAWSON H.M., ZAJAC M., PENROSE L.D.J. Effect of seedling temperature and its duration on development of wheat cultivars differing in vernalization response, *Field Crops Research* 57: 289–300, 1998.

ROBERTSON M. J., BROOKING I. R. and RITCHIE J. T. Temperature Response of Vernalization in Wheat: Modelling the Effect on the Final Number of Mainstem Leaves, *Annals of Botany* 78: 371-381, 1996.

SOVERO, M. Rapeseed, a new oilseed crop for the United States. p. 302-307. In: J. Janick and J.E. Simon (eds.), New crops. Wiley, New York, 1993.

STRECK, N.A., WEISS, A., BAENZIGER, P.S.. A generalized vernalization function for winter wheat, *Agron. J.* 95: 155–159, 2003.

WANG EL, ENGEL T. Simulation of phenological development on wheat crops. *Agric Syst* 58:1–24, 1998.

ANNEX XII. Summary tables for major crops

Table 1. Extents of suitable land, production potential and attainable yields of rain-fed maize by oblast under high, intermediate and low levels of input and management

Oblast	Total Area (10^3 ha)	High Input Level			Intermediate Input Level			Low Input Level			Actual Yield[b] (t/ha)
		VS+S+MS[a]			VS+S+MS			VS+S+MS			
		Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	
Southern and Eastern											
AR Krym	2641	75	312	4,2	77	228	3,0	280	353	1,3	3,9
Odes'ka	3321	2052	10021	4,9	2277	7524	3,3	2638	4538	1,7	2,8
Mykolaivs'ka	2385	1797	7143	4,0	2002	5225	2,6	2174	3359	1,5	2,5
Khersons'ka	2682	745	2554	3,4	835	2000	2,4	1446	1880	1,3	3,4
Zaporiz'ka	2718	1786	8763	4,9	2072	6768	3,3	2325	3853	1,7	2,5
Dnipropetrovs'ka	3173	2448	11172	4,6	2506	7789	3,1	2625	4608	1,8	2,9
Donets'ka	2639	2290	11465	5,0	2349	8074	3,4	2357	4311	1,8	2,7
Luhans'ka	2655	2051	9639	4,7	2141	6846	3,2	2252	3876	1,7	2,4
Kharkivs'ka	3129	2578	11161	4,3	2595	7395	2,8	2597	4566	1,8	2,4
Central											
Vinnyts'ka	2637	2070	10465	5,1	2100	6925	3,3	2073	3343	1,6	3,4
Cherkas'ka	2084	1549	7372	4,8	1565	4789	3,1	1568	2677	1,7	3,9
Poltavs'ka	2858	2123	9830	4,6	1865	5678	3,0	1635	2950	1,8	3,1
Kirovohrads'ka	2447	2139	9863	4,6	2194	6722	3,1	2198	3886	1,8	3,1
Northern											
Sums'ka	2370	1660	7414	4,5	1580	4521	2,9	1477	2443	1,7	3,0
Chernihivs'ka	3174	1907	8289	4,3	1420	3843	2,7	977	1532	1,6	3,6
Kyivs'ka	2880	1701	7929	4,7	1505	4325	2,9	1243	2069	1,7	3,6
Zhytomyrs'ka	2968	889	3442	3,9	771	1886	2,4	520	680	1,3	3,5
Volyns'ka	2003	259	782	3,0	252	473	1,9	161	174	1,1	4,5
Rivnens'ka	1994	355	1418	4,0	314	806	2,6	245	321	1,3	4,3
Western											
Ivano-Frankivs'ka	1387	252	1027	4,1	202	523	2,6	167	230	1,4	3,7
Zakarpats'ka	1271	267	1391	5,2	164	490	3,0	59	80	1,4	5,2
L'vivs'ka	2172	339	1124	3,3	230	474	2,1	171	193	1,1	4,2
Ternopil's'ka	1375	634	3200	5,0	641	2096	3,3	603	921	1,5	3,4
Khmel'nyts'ka	2054	1383	8817	6,4	1373	5764	4,2	1335	2442	1,8	3,7
Chernivets'ka	805	416	2315	5,6	381	1430	3,8	353	586	1,7	4,2
Ukraine	**59822**	**33765**	**156908**	**4,6**	**33411**	**102594**	**3,1**	**33479**	**55871**	**1,7**	**3,0**

[a] VS = very suitable; S = suitable; MS – moderately suitable
[b] Actual yield is average yield calculated on the basis of reported actual yields by State Statistic Committee of Ukraine for the period 1971-2000 by oblast

Table 2. Extents of suitable land, production potential and attainable yields of rain-fed sunflower by oblast under high, intermediate and low levels of input and management

Oblast	Total Area (10^3 ha)	High Input Level VS+S+MS[a]			Intermediate Input Level VS+S+MS			Low Input Level VS+S+MS			Actual Yield[b] (t/ha)
		Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	
Southern and Eastern											
AR Krym	2641	164	330	2,0	339	469	1,4	552	482	0,9	0,9
Odes'ka	3321	2511	5809	2,3	2616	4548	1,7	2676	2923	1,1	1,3
Mykolaivs'ka	2385	2167	4015	1,9	2173	3429	1,6	2176	2078	1,0	1,1
Khersons'ka	2682	1072	1847	1,7	1479	1977	1,3	1429	1175	0,8	1,0
Zaporiz'ka	2718	2291	5068	2,2	2083	3509	1,7	2136	2186	1,0	1,4
Dnipropetrovs'ka	3173	2690	5681	2,1	2684	4643	1,7	2634	2749	1,0	1,4
Donets'ka	2639	2376	5639	2,4	2379	4267	1,8	2358	2564	1,1	1,5
Luhans'ka	2655	2217	4895	2,2	2248	3843	1,7	2253	2311	1,0	1,3
Kharkivs'ka	3129	2654	5184	2,0	2646	4654	1,8	2624	2758	1,1	1,5
Central											
Vinnyts'ka	2637	2160	4863	2,3	2185	3875	1,8	2154	2074	1,0	1,3
Cherkas'ka	2084	1561	3149	2,0	1577	2717	1,7	1564	1540	1,0	1,5
Poltavs'ka	2858	2254	4578	2,0	1931	3405	1,8	1714	1806	1,1	1,5
Kirovohrads'ka	2447	2199	4645	2,1	2208	3836	1,7	2199	2281	1,0	1,3
Northern											
Sums'ka	2370	1728	3158	1,8	1663	2705	1,6	1569	1450	0,9	1,2
Chernihivs'ka	3174	1860	3367	1,8	1569	2353	1,5	1217	1058	0,9	1,3
Kyivs'ka	2880	1694	3362	2,0	1613	2623	1,6	1402	1312	0,9	1,1
Zhytomyrs'ka	2968	1361	1998	1,5	1170	1416	1,2	788	539	0,7	1,1
Volyns'ka	2003	65	61	0,9	48	39	0,8	33	15	0,5	1,5
Rivnens'ka	1994	461	665	1,4	400	485	1,2	278	192	0,7	1,0
Western											
Ivano-Frankivs'ka	1387	307	422	1,4	193	231	1,2	152	102	0,7	0,9
Zakarpats'ka	1271	277	643	2,3	274	386	1,4	153	114	0,7	1,1
L'vivs'ka	2172	168	186	1,1	88	86	1,0	57	32	0,6	2,5
Ternopil's'ka	1375	556	1106	2,0	551	812	1,5	553	446	0,8	0,9
Khmel'nyts'ka	2054	1399	3490	2,5	1395	2500	1,8	1299	1322	1,0	0,8
Chernivets'ka	805	430	1062	2,5	363	698	1,9	348	375	1,1	1,0
Ukraine	**59822**	**36622**	**75223**	**2,1**	**35875**	**59506**	**1,7**	**34318**	**33884**	**1,0**	**1,3**

[a] VS = very suitable; S = suitable; MS – moderately suitable
[b] Actual yield is average yield calculated on the basis of reported actual yields by State Statistic Committee of Ukraine for the period 1971-2000 by oblast

Table 3. Extents of suitable land, production potential and attainable yields of rain-fed spring barley by oblast under high, intermediate and low levels of input and management

Oblast	Total Area (10^3 ha)	High Input Level VS+S+MS[a]			Intermediate Input Level VS+S+MS			Low Input Level VS+S+MS			Actual Yield[b] (t/ha)
		Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	
Southern and Eastern											
AR Krym	2641	1401	3587	2,6	1393	2458	1,8	1261	1334	1,1	2,3
Odes'ka	3321	2709	8450	3,1	2779	6159	2,2	2767	3553	1,3	2,0
Mykolaivs'ka	2385	2172	7083	3,3	2178	5045	2,3	2180	2910	1,3	2,1
Khersons'ka	2682	1859	4929	2,7	1839	3497	1,9	1841	2044	1,1	1,9
Zaporiz'ka	2718	2366	7345	3,1	2364	5192	2,2	2365	2989	1,3	2,1
Dnipropetrovs'ka	3173	2729	8759	3,2	2733	6202	2,3	2686	3493	1,3	2,3
Donets'ka	2639	2372	7647	3,2	2386	5435	2,3	2384	3089	1,3	2,2
Luhans'ka	2655	2233	6800	3,0	2259	4890	2,2	2263	2839	1,3	1,8
Kharkivs'ka	3129	2658	8675	3,3	2689	6169	2,3	2652	3447	1,3	2,3
Central											
Vinnyts'ka	2637	2171	7722	3,6	2198	5339	2,4	2197	2871	1,3	2,6
Cherkas'ka	2084	1593	5696	3,6	1600	3937	2,5	1591	2149	1,4	2,9
Poltavs'ka	2858	2281	7558	3,3	2214	5056	2,3	1936	2510	1,3	2,6
Kirovohrads'ka	2447	2199	7594	3,5	2210	5346	2,4	2203	3015	1,4	2,6
Northern											
Sums'ka	2370	1780	6127	3,4	1737	4122	2,4	1658	2170	1,3	2,3
Chernihivs'ka	3174	2161	6996	3,2	1815	3974	2,2	1394	1705	1,2	2,2
Kyivs'ka	2880	1840	6336	3,4	1604	3805	2,4	1469	1899	1,3	2,6
Zhytomyrs'ka	2968	1762	6025	3,4	1433	3303	2,3	1079	1343	1,2	2,2
Volyns'ka	2003	1004	3165	3,2	912	1958	2,1	776	871	1,1	2,4
Rivnens'ka	1994	968	3244	3,4	840	1951	2,3	725	899	1,2	2,8
Western											
Ivano-Frankivs'ka	1387	620	2150	3,5	534	1234	2,3	444	544	1,2	2,7
Zakarpats'ka	1271	348	1110	3,2	309	629	2,0	307	336	1,1	2,1
L'vivs'ka	2172	1219	4153	3,4	1050	2377	2,3	840	1002	1,2	2,7
Ternopil's'ka	1375	1052	3941	3,7	1067	2696	2,5	1066	1420	1,3	2,5
Khmel'nyts'ka	2054	1422	5078	3,6	1400	3413	2,4	1362	1788	1,3	2,6
Chernivets'ka	805	462	1512	3,3	430	961	2,2	389	471	1,2	2,8
Ukraine	**59822**	**43381**	**141682**	**3,3**	**41973**	**95148**	**2,3**	**39835**	**50691**	**1,3**	**2,3**

[a] VS = very suitable; S = suitable; MS – moderately suitable
[b] Actual yield is average yield calculated on the basis of reported actual yields by State Statistic Committee of Ukraine for the period 1981-2000 by oblast

Table 4. Extents of suitable land, production potential and attainable yields of rain-fed sugar beet by oblast under high, intermediate and low levels of input and management

Oblast	Total Area (10^3 ha)	High Input Level			Intermediate Input Level			Low Input Level			Actual Yield[b] (t/ha)
		VS+S+MS[a]			VS+S+MS			VS+S+MS			
		Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	
Southern and Eastern											
AR Krym	2641	616	14200	23,1	651	8154	12,5	755	7177	9,5	13,9
Odes'ka	3321	2432	63880	26,3	2557	35829	14,0	2614	28594	10,9	16,6
Mykolaivs'ka	2385	2021	55760	27,6	2026	29743	14,7	2027	21983	10,8	17,7
Khersons'ka	2682	1004	22949	22,9	1065	12846	12,1	1131	10389	9,2	18,7
Zaporiz'ka	2718	2076	54606	26,3	2018	28411	14,1	2199	23091	10,5	16,3
Dnipropetrovs'ka	3173	2654	70229	26,5	2641	37114	14,1	2593	27263	10,5	20,8
Donets'ka	2639	2372	62806	26,5	2366	32971	13,9	2350	24480	10,4	15,5
Luhans'ka	2655	2129	53383	25,1	2189	29006	13,3	2195	21526	9,8	13,9
Kharkivs'ka	3129	2580	72709	28,2	2546	38091	15,0	2499	27029	10,8	19,8
Central											
Vinnyts'ka	2637	2170	78040	36,0	2158	40011	18,5	2106	25669	12,2	24,1
Cherkas'ka	2084	1513	51143	33,8	1507	26297	17,4	1461	17446	11,9	24,1
Poltavs'ka	2858	2145	62400	29,1	1761	28126	16,0	1597	18194	11,4	21,7
Kirovohrads'ka	2447	2199	65486	29,8	2133	33846	15,9	2127	24177	11,4	17,2
Northern											
Sums'ka	2370	1751	58674	33,5	1643	28737	17,5	1547	18371	11,9	19,2
Chernihivs'ka	3174	2019	64349	31,9	1391	22497	16,2	941	10737	11,4	22,1
Kyivs'ka	2880	1802	58274	32,3	1233	20537	16,7	988	11469	11,6	25,8
Zhytomyrs'ka	2968	1438	49000	34,1	1106	19246	17,4	914	10720	11,7	23,2
Volyns'ka	2003	933	27851	29,9	668	10960	16,4	562	6154	11,0	24,1
Rivnens'ka	1994	901	29246	32,5	704	12263	17,4	611	7040	11,5	25,8
Western											
Ivano-Frankivs'ka	1387	617	21086	34,2	442	7269	16,4	378	3926	10,4	29,6
Zakarpats'ka	1271	347	12086	34,8	311	4623	14,9	191	1743	9,1	0,0
L'vivs'ka	2172	1159	38480	33,2	836	13343	16,0	670	6789	10,1	27,9
Ternopil's'ka	1375	1051	38463	36,6	1066	19451	18,2	1066	12400	11,6	26,2
Khmel'nyts'ka	2054	1395	49206	35,3	1369	24823	18,1	1346	16337	12,1	23,1
Chernivets'ka	805	460	15783	34,3	391	6914	17,7	366	4343	11,9	26,6
Ukraine	**59822**	**39784**	**1190086**	**29,9**	**36778**	**571109**	**15,5**	**35234**	**387046**	**11,0**	**22,6**

[a] VS = very suitable; S = suitable; MS – moderately suitable
[b] Actual yield is average yield calculated on the basis of reported actual yields by State Statistic Committee of Ukraine for the period 1981-2000 by oblast

Table 5. Extents of suitable land, production potential and attainable yields of rain-fed potato by oblast under high, intermediate and low levels of input and management

Oblast	Total Area (10^3 ha)	High Input Level VS+S+MS[a]			Intermediate Input Level VS+S+MS			Low Input Level VS+S+MS			Actual Yield[b] (t/ha)
		Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	
Southern and Eastern											
AR Krym	2641	441	6691	15,2	613	6167	10,1	391	2302	5,9	10,9
Odes'ka	3321	2522	55422	22,0	2472	38105	15,4	2527	22833	9,0	7,6
Mykolaivs'ka	2385	2036	43531	21,4	2018	30098	14,9	2033	17731	8,7	7,9
Khersons'ka	2682	1156	20829	18,0	1076	13127	12,2	1328	8593	6,5	9,1
Zaporiz'ka	2718	1864	36847	19,8	2070	26658	12,9	2241	15011	6,7	6,9
Dnipropetrovs'ka	3173	2724	55553	20,4	2661	37218	14,0	2609	19593	7,5	8,6
Donets'ka	2639	2376	48738	20,5	2361	32669	13,8	2361	17367	7,4	8,9
Luhans'ka	2655	2241	42844	19,1	2300	29815	13,0	2276	15993	7,0	6,1
Kharkivs'ka	3129	2633	58622	22,3	2594	39218	15,1	2560	20291	7,9	9,6
Central											
Vinnyts'ka	2637	2172	62615	28,8	2160	41931	19,4	2156	21895	10,2	11,8
Cherkas'ka	2084	1548	40749	26,3	1532	27360	17,9	1522	14949	9,8	11,3
Poltavs'ka	2858	2196	49116	22,4	1766	27891	15,8	1540	13567	8,8	9,5
Kirovohrads'ka	2447	2203	52047	23,6	2137	35335	16,5	2133	20247	9,5	7,4
Northern											
Sums'ka	2370	1779	45753	25,7	1637	28000	17,1	1547	13513	8,7	11,9
Chernihivs'ka	3174	2034	52255	25,7	1430	23411	16,4	942	8149	8,7	14,2
Kyivs'ka	2880	1815	46691	25,7	1235	20913	16,9	1012	9651	9,5	13,4
Zhytomyrs'ka	2968	1438	40022	27,8	1163	20589	17,7	1015	9138	9,0	12,2
Volyns'ka	2003	933	24684	26,5	719	12575	17,5	658	5229	7,9	14,2
Rivnens'ka	1994	901	24542	27,2	766	13335	17,4	673	5629	8,4	12,2
Western											
Ivano-Frankivs'ka	1387	620	16084	25,9	444	7200	16,2	382	3240	8,5	12,8
Zakarpats'ka	1271	348	10771	31,0	310	4898	15,8	190	1404	7,4	12,0
L'vivs'ka	2172	1164	30171	25,9	845	13345	15,8	717	5564	7,8	13,2
Ternopil's'ka	1375	1052	29465	28,0	1065	19200	18,0	1062	9724	9,2	13,3
Khmel'nyts'ka	2054	1396	40247	28,8	1378	26742	19,4	1360	13825	10,2	12,7
Chernivets'ka	805	461	12935	28,1	391	7404	18,9	366	3575	9,8	13,6
Ukraine	**59822**	**40053**	**947225**	**23,6**	**37143**	**583204**	**15,7**	**35601**	**299015**	**8,4**	**11,5**

[a] VS = very suitable; S = suitable; MS – moderately suitable
[b] Actual yield is average yield calculated on the basis of reported actual yields by State Statistic Committee of Ukraine for the period 1981-2000 by oblast

Table 6. Extents of suitable land, production potential and attainable yields of rain-fed spring rape by oblast under high, intermediate and low levels of input and management

Oblast	Total Area (10^3 ha)	High Input Level VS+S+MS[a]			Intermediate Input Level VS+S+MS			Low Input Level VS+S+MS			Actual Yield[b] (t/ha)
		Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	
Southern and Eastern											
AR Krym	2641	974	1644	1,7	857	1033	1,2	869	572	0,7	1,0
Odes'ka	3321	2647	6326	2,4	2704	4522	1,7	2706	2460	0,9	0,9
Mykolaivs'ka	2385	2167	5168	2,4	2177	3634	1,7	2175	1999	0,9	0,7
Khersons'ka	2682	1587	3140	2,0	1756	2386	1,4	1774	1312	0,7	0,8
Zaporiz'ka	2718	2362	5377	2,3	2344	3760	1,6	2345	2039	0,9	0,7
Dnipropetrovs'ka	3173	2722	6730	2,5	2672	4654	1,7	2627	2473	0,9	0,8
Donets'ka	2639	2376	5973	2,5	2359	4182	1,8	2358	2260	1,0	0,6
Luhans'ka	2655	2234	5391	2,4	2248	3803	1,7	2253	2074	0,9	0,6
Kharkivs'ka	3129	2653	6965	2,6	2641	4864	1,8	2612	2561	1,0	0,6
Central											
Vinnyts'ka	2637	2172	6764	3,1	2200	4685	2,1	2201	2206	1,0	1,1
Cherkas'ka	2084	1589	4690	3,0	1598	3244	2,0	1591	1605	1,0	0,9
Poltavs'ka	2858	2183	5701	2,6	1845	3463	1,9	1647	1623	1,0	0,8
Kirovohrads'ka	2447	2200	6060	2,8	2207	4236	1,9	2203	2237	1,0	0,5
Northern											
Sums'ka	2370	1780	5227	2,9	1707	3441	2,0	1623	1628	1,0	0,9
Chernihivs'ka	3174	2123	5940	2,8	1797	3256	1,8	1328	1230	0,9	0,8
Kyivs'ka	2880	1839	5296	2,9	1700	3227	1,9	1475	1405	1,0	1,1
Zhytomyrs'ka	2968	1762	5004	2,8	1631	3035	1,9	1321	1210	0,9	0,7
Volyns'ka	2003	1003	2629	2,6	946	1682	1,8	816	682	0,8	1,1
Rivnens'ka	1994	968	2704	2,8	884	1693	1,9	784	716	0,9	1,0
Western											
Ivano-Frankivs'ka	1387	618	1727	2,8	561	966	1,7	516	414	0,8	1,6
Zakarpats'ka	1271	347	994	2,9	410	670	1,6	289	221	0,8	1,3
L'vivs'ka	2172	1215	3349	2,8	1116	1921	1,7	970	780	0,8	1,3
Ternopil's'ka	1375	1051	3178	3,0	1080	2195	2,0	1080	1038	1,0	1,1
Khmel'nyts'ka	2054	1422	4253	3,0	1426	2891	2,0	1389	1349	1,0	1,0
Chernivets'ka	805	461	1345	2,9	442	840	1,9	421	379	0,9	1,1
Ukraine	**59822**	**42455**	**111575**	**2,6**	**41308**	**74283**	**1,8**	**39373**	**36473**	**0,9**	**1,0**

[a] VS = very suitable; S = suitable; MS – moderately suitable
[b] Actual yield is average yield calculated on the basis of reported actual yields by State Statistic Committee of Ukraine for the period 1981-2000 by oblast

Table 7. Extents of suitable land, production potential and attainable yields of rain-fed winter rape by oblast under high, intermediate and low levels of input and management

Oblast	Total Area (10^3 ha)	High Input Level VS+S+MS[a]			Intermediate Input Level VS+S+MS			Low Input Level VS+S+MS		
		Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)
Southern and Eastern										
AR Krym	2641	1015	1957	1,9	858	1111	1,3	903	639	0,7
Odes'ka	3321	2711	7285	2,7	2719	4785	1,8	2708	2578	1,0
Mykolaivs'ka	2385	2176	5890	2,7	2178	3910	1,8	2179	2098	1,0
Khersons'ka	2682	1839	4036	2,2	1774	2587	1,5	1775	1421	0,8
Zaporiz'ka	2718	2362	6237	2,6	2344	4072	1,7	2344	2209	0,9
Dnipropetrovs'ka	3173	2723	7701	2,8	2673	4965	1,9	2628	2619	1,0
Donets'ka	2639	2376	6848	2,9	2360	4465	1,9	2360	2372	1,0
Luhans'ka	2655	2233	6069	2,7	2249	4001	1,8	2261	2156	1,0
Kharkivs'ka	3129	2662	7778	2,9	2661	5068	1,9	2614	2620	1,0
Central										
Vinnyts'ka	2637	2172	7139	3,3	2200	4590	2,1	2201	2197	1,0
Cherkas'ka	2084	1591	5076	3,2	1599	3264	2,0	1591	1634	1,0
Poltavs'ka	2858	2206	6341	2,9	1859	3538	1,9	1647	1657	1,0
Kirovohrads'ka	2447	2200	6772	3,1	2207	4404	2,0	2203	2306	1,0
Northern										
Sums'ka	2370	1783	5542	3,1	1708	3388	2,0	1623	1622	1,0
Chernihivs'ka	3174	2123	6306	3,0	1797	3211	1,8	1328	1228	0,9
Kyivs'ka	2880	1839	5561	3,0	1700	3143	1,8	1475	1394	0,9
Zhytomyrs'ka	2968	1762	5122	2,9	1631	2886	1,8	1321	1160	0,9
Volyns'ka	2003	1001	2657	2,7	945	1574	1,7	759	614	0,8
Rivnens'ka	1994	968	2753	2,8	884	1600	1,8	784	685	0,9
Western										
Ivano-Frankivs'ka	1387	609	1747	2,9	540	872	1,6	495	376	0,8
Zakarpats'ka	1271	339	1004	3,0	380	594	1,6	261	188	0,7
L'vivs'ka	2172	1176	3304	2,8	1026	1670	1,6	827	649	0,8
Ternopil's'ka	1375	1051	3259	3,1	1079	2091	1,9	1078	990	0,9
Khmel'nyts'ka	2054	1422	4409	3,1	1426	2789	2,0	1389	1321	1,0
Chernivets'ka	805	458	1389	3,0	430	793	1,8	417	360	0,9
Ukraine	**59822**	**42797**	**122182**	**2,9**	**41227**	**75371**	**1,8**	**39171**	**37093**	**0,9**

[a] VS = very suitable; S = suitable; MS – moderately suitable

Table 8. Extents of suitable land, production potential and attainable yields of rain-fed soybean by oblast under high, intermediate and low levels of input and management

Oblast	Total Area (10^3 ha)	High Input Level VS+S+MS[a]			Intermediate Input Level VS+S+MS			Low Input Level VS+S+MS			Actual Yield[b] (t/ha)
		Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	
Southern and Eastern											
AR Krym	2641	509	903	1,8	70	86	1,2	687	396	0,6	1,6
Odes'ka	3321	2695	6398	2,4	2511	3233	1,3	2693	2185	0,8	0,9
Mykolaivs'ka	2385	2165	4813	2,2	1539	1964	1,3	2172	1613	0,7	0,8
Khersons'ka	2682	1389	2781	2,0	748	906	1,2	1680	1104	0,7	1,3
Zaporiz'ka	2718	2362	5610	2,4	2153	2769	1,3	2345	1852	0,8	1,0
Dnipropetrovs'ka	3173	2722	6568	2,4	2491	3249	1,3	2633	2117	0,8	0,9
Donets'ka	2639	2350	5718	2,4	2264	2951	1,3	2356	1913	0,8	0,8
Luhans'ka	2655	2103	4676	2,2	1961	2344	1,2	2246	1631	0,7	0,6
Kharkivs'ka	3129	2274	5002	2,2	1970	2371	1,2	2339	1677	0,7	1,0
Central											
Vinnyts'ka	2637	623	1636	2,6	575	825	1,4	619	489	0,8	0,8
Cherkas'ka	2084	252	478	1,9	173	184	1,1	287	167	0,6	1,0
Poltavs'ka	2858	1573	3303	2,1	953	1145	1,2	1199	833	0,7	1,1
Kirovohrads'ka	2447	1555	3167	2,0	1258	1417	1,1	1779	1160	0,7	0,6
Northern											
Sums'ka	2370	83	161	1,9	72	75	1,0	88	55	0,6	1,0
Chernihivs'ka	3174	0	0	0,0	0	0	0,0	0	0	0,0	1,0
Kyivs'ka	2880	93	162	1,7	10	10	1,0	40	20	0,5	0,9
Zhytomyrs'ka	2968	0	0	0,0	0	0	0,0	0	0	0,0	1,2
Volyns'ka	2003	0	0	0,0	0	0	0,0	0	0	0,0	1,0
Rivnens'ka	1994	0	0	0,0	0	0	0,0	0	0	0,0	1,4
Western											
Ivano-Frankivs'ka	1387	0	0	0,0	0	0	0,0	0	0	0,0	0,8
Zakarpats'ka	1271	152	315	2,1	0	0	0,0	10	5	0,5	1,1
L'vivs'ka	2172	0	0	0,0	0	0	0,0	0	0	0,0	1,2
Ternopil's'ka	1375	0	0	0,0	0	0	0,0	0	0	0,0	0,8
Khmel'nyts'ka	2054	18	42	2,3	16	20	1,3	12	8	0,7	0,8
Chernivets'ka	805	99	226	2,3	81	103	1,3	77	50	0,6	1,3
Ukraine	**59822**	**23017**	**51959**	**2,3**	**18845**	**23652**	**1,3**	**23262**	**17275**	**0,7**	**1,1**

[a] VS = very suitable; S = suitable; MS – moderately suitable
[b] Actual yield is average yield calculated on the basis of reported actual yields by State Statistic Committee of Ukraine for the period 1981-2000 by oblast

Table 9. Extents of suitable land, production potential and attainable yields of rain-fed flax by oblast under high, intermediate and low levels of input and management

Oblast	Total Area (10^3 ha)	High Input Level VS+S+MS[a]			Intermediate Input Level VS+S+MS			Low Input Level VS+S+MS			Actual Yield[b] (t/ha)
		Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	
Southern and Eastern											
AR Krym	2641	1212	610	0,5	1047	290	0,3	1027	159	0,2	0,0
Odes'ka	3321	2728	1712	0,6	2767	923	0,3	2719	512	0,2	0,0
Mykolaivs'ka	2385	2164	1229	0,6	2168	640	0,3	2167	345	0,2	0,0
Khersons'ka	2682	1820	888	0,5	1868	483	0,3	1755	257	0,1	0,0
Zaporiz'ka	2718	2221	1183	0,5	2222	605	0,3	2220	320	0,1	0,0
Dnipropetrovs'ka	3173	2730	1544	0,6	2676	789	0,3	2606	417	0,2	0,0
Donets'ka	2639	2272	1276	0,6	2280	660	0,3	2250	349	0,2	0,0
Luhans'ka	2655	2206	1213	0,5	2267	639	0,3	2217	345	0,2	0,0
Kharkivs'ka	3129	2634	1613	0,6	2621	865	0,3	2557	475	0,2	0,0
Central											
Vinnyts'ka	2637	2171	2111	1,0	2199	1351	0,6	2197	808	0,4	0,0
Cherkas'ka	2084	1596	1500	0,9	1599	951	0,6	1590	595	0,4	0,0
Poltavs'ka	2858	2291	1626	0,7	1967	834	0,4	1710	461	0,3	0,0
Kirovohrads'ka	2447	2203	1629	0,7	2209	948	0,4	2207	574	0,3	0,0
Northern											
Sums'ka	2370	1782	1608	0,9	1726	925	0,5	1623	543	0,3	0,6
Chernihivs'ka	3174	2123	1811	0,9	1845	893	0,5	1367	417	0,3	0,6
Kyivs'ka	2880	1838	1745	0,9	1748	1055	0,6	1478	587	0,4	0,4
Zhytomyrs'ka	2968	1761	1705	1,0	1643	1017	0,6	1319	523	0,4	0,5
Volyns'ka	2003	1004	866	0,9	954	517	0,5	816	268	0,3	0,5
Rivnens'ka	1994	967	916	0,9	893	551	0,6	784	302	0,4	0,5
Western											
Ivano-Frankivs'ka	1387	605	614	1,0	541	322	0,6	494	190	0,4	0,5
Zakarpats'ka	1271	343	351	1,0	397	213	0,5	286	94	0,3	0,0
L'vivs'ka	2172	1211	1163	1,0	1089	622	0,6	933	340	0,4	0,5
Ternopil's'ka	1375	1053	1061	1,0	1082	644	0,6	1081	393	0,4	0,1
Khmel'nyts'ka	2054	1422	1509	1,1	1424	967	0,7	1389	586	0,4	0,4
Chernivets'ka	805	458	430	0,9	434	240	0,6	422	139	0,3	0,5
Ukraine	**59822**	**42815**	**31913**	**0,7**	**41666**	**17944**	**0,4**	**39214**	**9999**	**0,3**	**0,5**

[a] VS = very suitable; S = suitable; MS – moderately suitable

[b] Actual yield is average yield calculated on the basis of reported actual yields by State Statistic Committee of Ukraine for the period 1981-2000 by oblast

Table 10. Extents of suitable land, production potential and attainable yields of rain-fed tomato by oblast under high, intermediate and low levels of input and management

Oblast	Total Area (10^3 ha)	High Input Level VS+S+MS[a]			Intermediate Input Level VS+S+MS			Low Input Level VS+S+MS			Actual Yield[b] (t/ha)
		Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	
Southern and Eastern											
AR Krym	2641	96	1747	18,2	107	1300	12,1	284	2300	8,1	17,3
Odes'ka	3321	2194	47940	21,9	2385	35547	14,9	2646	27820	10,5	14,1
Mykolaivs'ka	2385	1814	36687	20,2	1824	25653	14,1	2174	20087	9,2	12,7
Khersons'ka	2682	851	14280	16,8	826	9773	11,8	1098	9000	8,2	18,0
Zaporiz'ka	2718	1693	34333	20,3	1766	24693	14,0	2128	20347	9,6	13,2
Dnipropetrovs'ka	3173	2572	52567	20,4	2602	36880	14,2	2559	25000	9,8	15,2
Donets'ka	2639	2303	47860	20,8	2371	34073	14,4	2350	23900	10,2	16,1
Luhans'ka	2655	2008	38647	19,2	2034	27080	13,3	2220	20267	9,1	13,7
Kharkivs'ka	3129	2592	52587	20,3	2612	35853	13,7	2600	24887	9,6	9,8
Central											
Vinnyts'ka	2637	2133	48353	22,7	2155	32360	15,0	2174	21820	10,0	9,3
Cherkas'ka	2084	1545	35053	22,7	1551	23673	15,3	1589	16433	10,3	16,8
Poltavs'ka	2858	2230	46067	20,7	1928	27480	14,3	1696	16973	10,0	11,8
Kirovohrads'ka	2447	2156	47213	21,9	2203	32833	14,9	2202	22733	10,3	10,0
Northern											
Sums'ka	2370	1718	36207	21,1	1626	21400	13,2	1459	13267	9,1	10,3
Chernihivs'ka	3174	1934	39233	20,3	1580	19447	12,3	1057	9147	8,7	10,3
Kyivs'ka	2880	1799	39900	22,2	1557	22647	14,5	1374	13787	10,0	13,4
Zhytomyrs'ka	2968	1551	31827	20,5	1270	15747	12,4	878	7367	8,4	8,1
Volyns'ka	2003	689	11393	16,5	698	6727	9,6	407	2413	5,9	7,6
Rivnens'ka	1994	769	14633	19,0	680	7833	11,5	505	3853	7,6	5,4
Western											
Ivano-Frankivs'ka	1387	532	10673	20,1	391	4820	12,3	354	2700	7,6	8,8
Zakarpats'ka	1271	306	7053	23,1	271	3913	14,4	200	1653	8,3	16,0
L'vivs'ka	2172	977	18173	18,6	833	8727	10,5	591	3480	5,9	9,2
Ternopil's'ka	1375	1011	21067	20,8	993	13067	13,2	1034	8387	8,1	7,8
Khmel'nyts'ka	2054	1369	31847	23,3	1361	21187	15,6	1335	13813	10,3	7,6
Chernivets'ka	805	447	10167	22,7	393	6047	15,4	371	3853	10,4	13,1
Ukraine	**59822**	**37289**	**775513**	**20,8**	**36017**	**498767**	**13,8**	**35285**	**335287**	**9,5**	**13,6**

[a] VS = very suitable; S = suitable; MS – moderately suitable
[b] Actual yield is average yield calculated on the basis of reported actual yields by State Statistic Committee of Ukraine for the period 1981-2000 by oblast

Table 11. Extents of suitable land, production potential and attainable yields of rain-fed onion by oblast under high, intermediate and low levels of input and management

Oblast	Total Area (10^3 ha)	High Input Level			Intermediate Input Level			Low Input Level			Actual Yield[b] (t/ha)
		VS+S+MS[a]			VS+S+MS			VS+S+MS			
		Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	
Southern and Eastern											
AR Krym	2641	84	51562	19,5	120	28611	10,8	411	17392	6,6	11,4
Odes'ka	3321	2177	75258	22,7	2341	45226	13,6	2599	31383	9,4	8,0
Mykolaivs'ka	2385	1995	50187	21,0	2024	30661	12,9	2026	21684	9,1	14,1
Khersons'ka	2682	804	50771	18,9	841	30828	11,5	1119	20756	7,7	10,7
Zaporiz'ka	2718	1717	59014	21,7	1789	35318	13,0	2156	23659	8,7	10,0
Dnipropetrovs'ka	3173	2664	68725	21,7	2659	42044	13,3	2610	29898	9,4	9,5
Donets'ka	2639	2368	57513	21,8	2352	34805	13,2	2352	24722	9,4	16,0
Luhans'ka	2655	2089	55862	21,0	2181	33793	12,7	2230	23867	9,0	9,8
Kharkivs'ka	3129	2641	69499	22,2	2596	42532	13,6	2560	29921	9,6	9,8
Central											
Vinnyts'ka	2637	2169	69177	26,2	2157	41297	15,7	2114	27493	10,4	6,1
Cherkas'ka	2084	1528	54610	26,2	1518	32647	15,7	1486	22046	10,6	9,0
Poltavs'ka	2858	2226	66772	23,4	1802	41871	14,7	1548	29491	10,3	6,7
Kirovohrads'ka	2447	2200	59069	24,1	2134	36220	14,8	2127	25195	10,3	6,9
Northern											
Sums'ka	2370	1775	59435	25,1	1668	35995	15,2	1555	24538	10,4	8,6
Chernihivs'ka	3174	2044	74340	23,4	1587	44093	13,9	992	30673	9,7	7,5
Kyivs'ka	2880	1806	70411	24,4	1319	42825	14,9	1051	29248	10,2	11,3
Zhytomyrs'ka	2968	1762	73689	24,8	1380	44219	14,9	1026	29294	9,9	9,0
Volyns'ka	2003	981	41979	21,0	743	26329	13,1	661	17070	8,5	8,2
Rivnens'ka	1994	967	46808	23,5	780	28598	14,3	667	19053	9,6	5,8
Western											
Ivano-Frankivs'ka	1387	613	35403	25,5	500	20620	14,9	376	13403	9,7	10,5
Zakarpats'ka	1271	341	32750	25,8	269	16915	13,3	185	10626	8,4	6,5
L'vivs'ka	2172	1206	51701	23,8	938	30658	14,1	699	19597	9,0	8,2
Ternopil's'ka	1375	1051	37722	27,4	1065	22034	16,0	1067	14313	10,4	7,9
Khmel'nyts'ka	2054	1423	55168	26,9	1395	32756	15,9	1368	21591	10,5	6,4
Chernivets'ka	805	459	19912	24,7	406	11830	14,7	366	7962	9,9	8,5
Ukraine	**59822**	**39090**	**1399550**	**23,4**	**36564**	**842586**	**14,1**	**35351**	**573643**	**9,6**	**9,8**

[a] VS = very suitable; S = suitable; MS – moderately suitable

[b] Actual yield is average yield calculated on the basis of reported actual yields by State Statistic Committee of Ukraine for the period 1981-2000 by oblast

Table 12. Extents of suitable land, production potential and attainable yields of rain-fed cabbage by oblast under high, intermediate and low levels of input and management

Oblast	Total Area (10^3 ha)	High Input Level VS+S+MS[a]			Intermediate Input Level VS+S+MS			Low Input Level VS+S+MS			Actual Yield[b] (t/ha)
		Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	Suitable Extents (10^3 ha)	Potential Production (10^3 t)	Potential Yield (t/ha)	
Southern and Eastern											
AR Krym	2641	376	9570	25,5	481	8220	17,1	743	7690	10,3	16,7
Odes'ka	3321	2398	91500	38,2	2480	65930	26,6	2620	43210	16,5	12,4
Mykolaivs'ka	2385	1607	68780	42,8	1873	55200	29,5	2166	38750	17,9	12,6
Khersons'ka	2682	936	29540	31,6	954	21460	22,5	1108	15200	13,7	14,0
Zaporiz'ka	2718	1947	56270	28,9	1985	40850	20,6	2073	25670	12,4	14,1
Dnipropetrovs'ka	3173	2615	86480	33,1	2570	59570	23,2	2594	37030	14,3	18,5
Donets'ka	2639	2367	77970	32,9	2378	54430	22,9	2357	32990	14,0	27,1
Luhans'ka	2655	2203	61680	28,0	2223	45440	20,4	2235	27580	12,3	17,9
Kharkivs'ka	3129	2604	95020	36,5	2593	65330	25,2	2593	40360	15,6	19,0
Central											
Vinnyts'ka	2637	2110	99630	47,2	2133	71130	33,3	2155	43470	20,2	16,3
Cherkas'ka	2084	1543	74270	48,1	1550	52990	34,2	1548	32260	20,8	18,1
Poltavs'ka	2858	2206	86900	39,4	1839	52430	28,5	1626	29150	17,9	15,1
Kirovohrads'ka	2447	2138	96740	45,2	2191	70660	32,3	2199	44190	20,1	12,1
Northern											
Sums'ka	2370	1764	76230	43,2	1684	51040	30,3	1558	28970	18,6	20,8
Chernihivs'ka	3174	2032	82990	40,8	1548	43540	28,1	990	17730	17,9	19,1
Kyivs'ka	2880	1659	76110	45,9	1415	46570	32,9	1175	24130	20,5	18,8
Zhytomyrs'ka	2968	1739	76360	43,9	1412	43140	30,6	1007	18590	18,5	18,1
Volyns'ka	2003	1005	40300	40,1	919	26010	28,3	774	12520	16,2	21,0
Rivnens'ka	1994	963	40820	42,4	844	25230	29,9	713	12570	17,6	26,2
Western											
Ivano-Frankivs'ka	1387	611	27750	45,4	496	15460	31,2	383	7160	18,7	18,1
Zakarpats'ka	1271	342	17380	50,8	273	8300	30,4	194	3300	17,0	17,8
L'vivs'ka	2172	1190	51470	43,3	986	29000	29,4	714	12350	17,3	19,5
Ternopil's'ka	1375	1049	51070	48,7	1059	35670	33,7	1065	21150	19,9	16,9
Khmel'nyts'ka	2054	1376	60640	44,1	1356	41960	30,9	1333	24640	18,5	19,4
Chernivets'ka	805	453	19430	42,9	408	12260	30,0	368	6670	18,1	22,1
Ukraine	**59822**	**39233**	**1554910**	**39,6**	**37650**	**1041820**	**27,7**	**36291**	**607330**	**16,7**	**18,2**

[a] VS = very suitable; S = suitable; MS – moderately suitable

[b] Actual yield is average yield calculated on the basis of reported actual yields by State Statistic Committee of Ukraine for the period 1981-2000 by oblast

ANNEX XIII. Suitability and yield maps for major crops

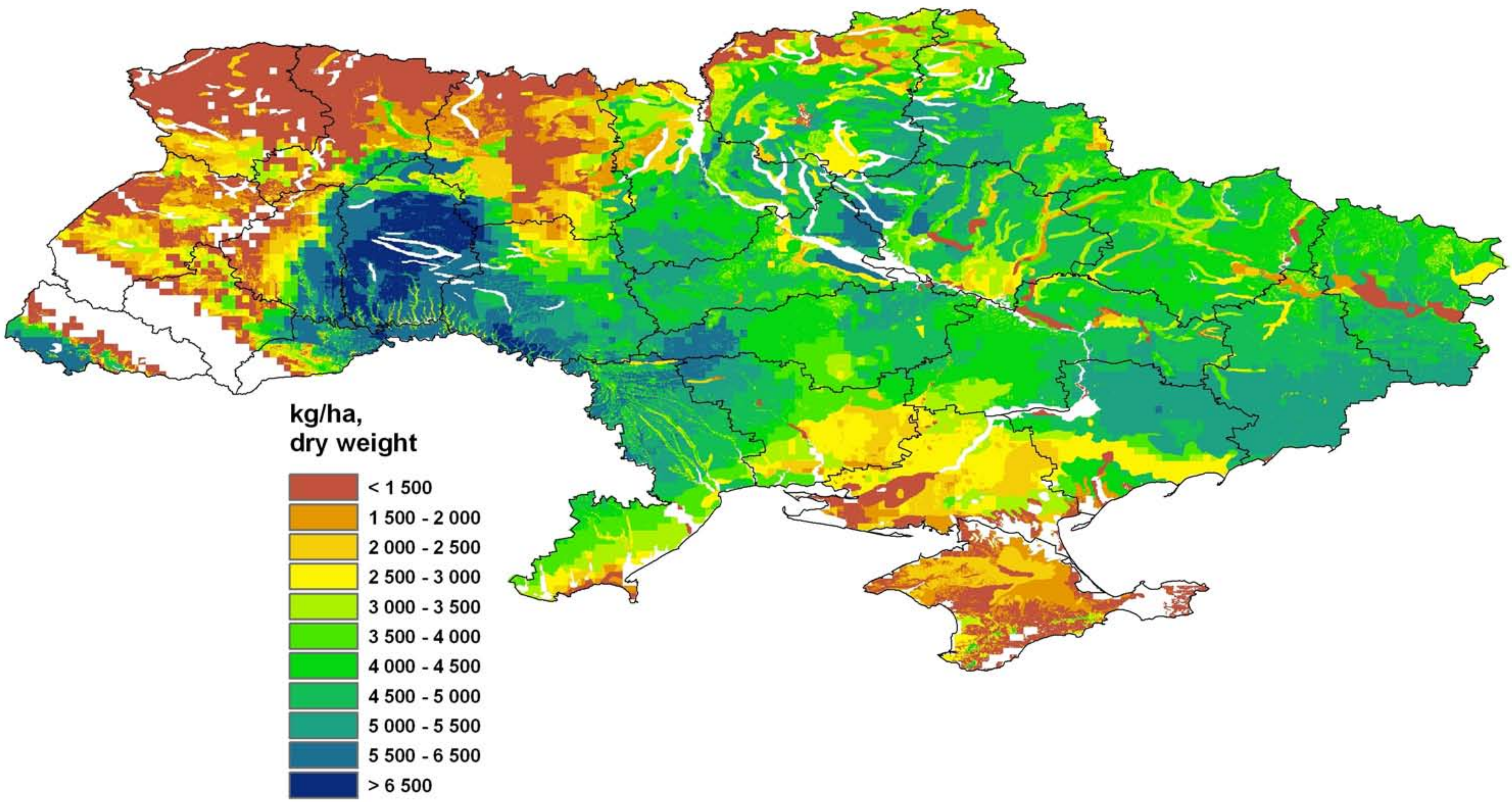


Figure 1a. Average potential yields for rain-fed maize under high level of input and management (1971-2000)

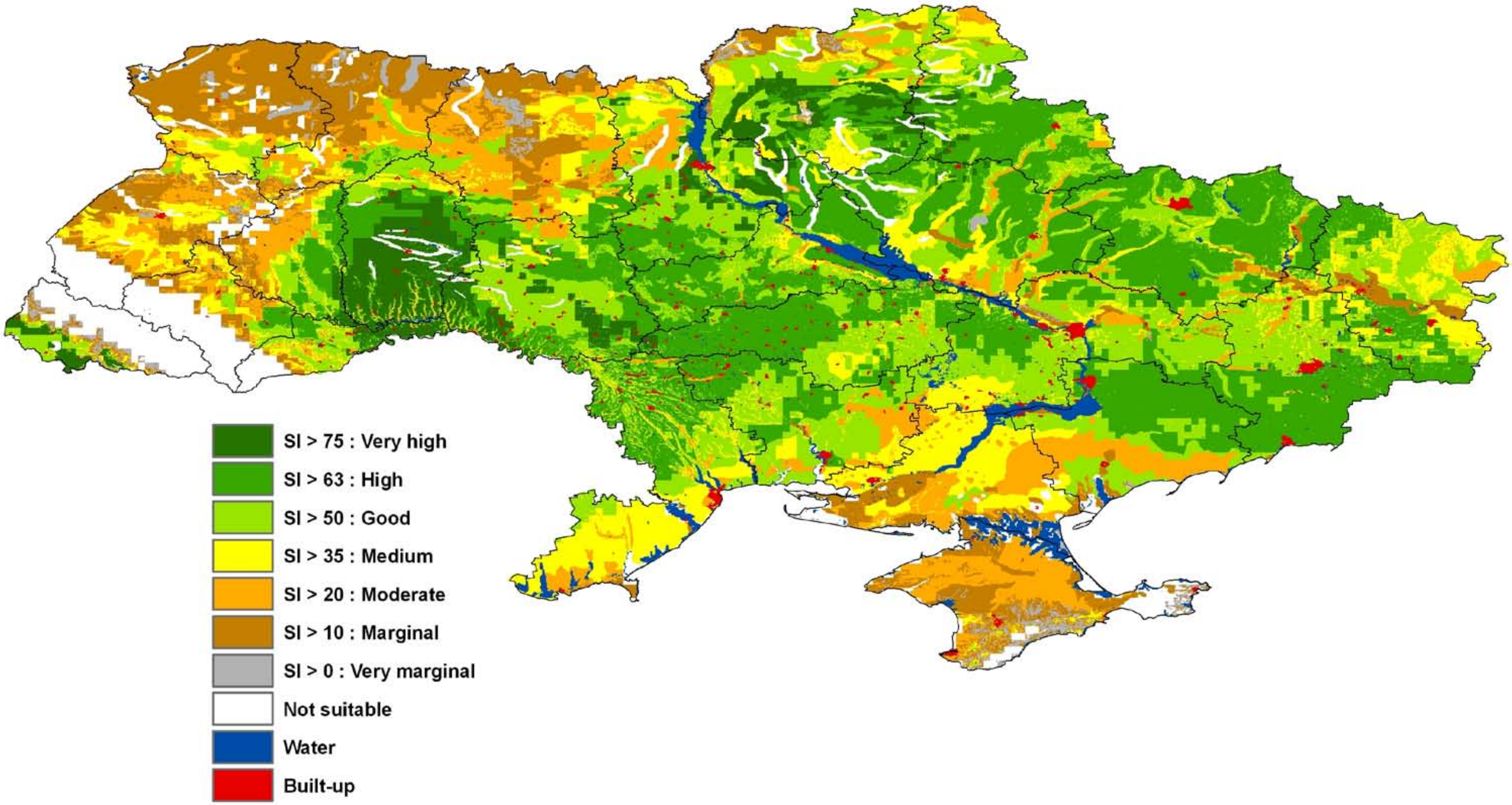


Figure 1b. Suitability for rain-fed maize under high level of input and management (1971-2000)

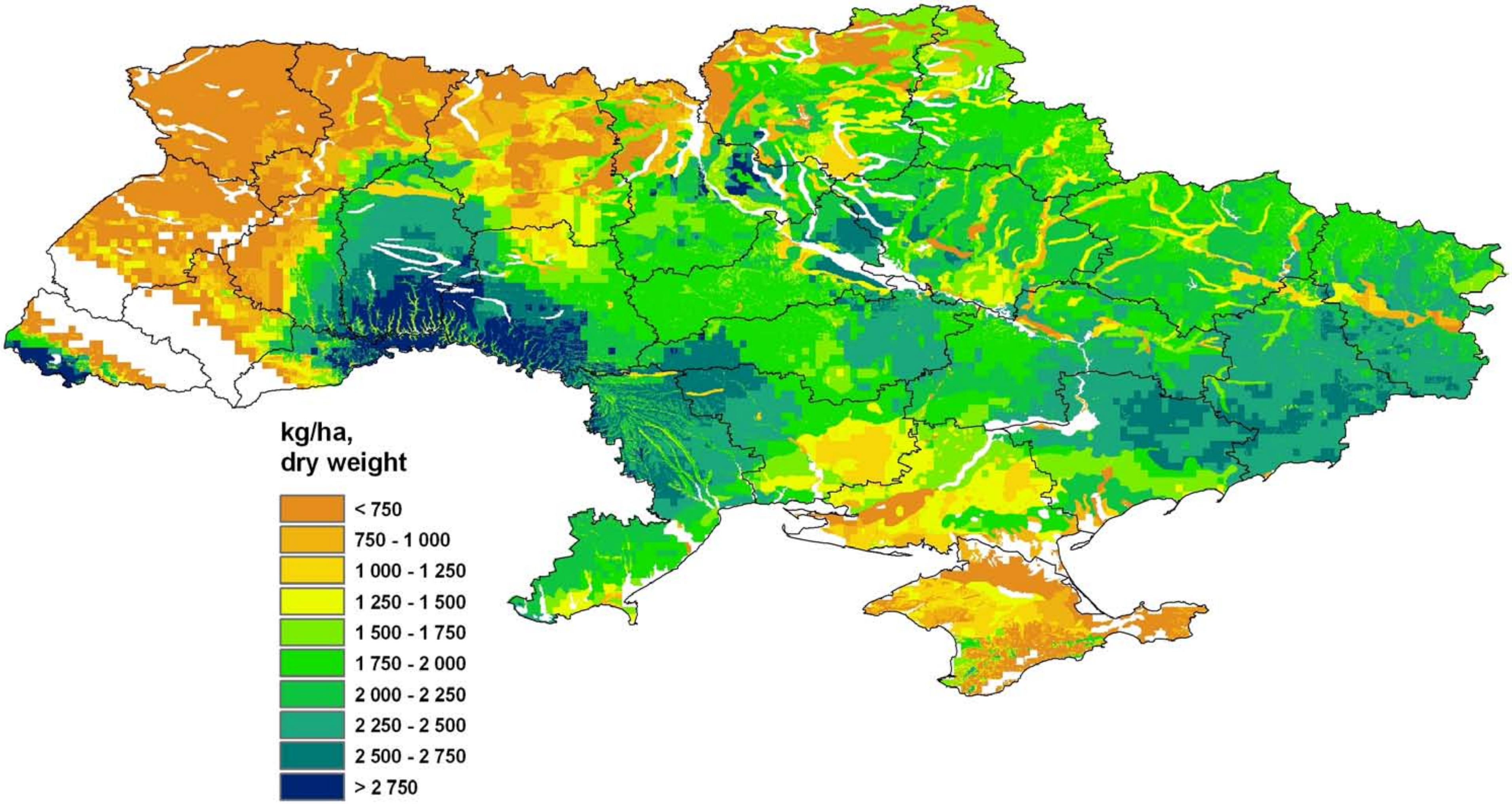


Figure 2a. Average potential yields for rain-fed sunflower under high level of input and management (1971-2000)

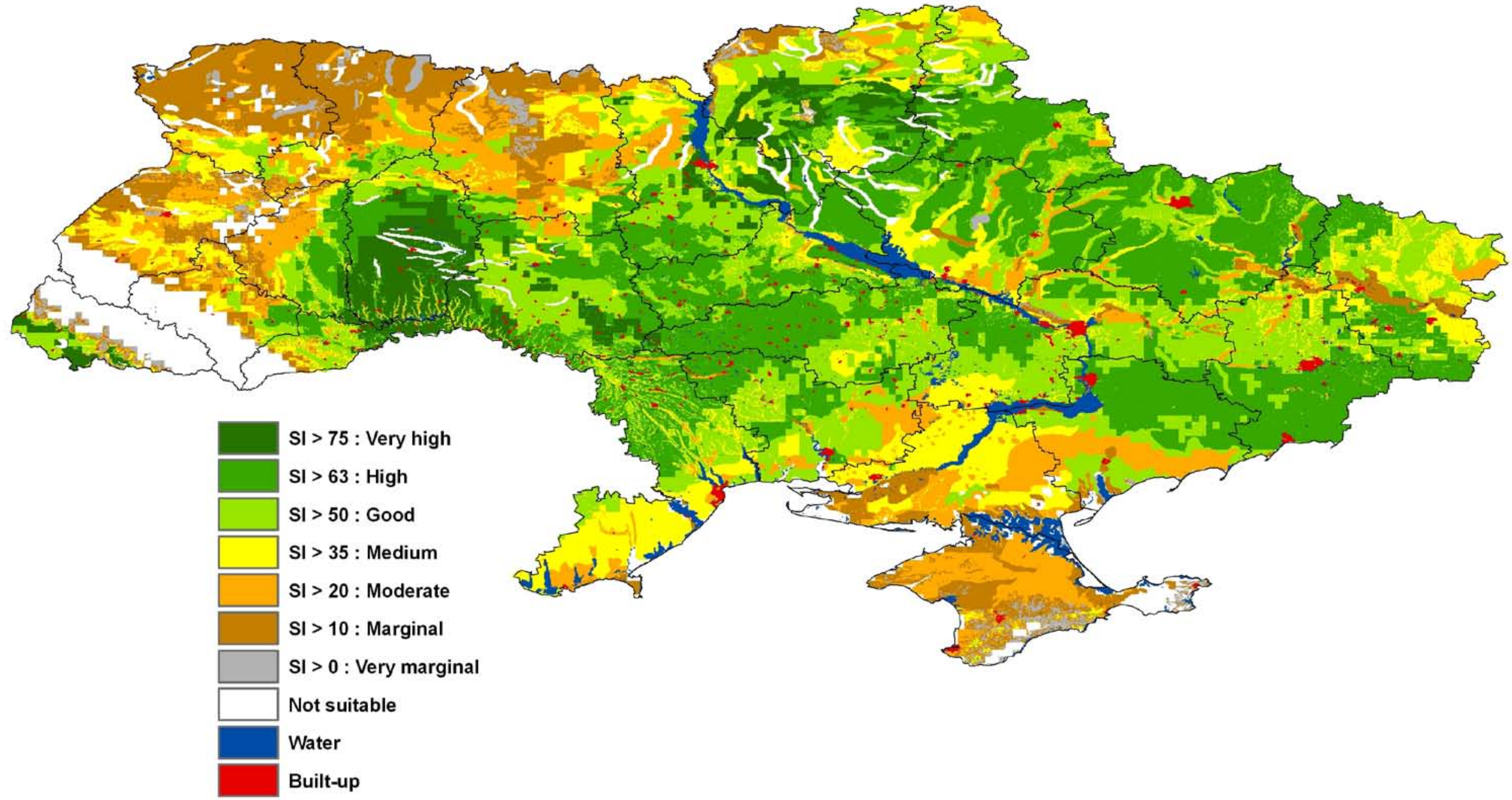


Figure 2b. Suitability for rain-fed sunflower under high level of input and management (1971-2000)

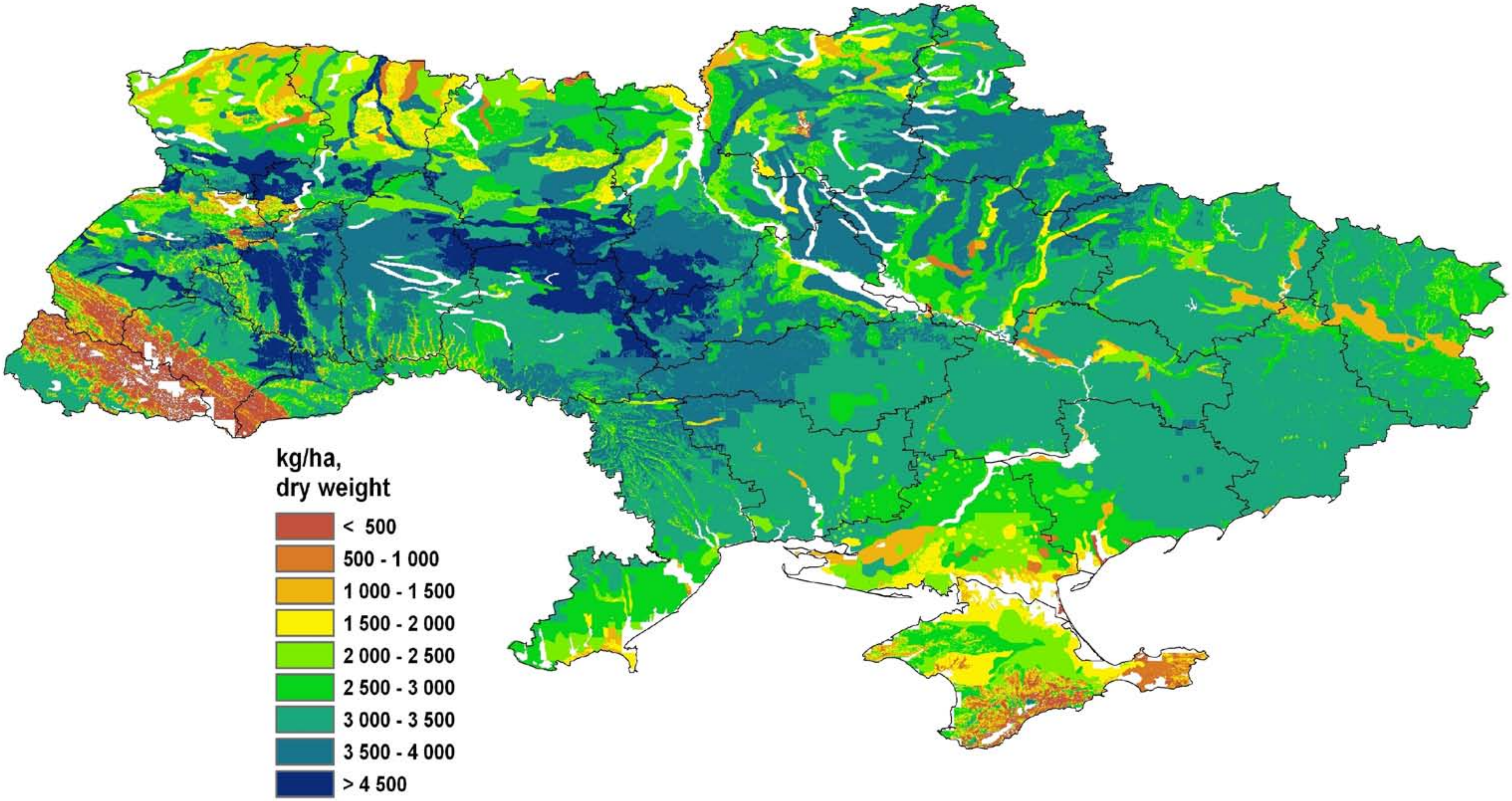


Figure 3a. Average potential yields for rain-fed spring barley under high level of input and management (1971-2000)

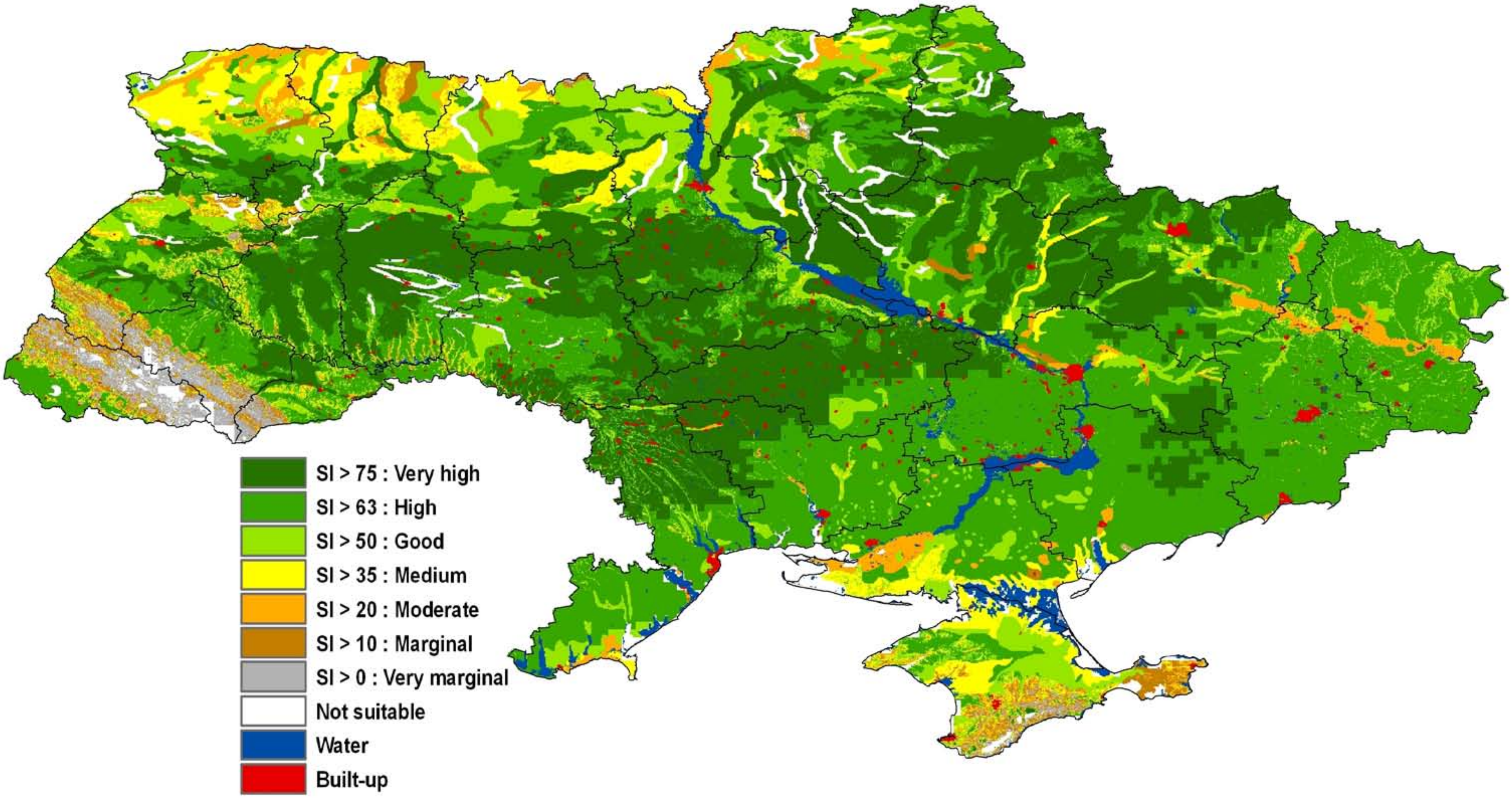


Figure 3b. Suitability for rain-fed spring barley under high level of input and management (1971-2000)

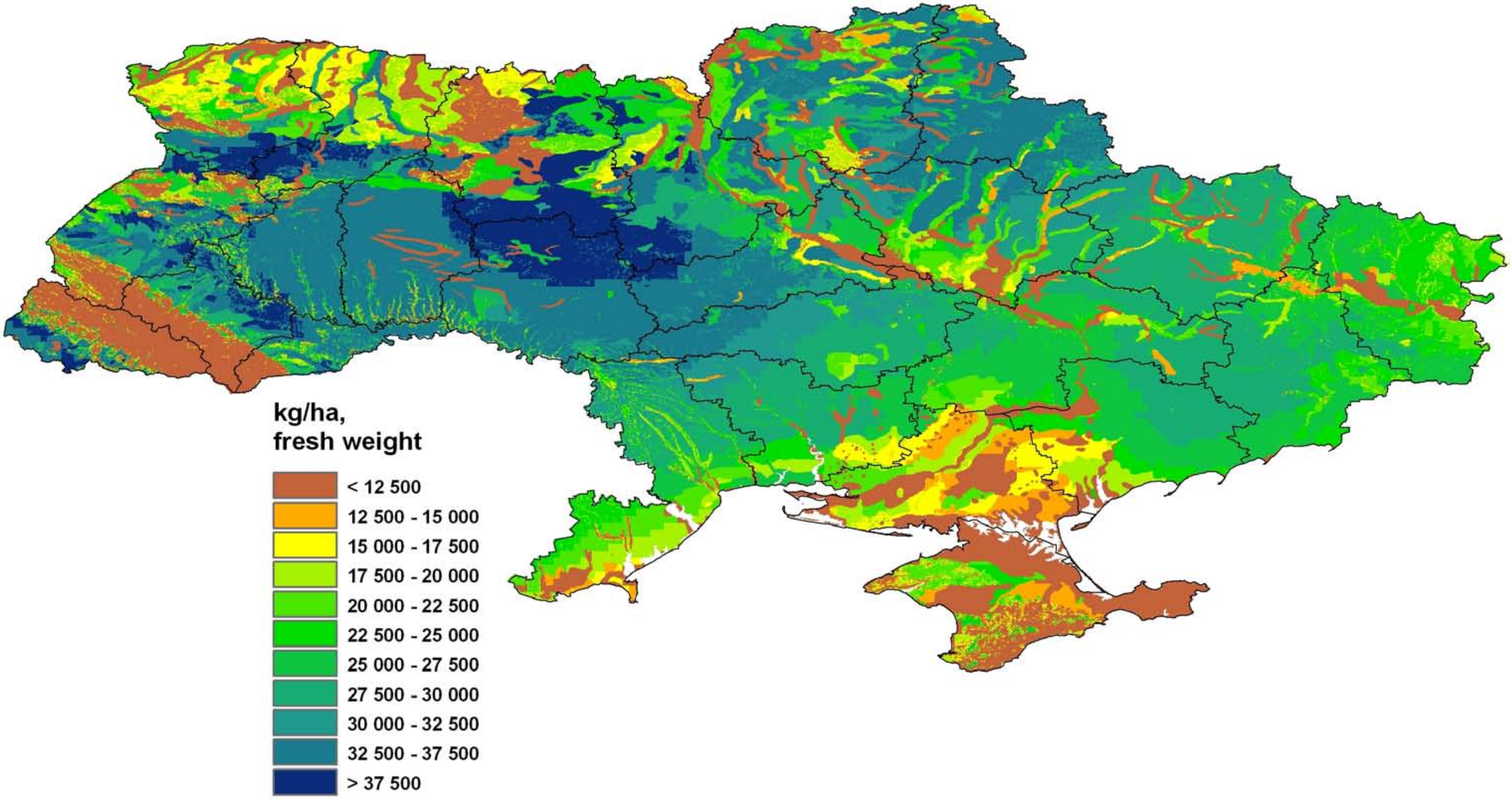


Figure 4a. Average potential yields for rain-fed sugar beet under high level of input and management (1971-2000)

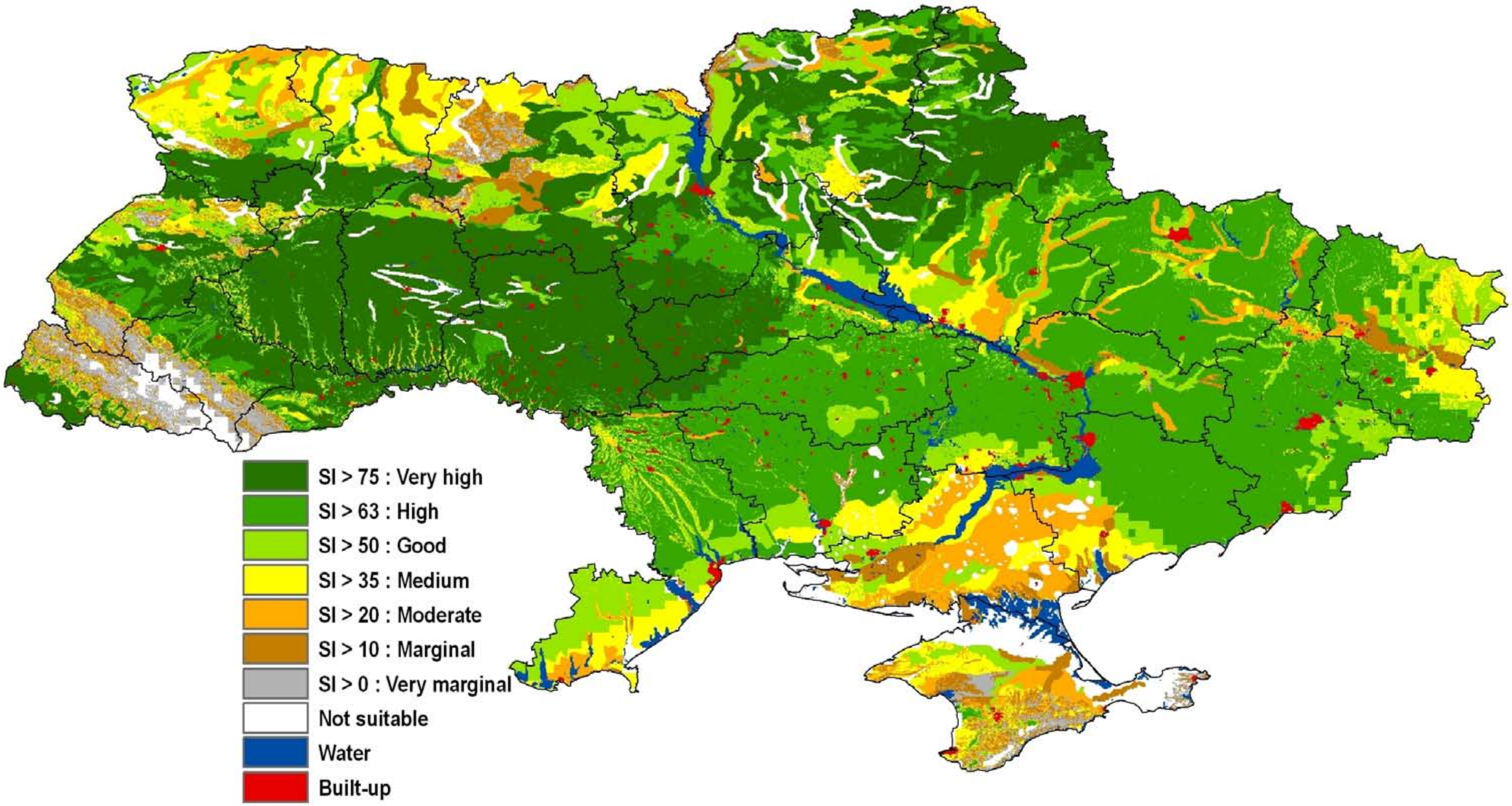


Figure 4b. Suitability for rain-fed sugar beet under high level of input and management (1971-2000)

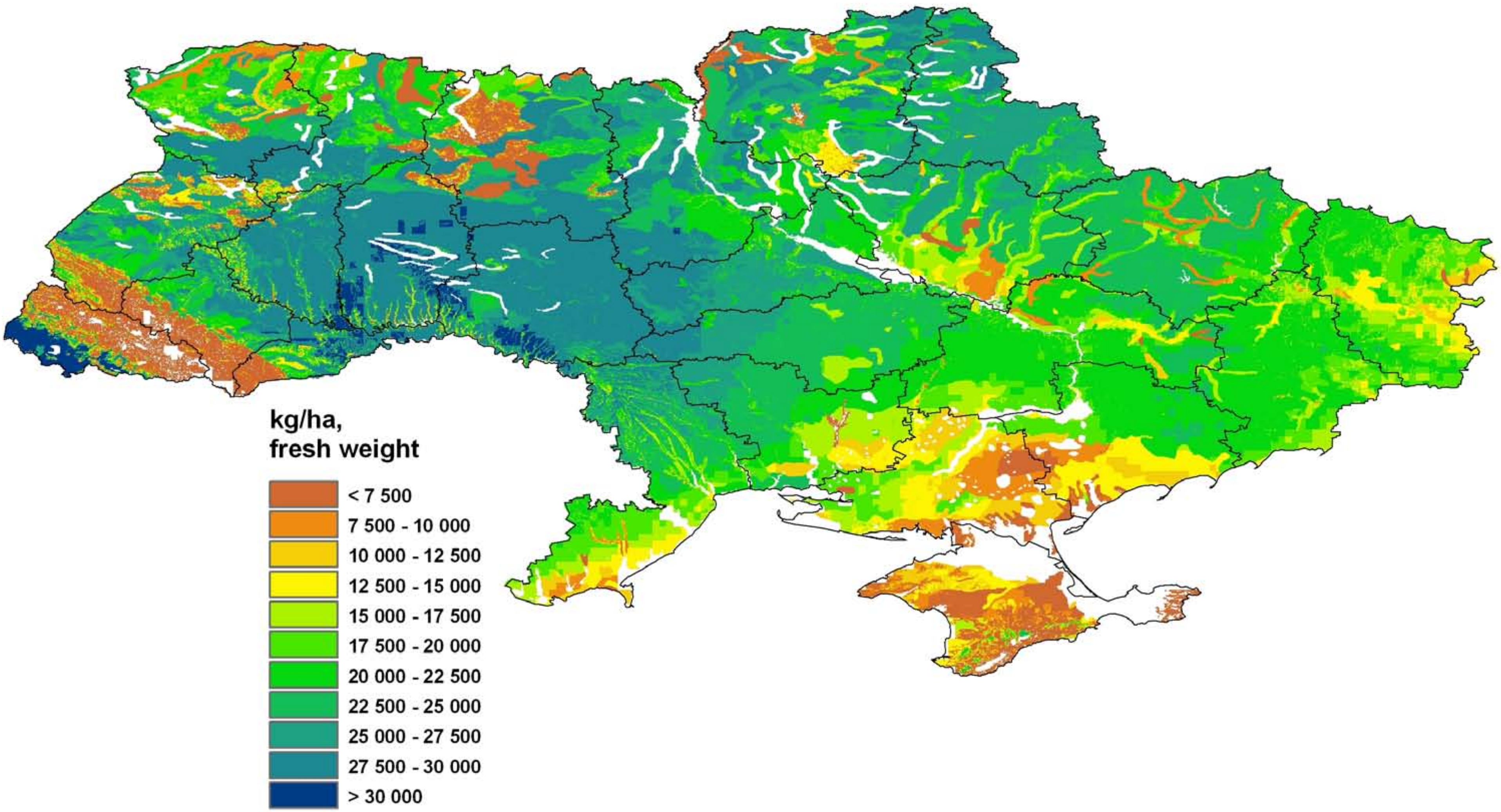


Figure 5a. Average potential yields for rain-fed potato under high level of input and management (1971-2000)

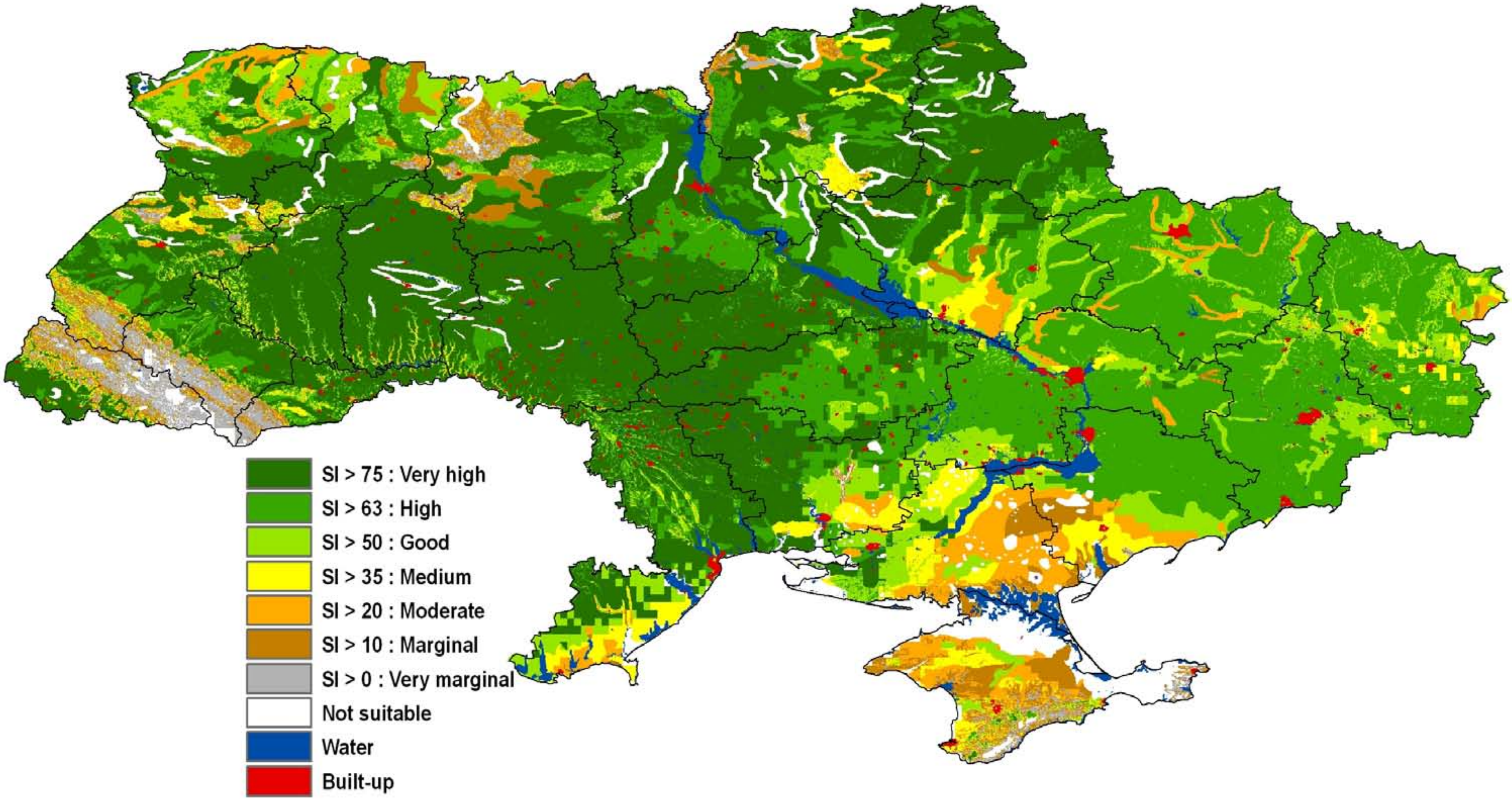


Figure 5b. Suitability for rain-fed potato under high level of input and management (1971-2000)

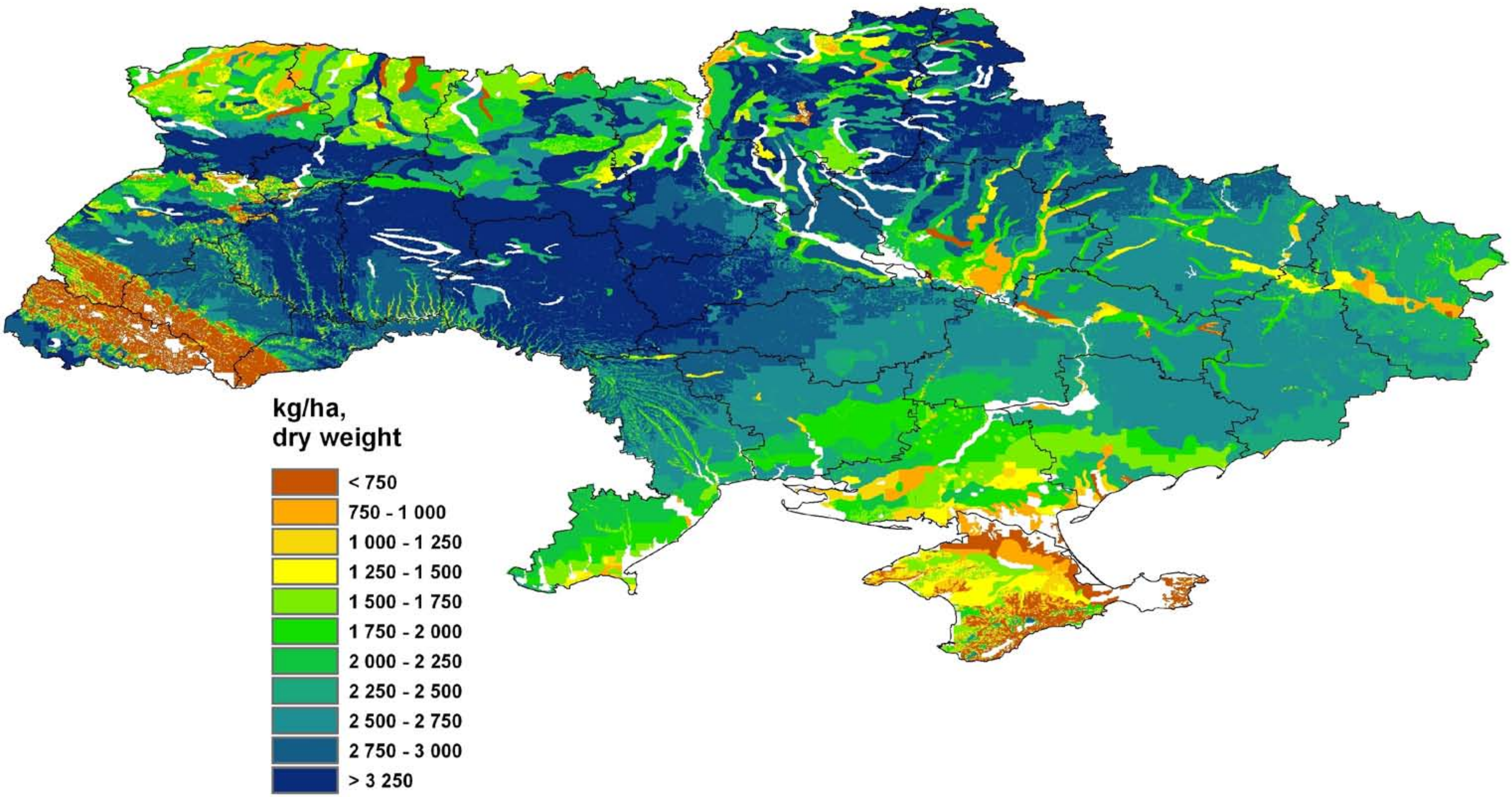


Figure 6a. Average potential yields for rain-fed spring rape under high level of input and management (1971-2000)

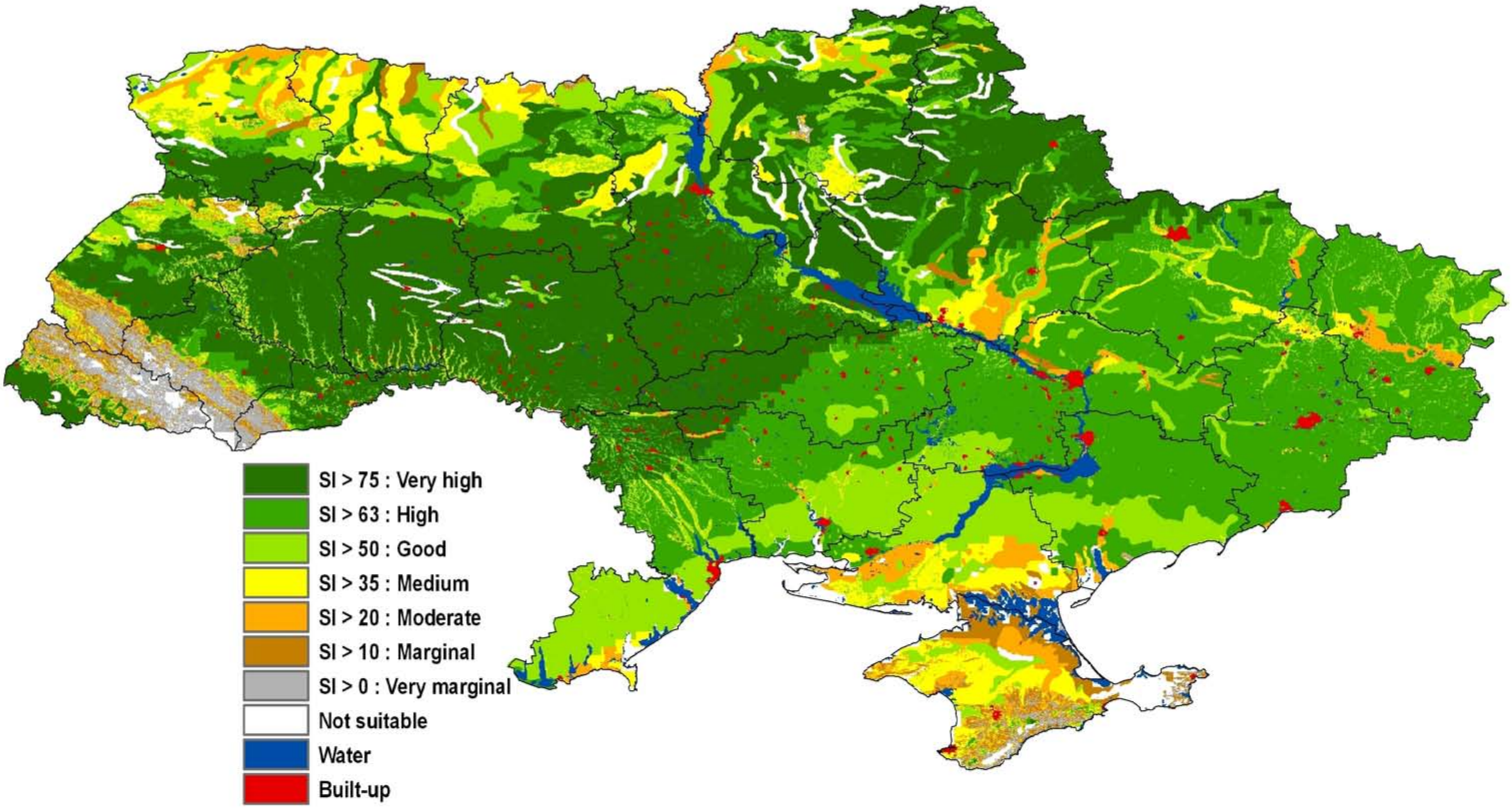


Figure 6b. Suitability for rain-fed spring rape under high level of input and management (1971-2000)

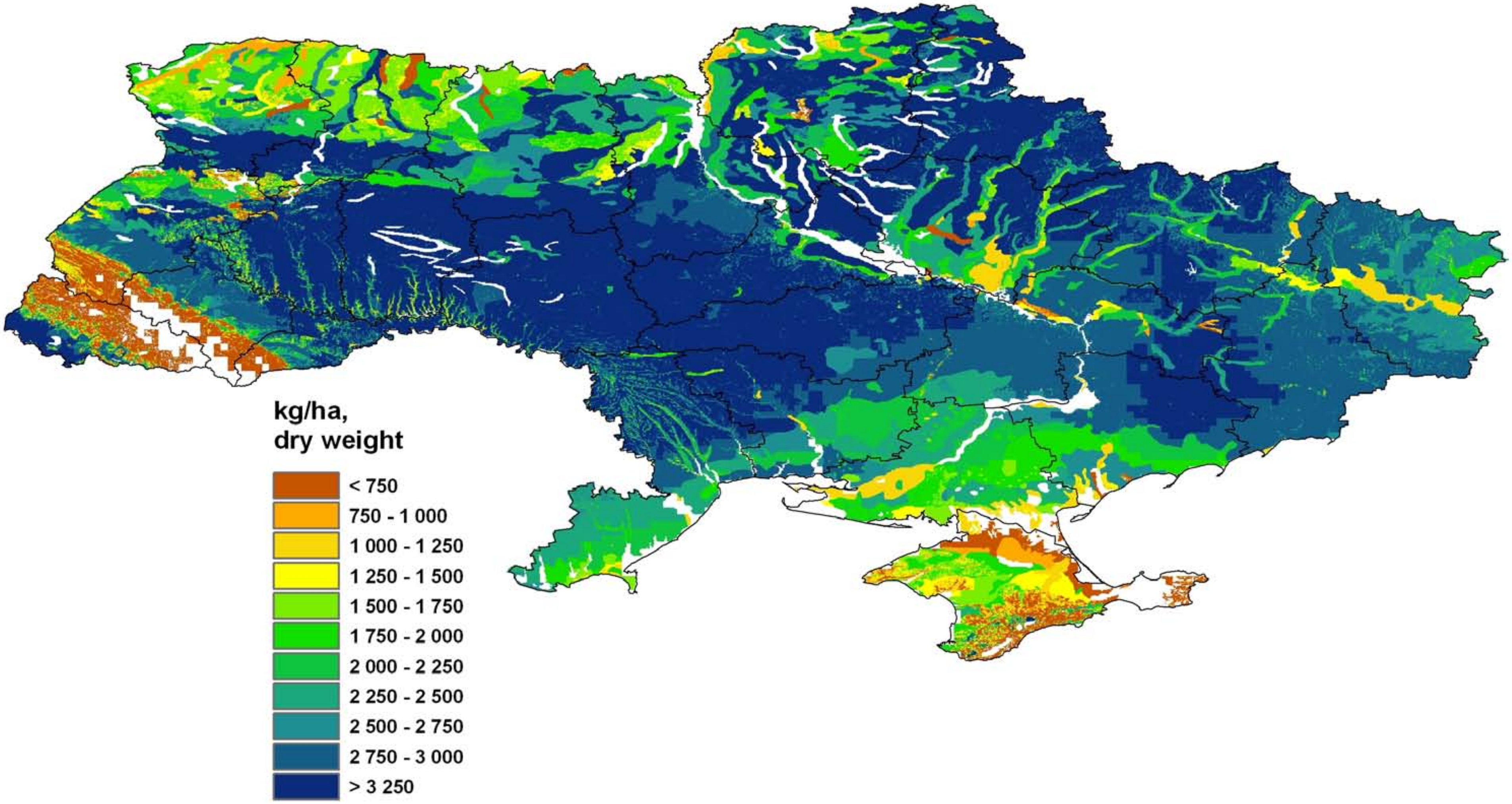


Figure 7a. Average potential yields for rain-fed winter rape under high level of input and management (1971-2000)

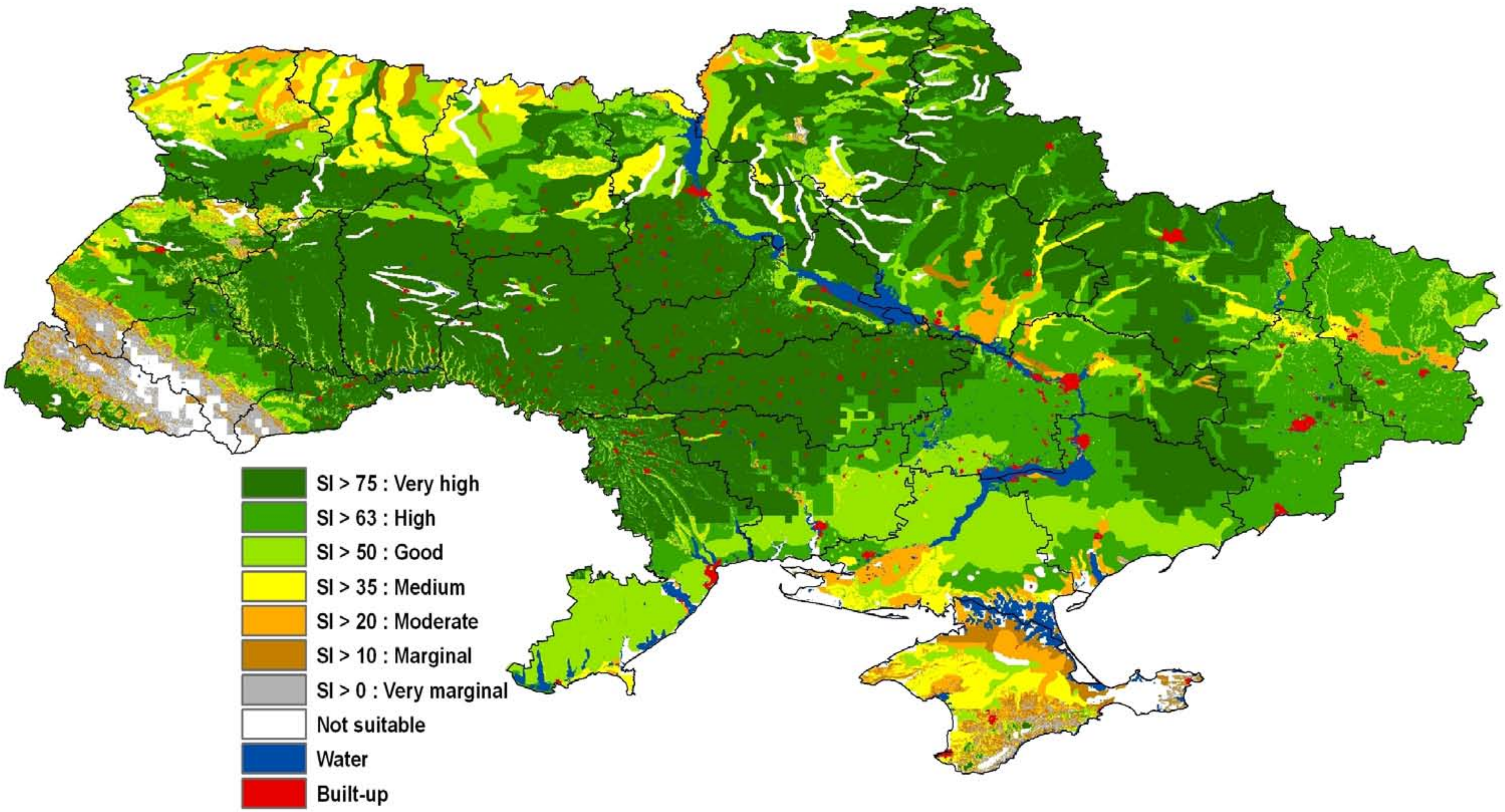


Figure 7b. Suitability for rain-fed winter rape under high level of input and management (1971-2000)

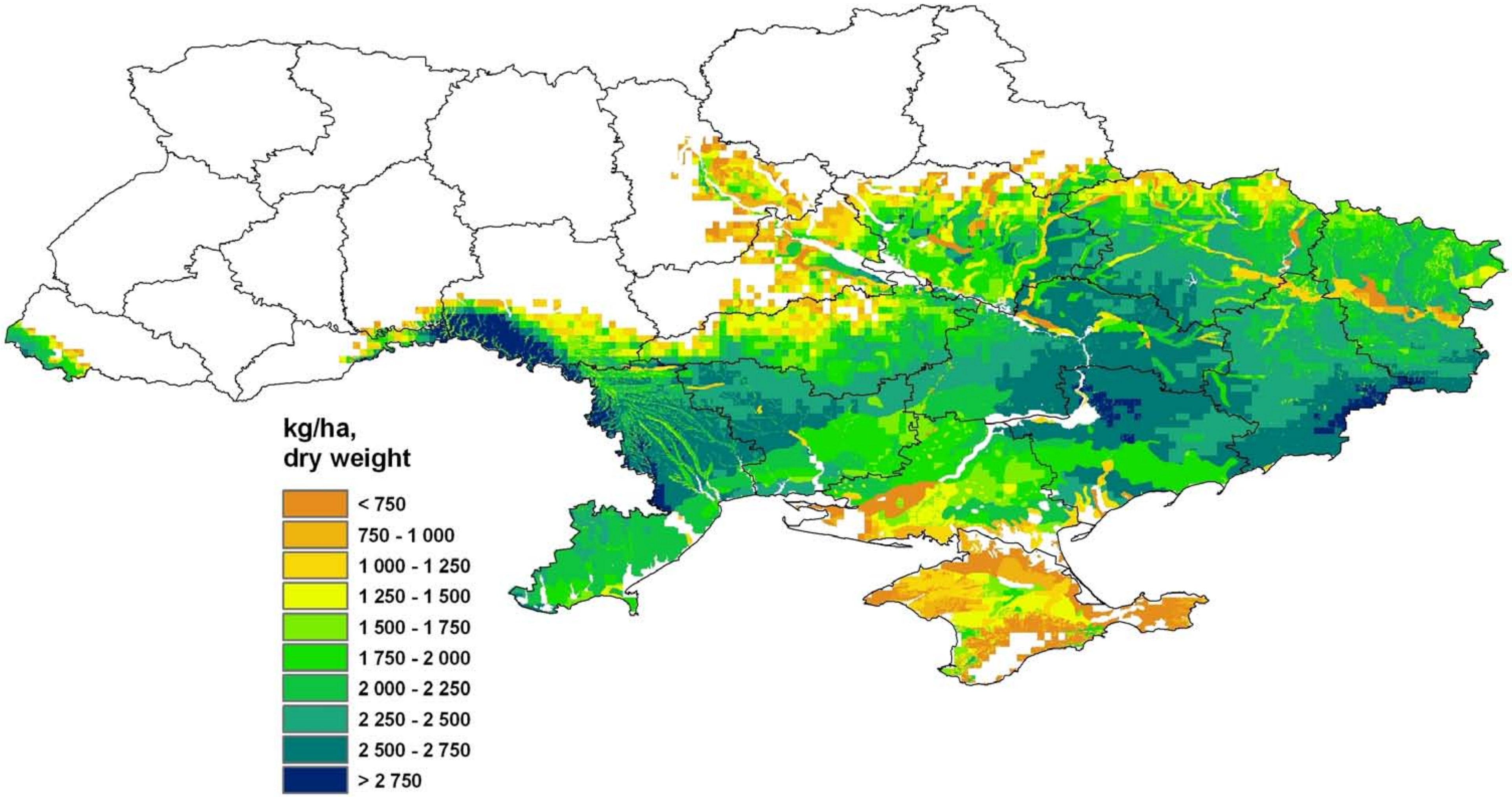


Figure 8a. Average potential yields for rain-fed soybean under high level of input and management (1971-2000)

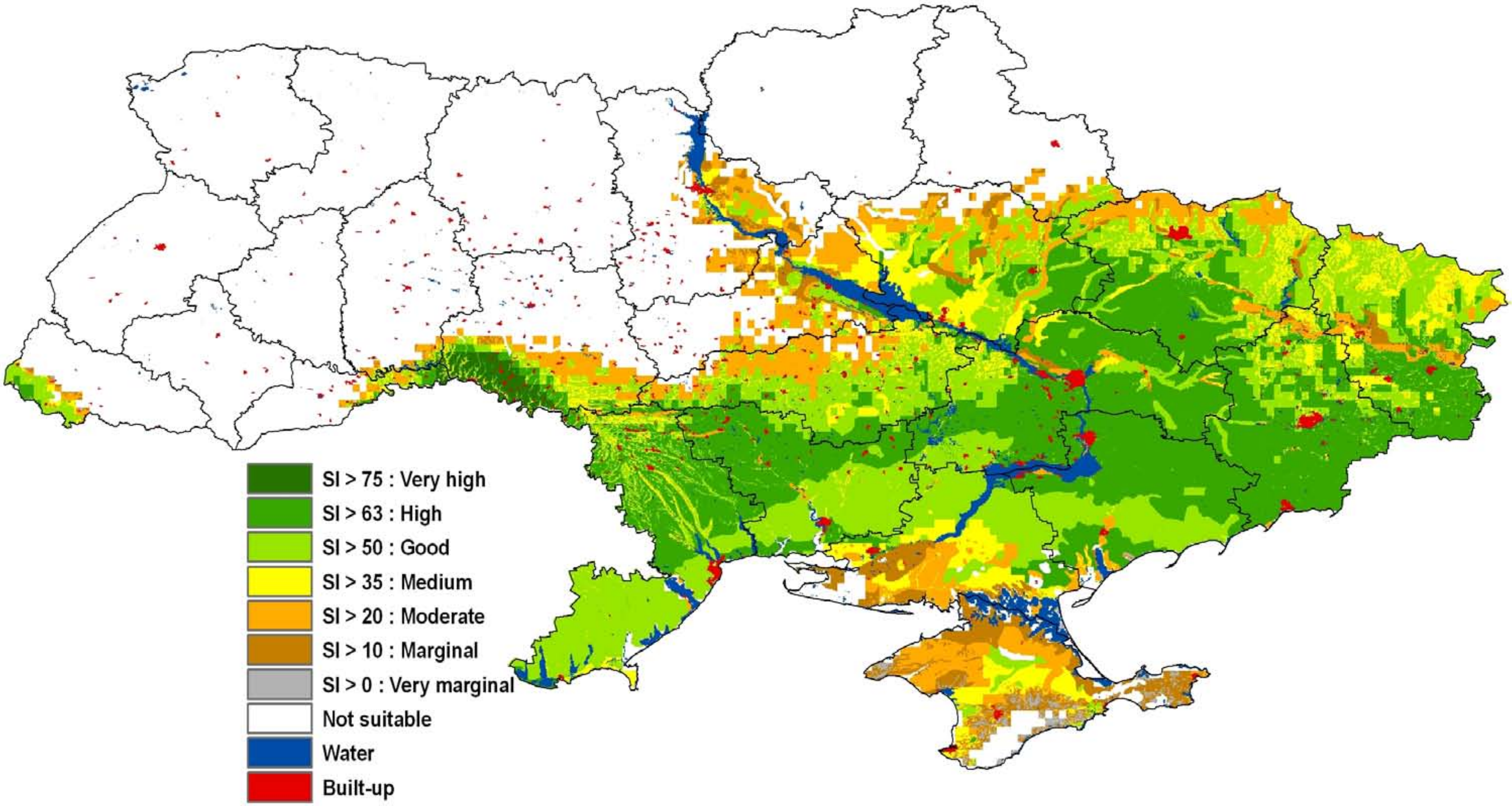


Figure 8b. Suitability for rain-fed soybean under high level of input and management (1971-2000)

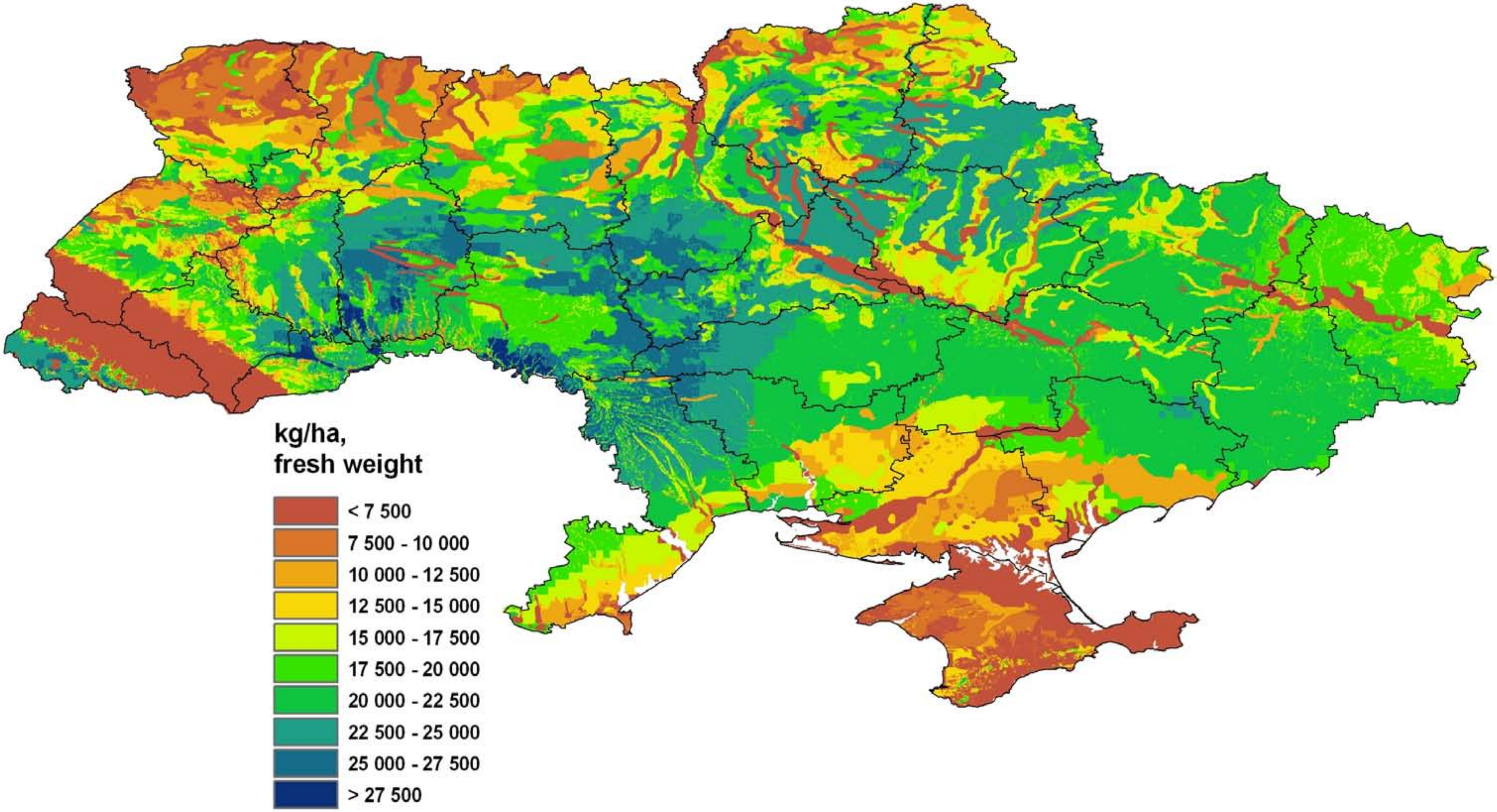


Figure 9a. Average potential yields for rain-fed tomato under high level of input and management (1971-2000)

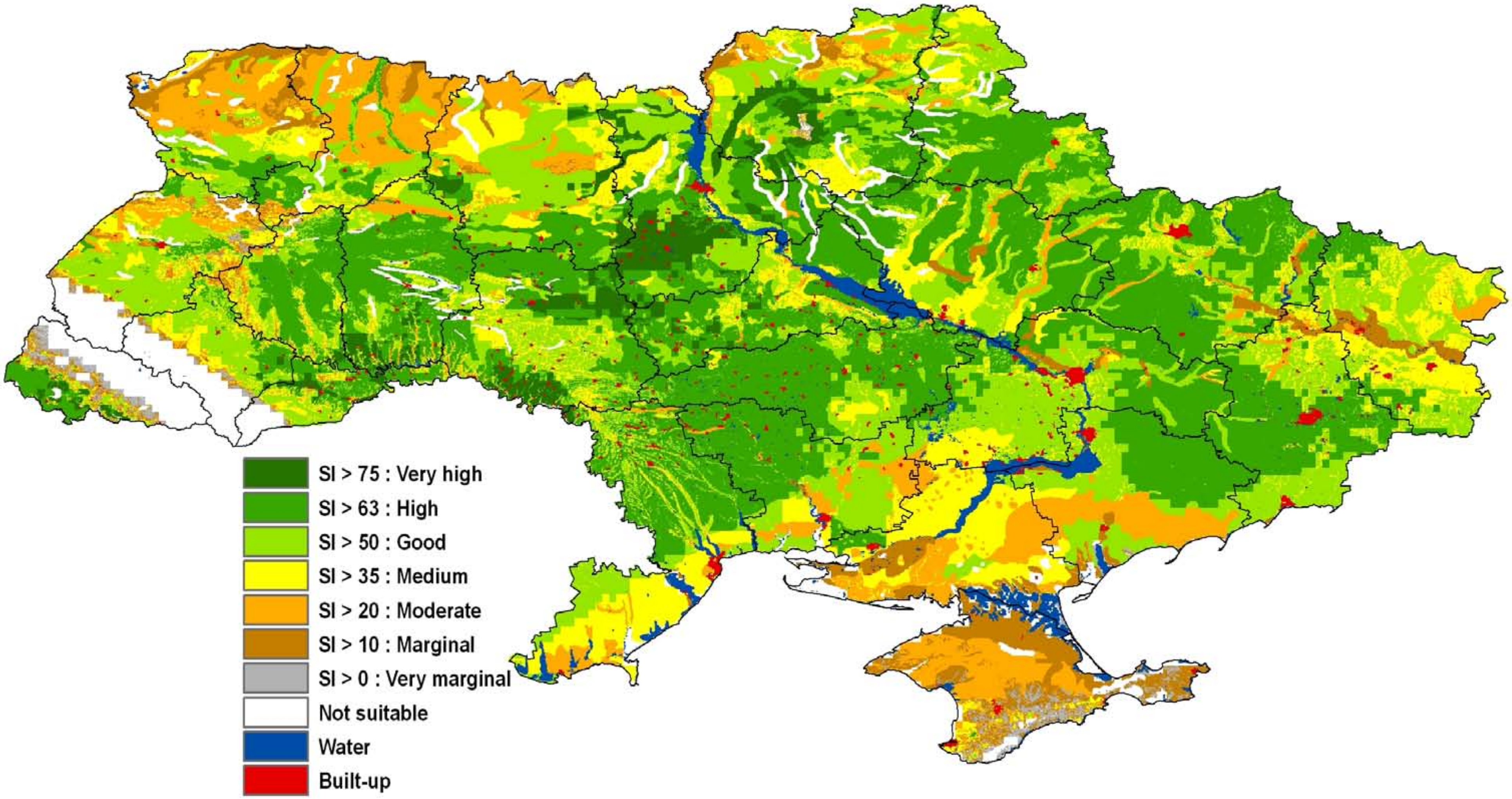


Figure 9b. Suitability for rain-fed tomato under high level of input and management (1971-2000)

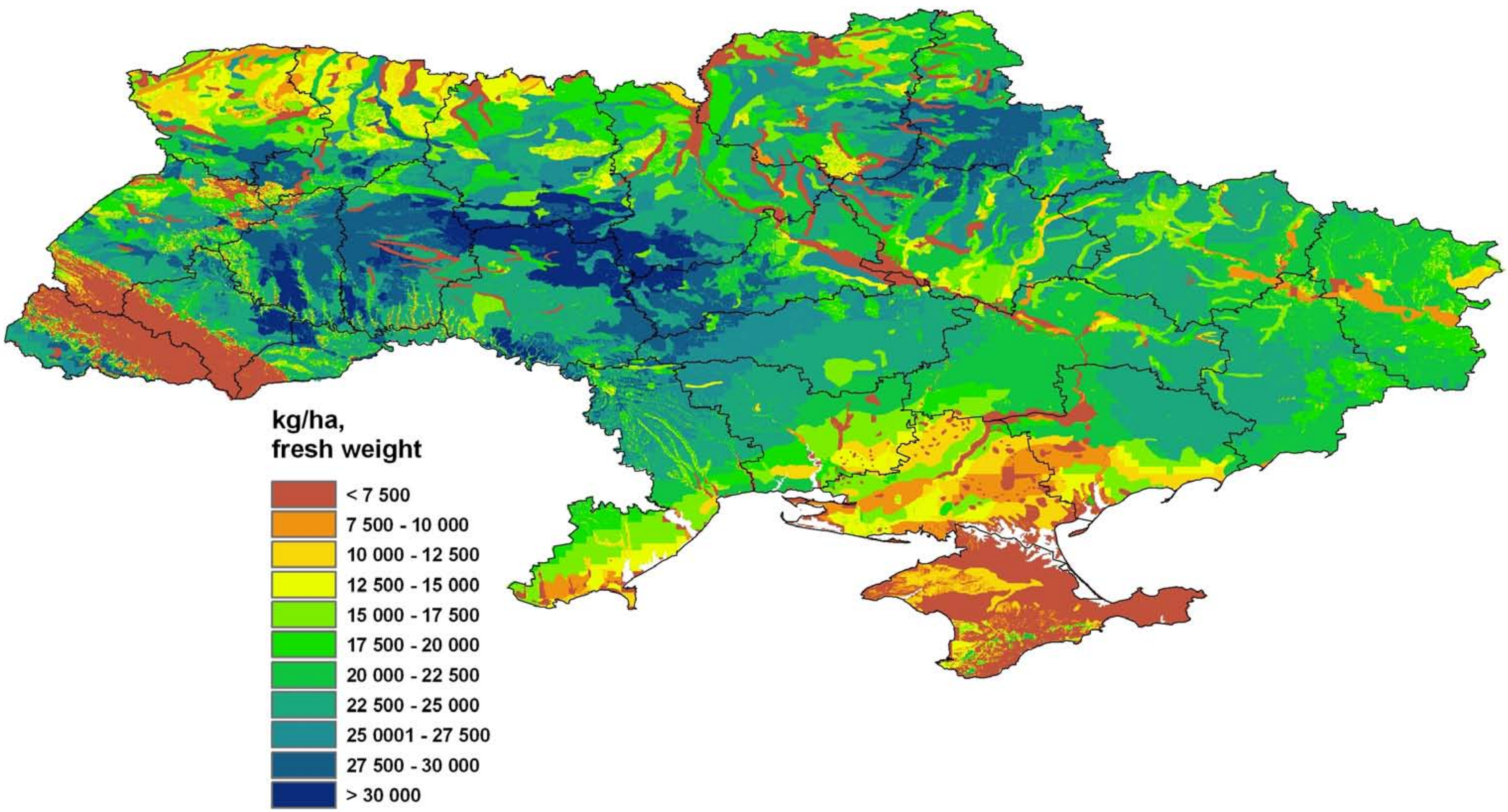


Figure 10a. Average potential yields for rain-fed onion under high level of input and management (1971-2000)

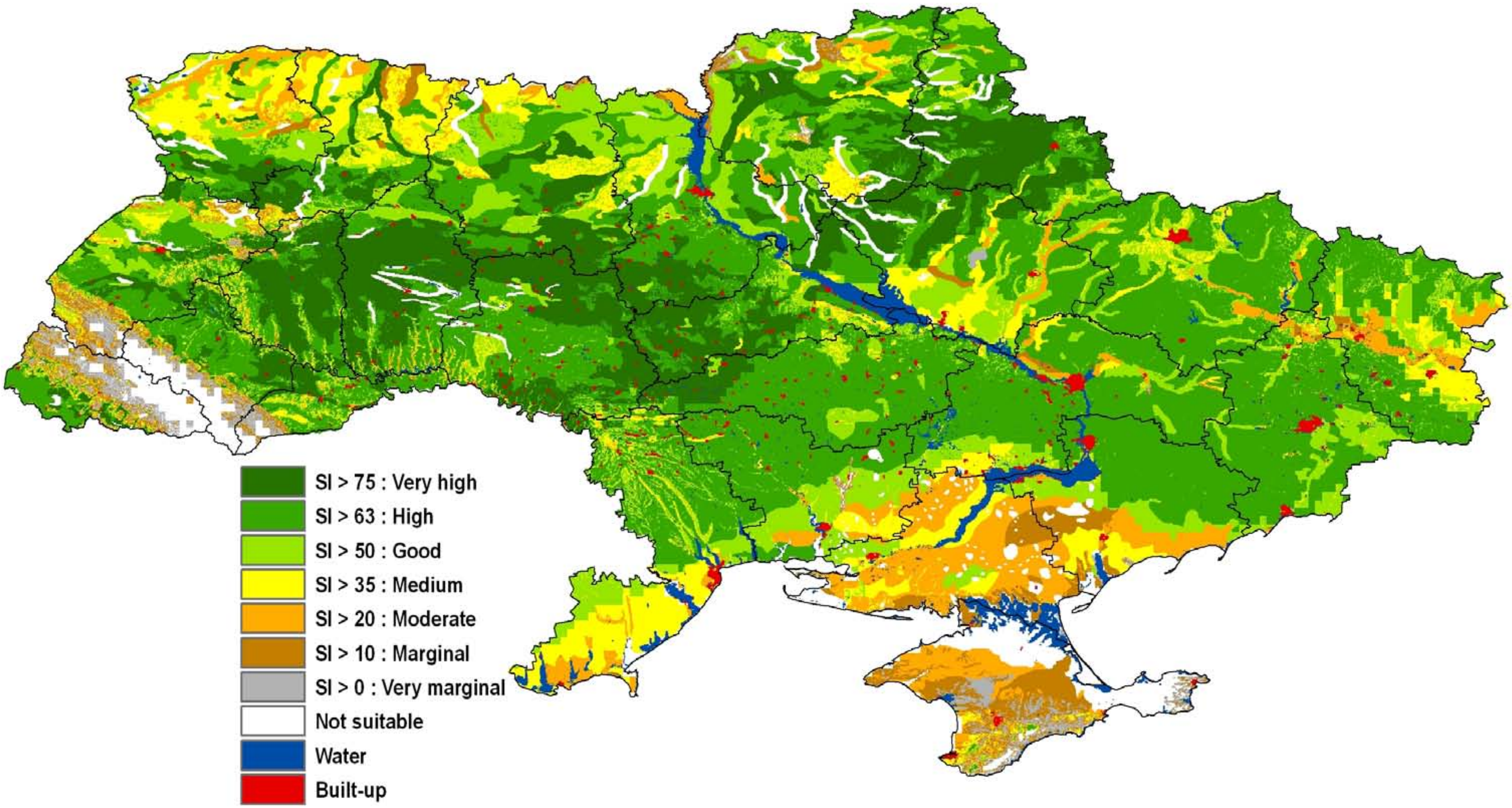


Figure 10b. Suitability for rain-fed onion under high level of input and management (1971-2000)

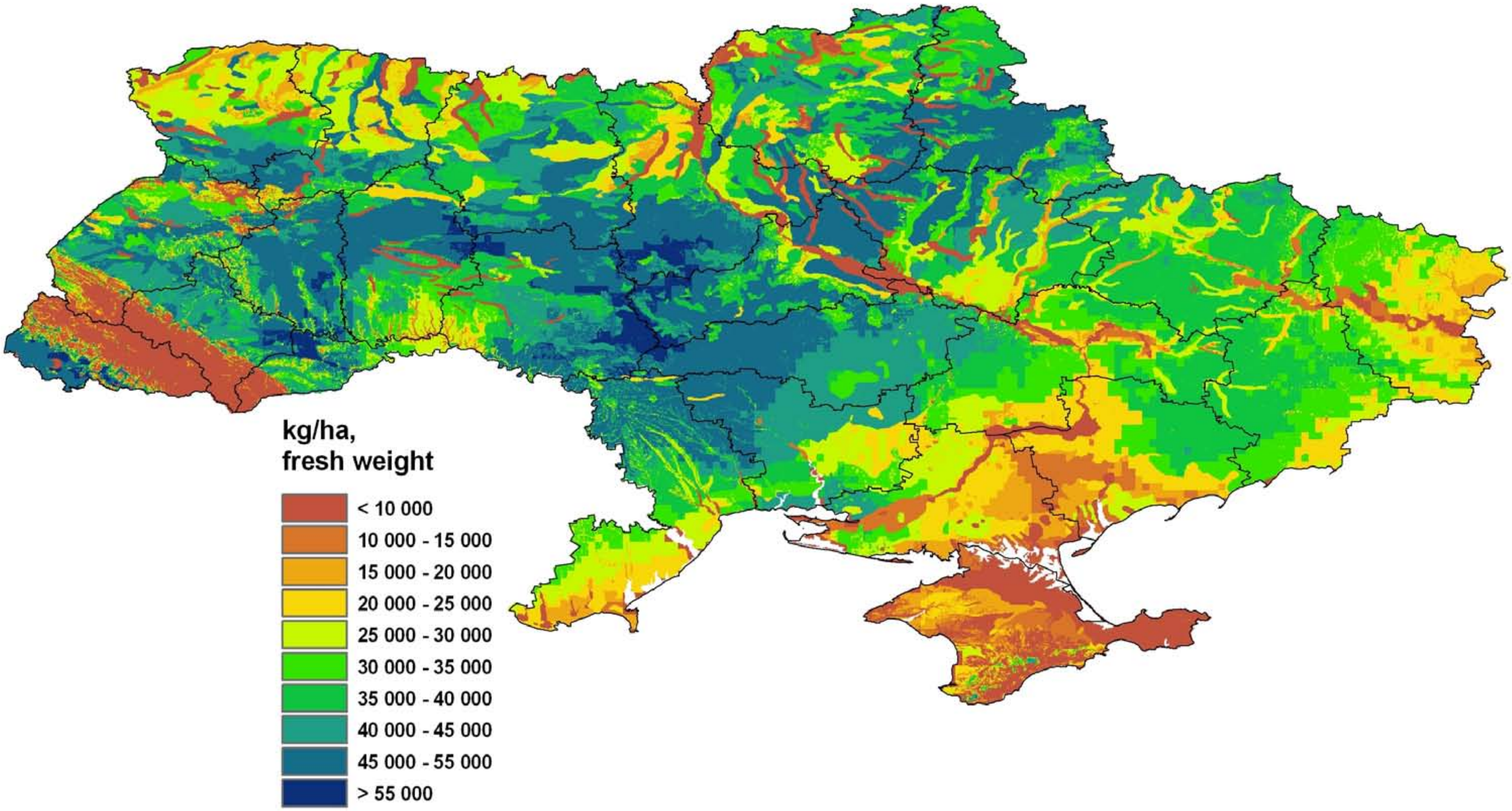


Figure 11a. Average potential yields for rain-fed cabbage for high input level management (1971-2000)

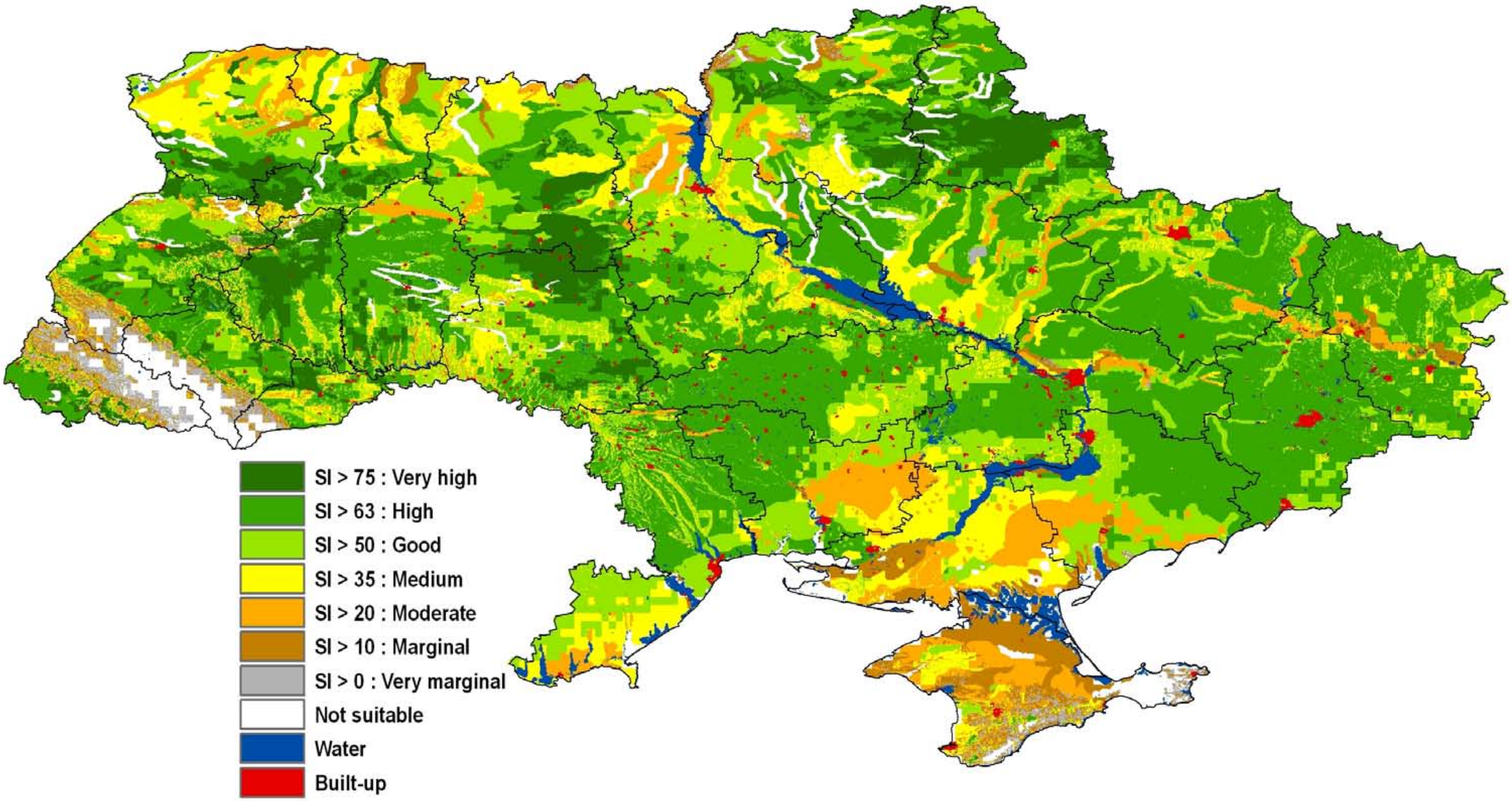


Figure 11b. Suitability for rain-fed cabbage for high input level management (1971-2000)

ANNEX 14. Potential production and attainable yields under irrigation vs. rain-fed conditions for winter wheat, maize and sunflower

Table 1. Production potential and attainable yields of winter wheat under irrigation and rain-fed conditions

Oblast	Area equipped for irrigation, (10^3 ha)	With irrigation					Without irrigation				
		Average Potential Yield (t/ha)	Potential Production (10^3 t)	VS			Average Potential Yield (t/ha)	Potential Production (10^3 t)	VS		
				Suitable Extents (10^3 ha)	Potential Yield (t/ha)	Potential Production (10^3 t)			Suitable Extents (10^3 ha)	Potential Yield (t/ha)	Potential Production (10^3 t)
Southern and Eastern											
AR Krym	324	7,3	2224	120	8,5	1022	4,9	1478	1	6,0	6
Odes'ka	215	7,8	1647	158	8,4	1320	5,7	1184	17	7,3	124
Mykolaivs'ka	174	8,0	1405	150	8,3	1249	6,7	1162	61	6,9	420
Khersons'ka	412	7,8	3075	284	8,4	2394	5,3	2098	0	0,0	0
Zaporiz'ka	230	8,0	1795	182	8,4	1524	5,9	1320	3	7,3	22
Dnipropetrovs'ka	244	8,2	1987	225	8,3	1877	6,5	1561	10	7,0	70
Donets'ka	202	8,2	1658	187	8,4	1568	6,6	1334	96	6,9	658
Luhans'ka	97	8,2	790	82	8,5	699	6,2	595	0	0,0	0
Kharkivs'ka	97	7,8	745	69	8,3	570	6,4	617	64	6,9	441
Central											
Vinnyts'ka	36	7,8	273	26	8,3	217	7,3	255	26	7,8	203
Cherkas'ka	48	7,8	326	34	8,1	276	7,0	294	34	7,3	249
Poltavs'ka	46	7,6	290	27	8,3	223	6,7	255	26	7,4	193
Kirovohrads'ka	48	8,1	390	45	8,3	374	6,9	322	31	6,9	214
Northern											
Sums'ka	25	7,7	161	12	8,4	101	6,9	144	12	7,6	91
Chernihivs'ka	12	7,0	77	4	8,8	35	6,5	71	4	8,3	33
Kyivs'ka	112	6,7	655	32	8,3	265	6,4	625	32	7,9	252
Zhytomyrs'ka	7	6,9	48	2	6,5	13	6,4	45	2	6,0	12
Volyns'ka	3	5,7	17	1	5,0	5	5,0	15	1	4,0	4
Rivnens'ka	2	5,7	17	1	7,0	7	5,3	16	1	6,0	6
Western											
Ivano-Frankivs'ka	2	7,0	14	1	9,0	9	6,5	13	1	8,0	8
Zakarpats'ka	14	7,2	94	6	8,7	52	6,9	90	6	8,3	50
L'vivs'ka	0	0,0	0	0	0,0	0	0,0	0	0	0,0	0
Ternopil's'ka	8	7,9	63	7	7,7	54	7,5	60	7	7,3	51
Khmel'nyts'ka	4	8,0	32	3	8,3	25	7,3	29	3	7,7	23
Chernivets'ka	16	7,2	115	8	8,1	65	6,6	106	8	7,5	60
Ukraine	**2378**	**7,8**	**17899**	**1666**	**8,4**	**13945**	**6,0**	**13693**	**446**	**7,2**	**3191**

Table 2. Production potential and attainable yields of maize under irrigation and rain-fed conditions

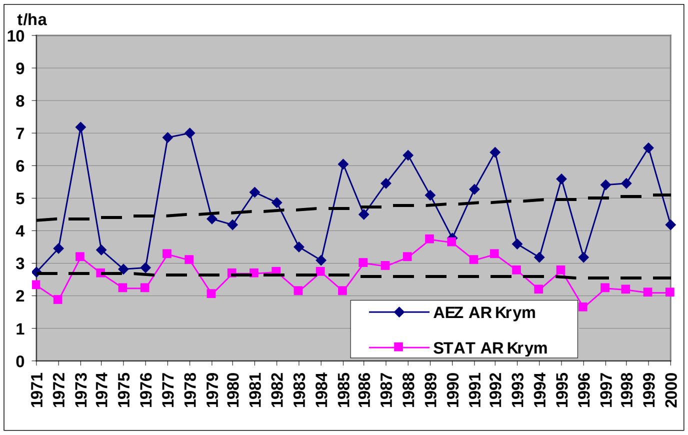
Oblast	Area equipped for irrigation, (10^3 ha)	With irrigation					Without irrigation				
		Average Potential Yield (t/ha)	Potential Production (10^3 t)	VS			Average Potential Yield (t/ha)	Potential Production (10^3 t)	VS		
				Suitable Extents (10^3 ha)	Potential Yield (t/ha)	Potential Production (10^3 t)			Suitable Extents (10^3 ha)	Potential Yield (t/ha)	Potential Production (10^3 t)
Southern and Eastern											
AR Krym	324	7,3	2179	8	9,4	75	2,3	680	0	0,0	0
Odes'ka	215	8,1	1688	98	9,2	900	3,6	750	0	1,0	0
Mykolaivs'ka	174	7,8	1364	67	9,1	607	3,1	537	0	0,0	0
Khersons'ka	412	8,3	3257	230	9,2	2119	2,8	1107	0	0,0	0
Zaporiz'ka	230	8,7	1943	157	9,3	1459	4,0	898	0	0,0	0
Dnipropetrovs'ka	244	8,7	2121	202	9,1	1838	4,4	1054	0	0,0	0
Donets'ka	202	8,9	1783	182	9,1	1649	3,7	989	29	6,0	173
Luhans'ka	97	8,6	837	79	9,1	717	4,6	450	0	0,0	0
Kharkivs'ka	97	8,2	786	72	8,7	624	4,2	406	0	0,0	0
Central											
Vinnyts'ka	36	7,9	278	26	8,5	220	5,1	180	8	5,9	47
Cherkas'ka	48	8,2	338	33	8,6	283	5,2	218	0	0,0	0
Poltavs'ka	46	7,9	302	27	8,6	231	4,8	184	0	1,0	0
Kirovohrads'ka	48	8,5	409	45	8,7	392	4,6	223	0	0,0	0
Northern											
Sums'ka	25	7,1	150	11	8,4	92	4,3	94	2	6,0	12
Chernihivs'ka	12	7,3	44	2	9,5	19	4,5	45	2	6,5	13
Kyivs'ka	112	6,7	655	31	8,4	260	4,4	436	12	5,3	63
Zhytomyrs'ka	7	5,6	28	1	6,0	6	3,3	23	0	0,0	0
Volyns'ka	3	0,0	0	0	0,0	0	0,0	0	0	0,0	0
Rivnens'ka	2	0,0	0	0	0,0	0	0,0	0	0	0,0	0
Western											
Ivano-Frankivs'ka	2	4,0	4	0	1,0	0	2,0	6	0	0,0	0
Zakarpats'ka	14	7,6	99	6	9,2	55	5,8	75	3	6,3	19
L'vivs'ka	0	0,0	0	0	0,0	0	0,0	0	0	0,0	0
Ternopil's'ka	8	4,0	32	0	1,0	0	3,3	26	0	1,0	0
Khmel'nyts'ka	4	6,3	25	2	7,5	15	6,3	25	1	9,0	9
Chernivets'ka	16	7,0	105	4	9,0	36	4,8	76	1	7,0	7
Ukraine	**2378**	**8,1**	**18431**	**1283**	**9,0**	**11599**	**3,7**	**8482**	**29**	**6,0**	**173**

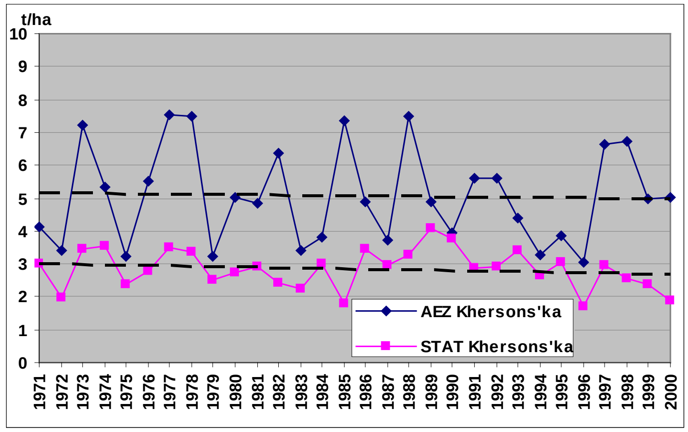
Table 3. Production potential and attainable yields of sunflower under irrigation and rain-fed conditions

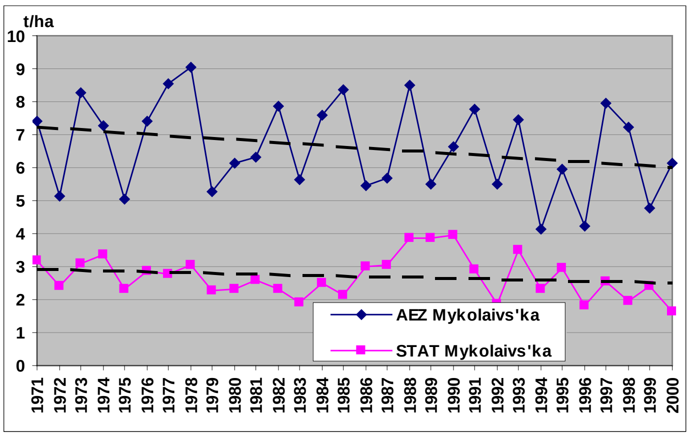
Oblast	Area equipped for irrigation, (10^3 ha)	With irrigation					Without irrigation				
		Average Potential Yield (t/ha)	Potential Production (10^3 t)	VS			Average Potential Yield (t/ha)	Potential Production (10^3 t)	VS		
				Suitable Extents (10^3 ha)	Potential Yield (t/ha)	Potential Production (10^3 t)			Suitable Extents (10^3 ha)	Potential Yield (t/ha)	Potential Production (10^3 t)
Southern and Eastern											
AR Krym	324	3,4	970	10	4,5	45	1,3	387	0	0,0	0
Odes'ka	215	3,8	799	104	4,3	447	2,1	431	0	1,0	0
Mykolaivs'ka	174	3,6	635	67	4,3	285	1,5	265	0	0,0	0
Khersons'ka	412	3,8	1506	230	4,3	984	1,6	633	0	0,0	0
Zaporiz'ka	230	3,9	880	157	4,2	661	2,1	463	0	0,0	0
Dnipropetrovs'ka	244	4,1	986	202	4,2	857	2,1	517	0	0,0	0
Donets'ka	202	4,2	839	182	4,3	776	2,3	472	0	0,0	0
Luhans'ka	97	4,1	395	79	4,3	339	2,3	219	0	0,0	0
Kharkivs'ka	97	4,0	383	75	4,2	314	1,9	183	0	0,0	0
Central											
Vinnyts'ka	36	3,7	131	24	4,2	100	2,3	79	12	2,7	32
Cherkas'ka	48	4,0	166	34	4,2	142	2,3	98	4	2,5	10
Poltavs'ka	46	3,9	147	27	4,3	115	2,1	79	2	2,0	4
Kirovohrads'ka	48	4,1	199	45	4,2	191	2,2	107	0	0,0	0
Northern											
Sums'ka	25	3,1	66	11	3,5	39	1,8	37	0	0,0	0
Chernihivs'ka	12	2,9	20	3	3,7	11	1,6	18	1	3,0	3
Kyivs'ka	112	3,2	318	43	4,0	170	1,9	184	12	2,2	26
Zhytomyrs'ka	7	2,5	10	0	0,0	0	1,1	9	0	0,0	0
Volyns'ka	3	0,0	0	0	0,0	0	0,0	0	0	0,0	0
Rivnens'ka	2	0,0	0	0	0,0	0	0,0	0	0	0,0	0
Western											
Ivano-Frankivs'ka	2	0,0	0	0	0,0	0	0,0	0	0	0,0	0
Zakarpats'ka	14	3,7	48	11	3,9	43	2,6	34	4	3,3	13
L'vivs'ka	0	0,0	0	0	0,0	0	0,0	0	0	0,0	0
Ternopil's'ka	8	1,9	13	0	0,0	0	0,9	7	0	0,0	0
Khmel'nyts'ka	4	2,7	8	0	0,0	0	2,3	9	0	0,0	0
Chernivets'ka	16	3,0	45	3	4,0	12	1,9	29	0	0,0	0
Ukraine	**2378**	**3,8**	**8568**	**1307**	**4,2**	**5532**	**1,9**	**4268**	**35**	**2,5**	**89**

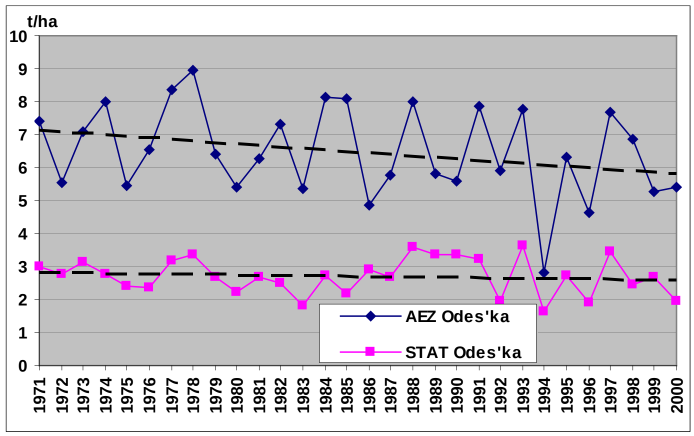
ANNEX XV. Estimated potential vs. observed yields for winter wheat at oblast' level in 1971–2000

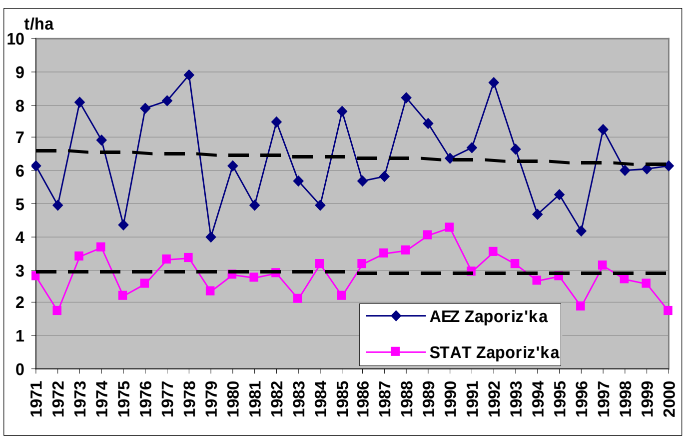
Southern and Eastern region

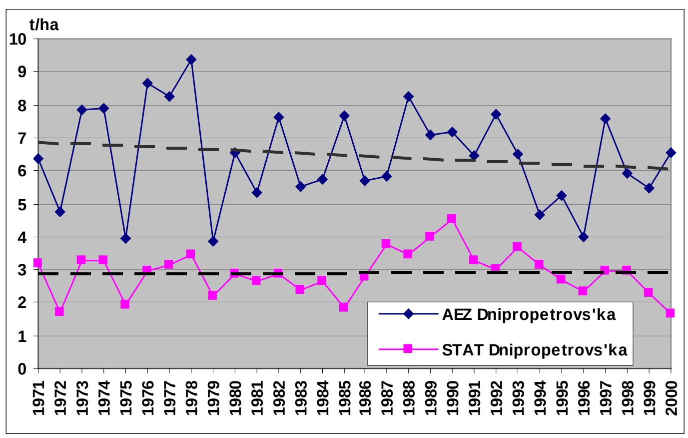


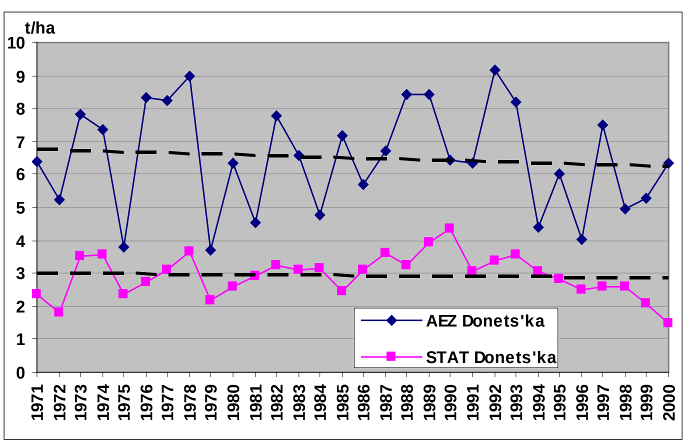


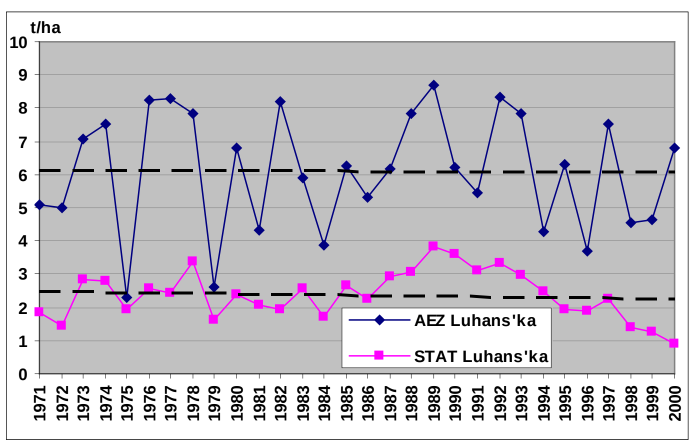


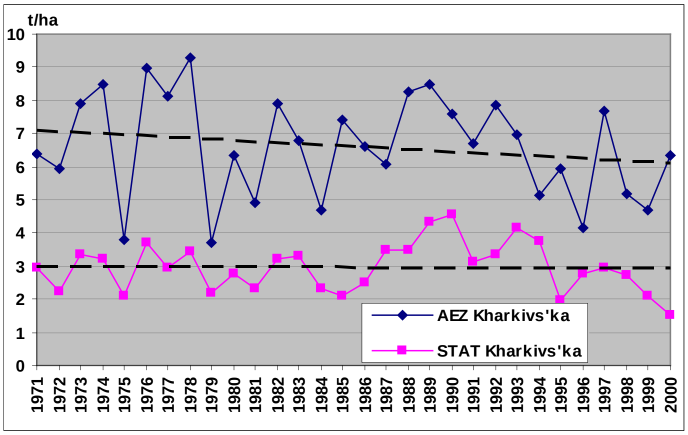




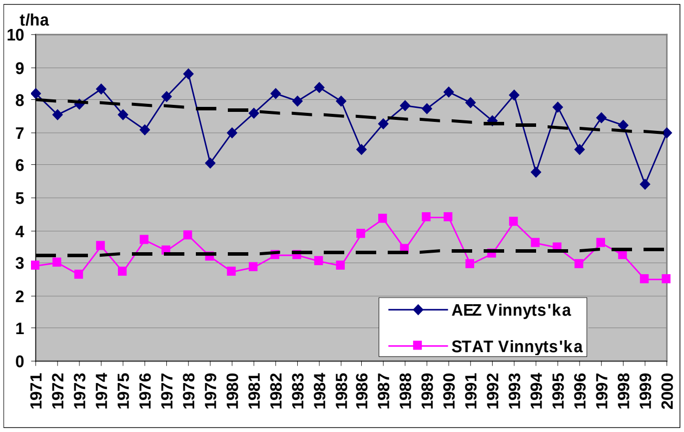


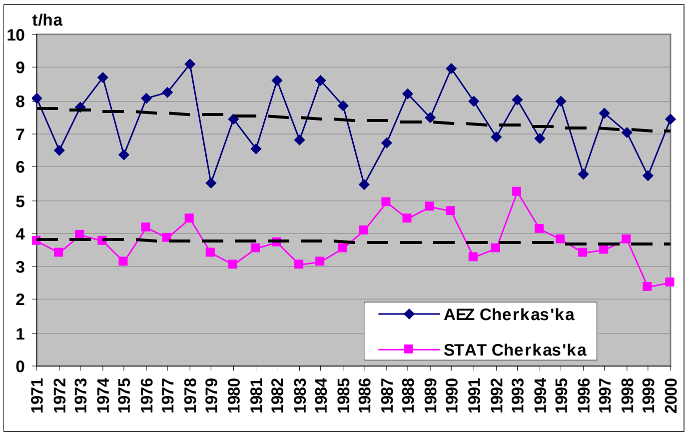


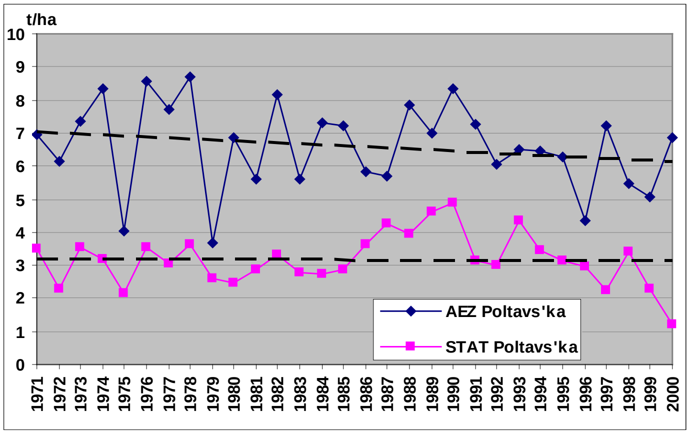


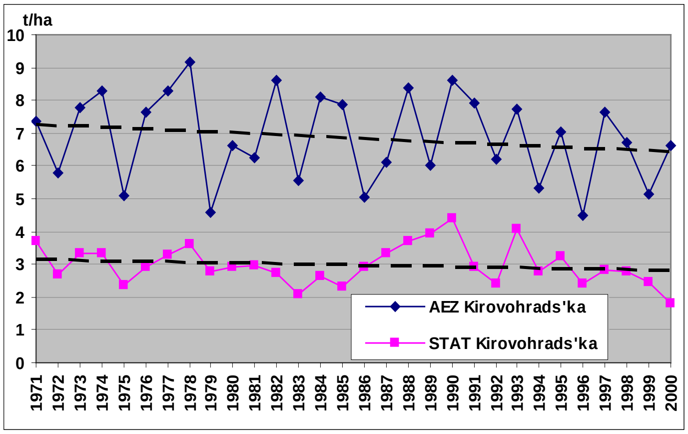


Central region

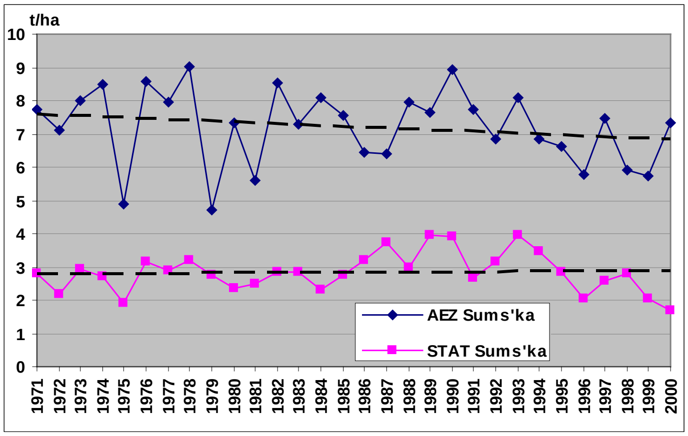


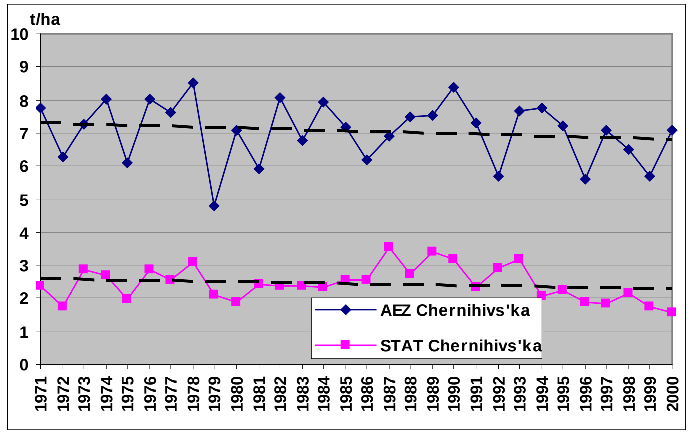


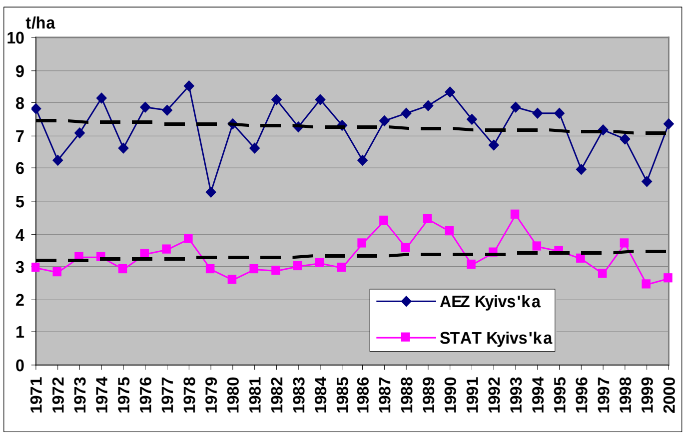


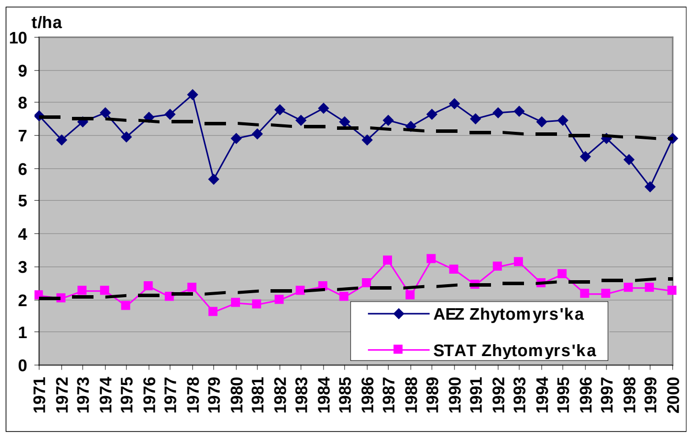


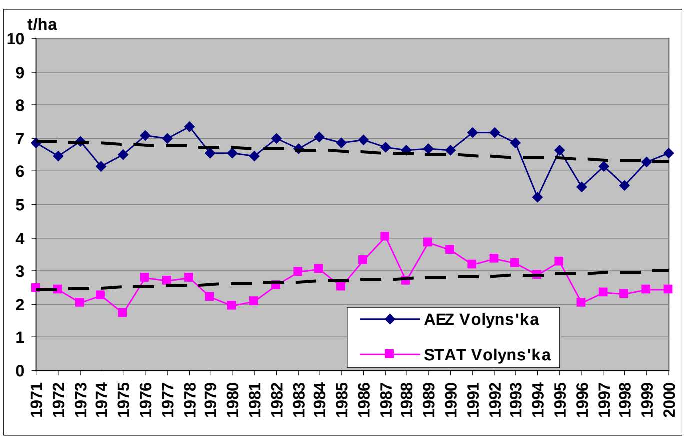
Northern region

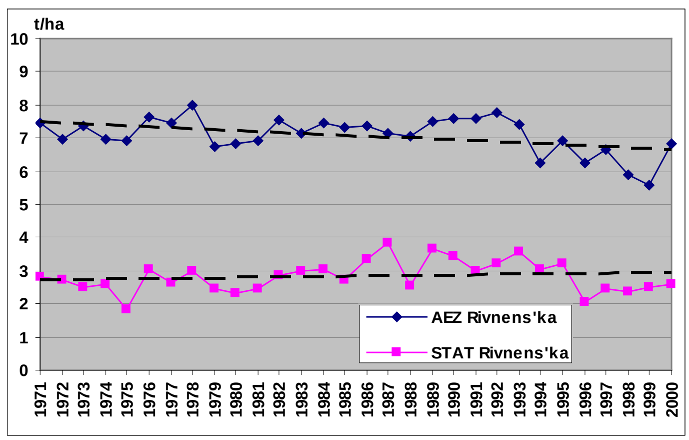




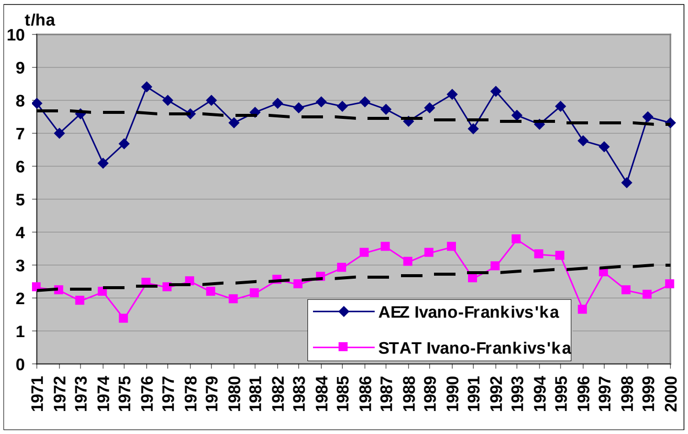


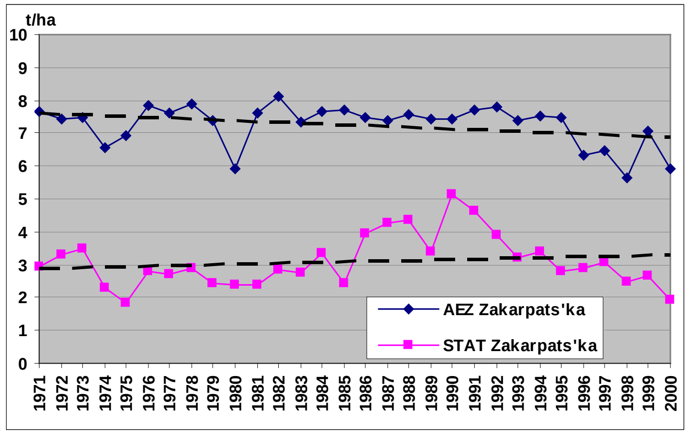


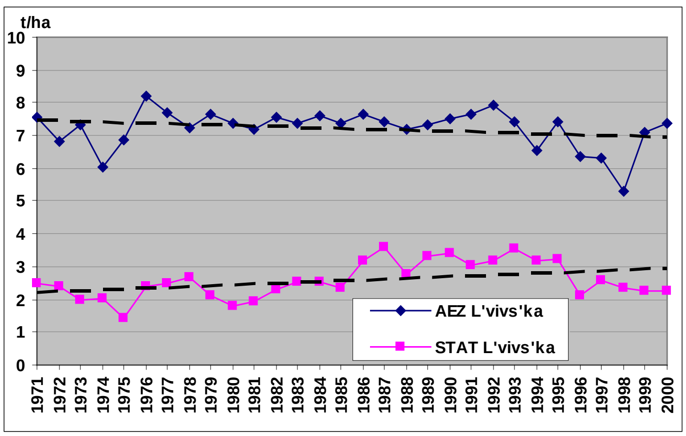


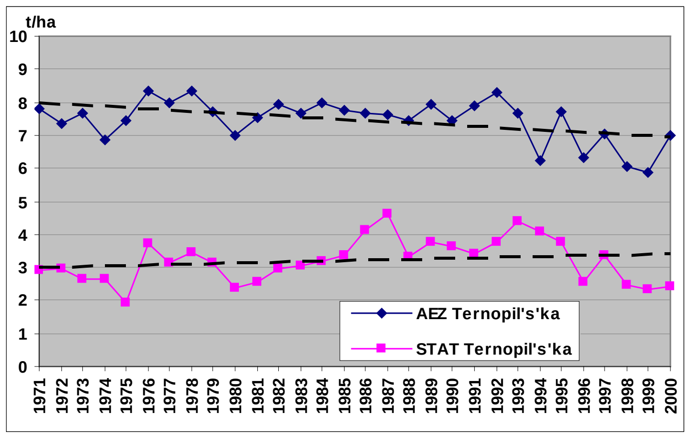


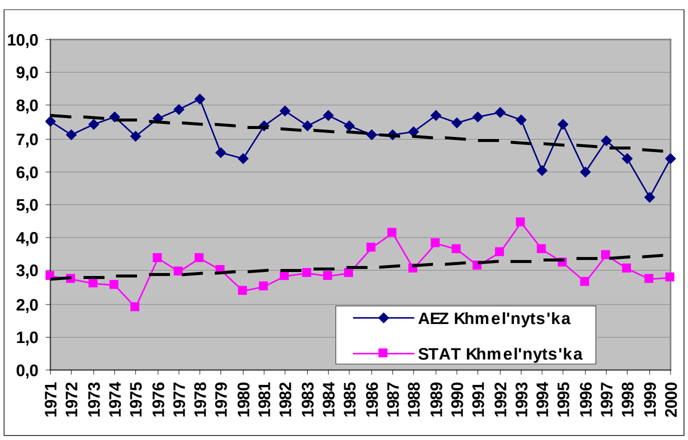
Western region

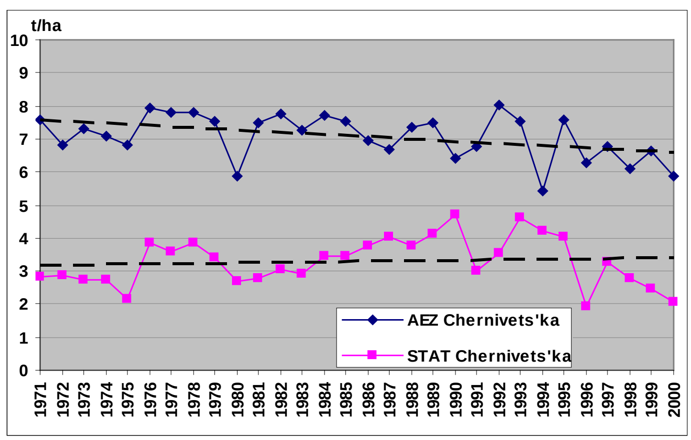












ANNEX 16. Estimated potential vs. observed yields for winter wheat at rayon’s level (Odes’ka, Cherkas’ka, L’vivs’ka and Kharkivs’ka oblasts)

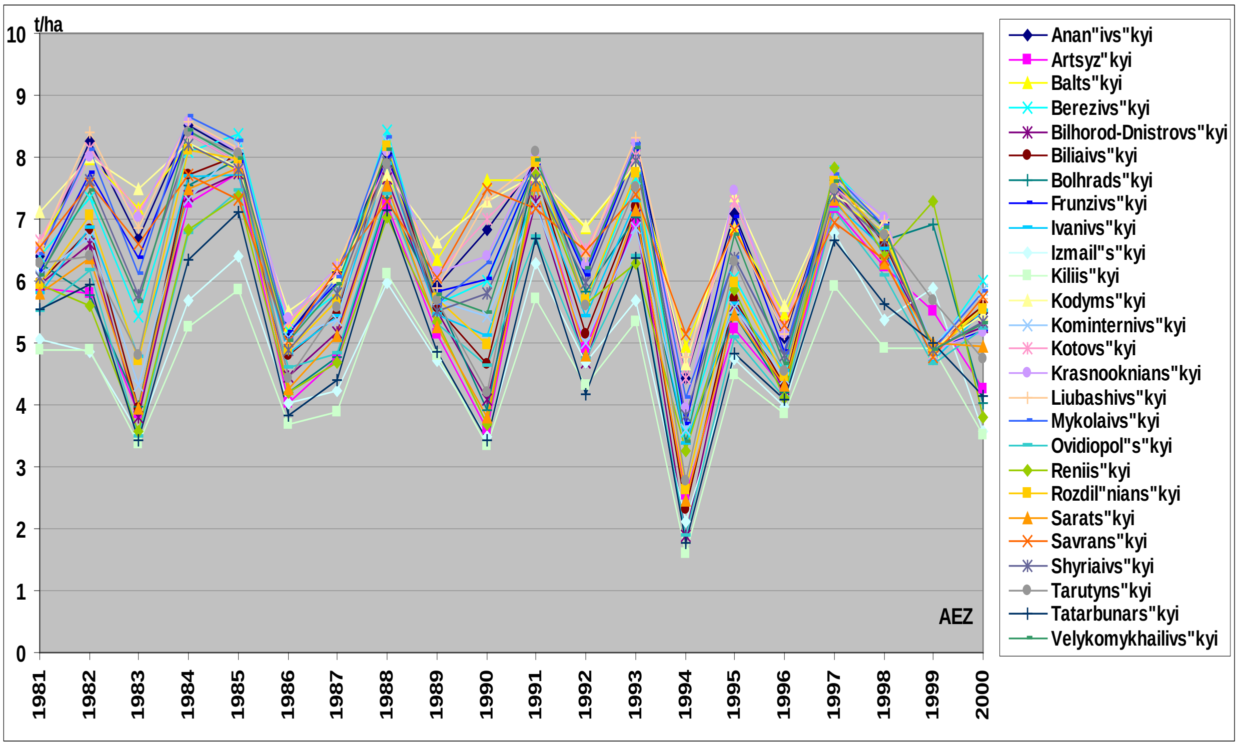


Figure 1a. Estimated potential yields of winter wheat at rayon's level, Odes'ka oblast' (1981-2000)

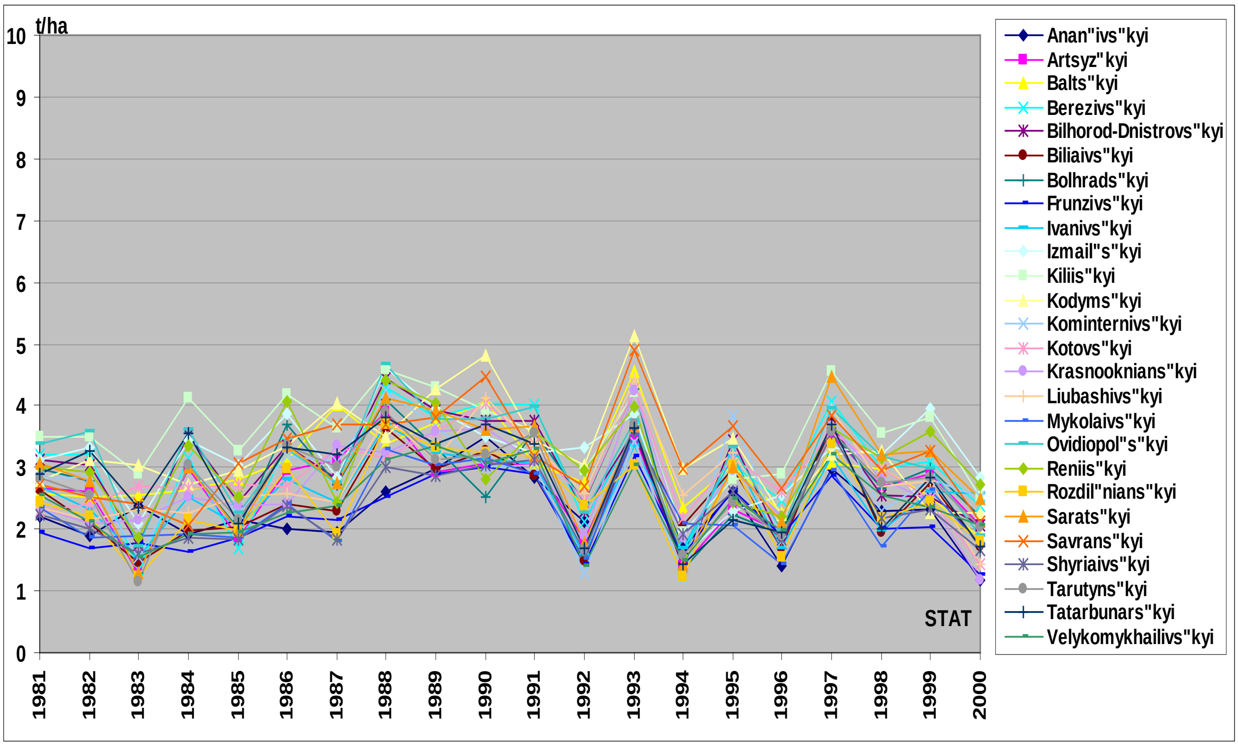


Figure 1b. Observed yields of winter wheat at rayon's level, Odes'ka oblast' (1981-2000)

Table 1c. Changes in means and variability of winter wheat estimated and observed yields at rayon’s level, Odes’ka oblast’ (1981-2000)

	National statistic (calculated on year-by-year basis)				AEZ (calculated on year-by-year basis)			
	Average yield (t/ha)		Coefficient of variation (%)		Average potential yield (t/ha)		Coefficient of variation (%)	
	1981-1990	1991-2000	1981-1990	1991-2000	1981-1990	1991-2000	1981-1990	1991-2000
Anan"ivs"kyi	2,4	2,3	22,4	32,8	7,0	6,4	16,5	21,2
Artsyz"kyi	2,7	2,5	26,3	28,9	5,5	5,5	27,3	28,4
Balts"kyi	3,1	2,8	19,8	25,6	7,1	6,4	13,2	17,3
Berezivs"kyi	3,1	2,9	30,8	27,3	6,7	6,1	19,0	24,2
Bilhorod-Dnistrovs"kyi	3,2	2,7	24,1	31,6	5,8	5,5	25,1	31,1
Biliaivs"kyi	2,5	2,5	26,6	32,7	6,1	5,7	24,4	29,3
Bolhrads"kyi	2,8	2,7	28,2	32,6	5,8	5,9	26,5	27,1
Frunzivs"kyi	2,2	2,2	22,8	31,0	6,8	6,2	16,7	24,1
Ivanivs"kyi	2,6	2,5	23,2	28,2	6,2	5,8	20,5	23,5
Izmail"s"kyi	3,4	3,0	20,5	24,2	4,8	4,9	20,9	28,5
Kiliis"kyi	3,8	3,3	13,7	24,4	4,6	4,5	21,7	28,3
Kodyms"kyi	3,5	3,1	20,1	27,4	7,2	6,5	12,2	18,6
Kominternivs"kyi	3,0	2,6	24,5	37,7	6,2	5,8	21,4	23,0
Kotovs"kyi	3,0	2,9	18,8	28,0	7,1	6,4	14,3	20,7
Krasnooknians"kyi	2,8	2,6	22,1	34,7	7,0	6,4	15,2	23,6
Liubashivs"kyi	2,8	2,9	24,9	30,2	7,1	6,5	16,9	20,0
Mykolaivs"kyi	2,4	2,3	25,3	31,0	6,9	6,3	18,9	22,5
Ovidiopol"s"kyi	3,3	2,9	25,7	31,4	5,6	5,2	23,3	29,3
Reniis"kyi	3,1	3,0	26,1	25,4	5,4	5,8	25,4	28,1
Rozdil"nians"kyi	2,5	2,4	30,6	30,5	6,3	5,9	22,0	28,2
Sarats"kyi	3,0	2,9	28,7	32,4	5,7	5,5	26,6	28,7
Savrans"kyi	3,2	3,2	23,8	23,9	6,8	6,2	12,6	14,8
Shyriaivs"kyi	2,3	2,4	23,5	30,4	6,5	6,1	18,5	22,4
Tarutyns"kyi	2,8	2,6	26,5	31,2	6,2	5,9	24,7	27,4
Tatarbunars"kyi	3,2	2,5	17,8	35,0	5,2	4,9	27,5	30,7
Velykomykhailivs"kyi	2,4	2,4	24,3	28,0	6,6	6,2	19,0	25,5
Odes'ka	**2,8**	**2,6**	**20,2**	**27,5**	**6,3**	**6,0**	**18,4**	**20,3**

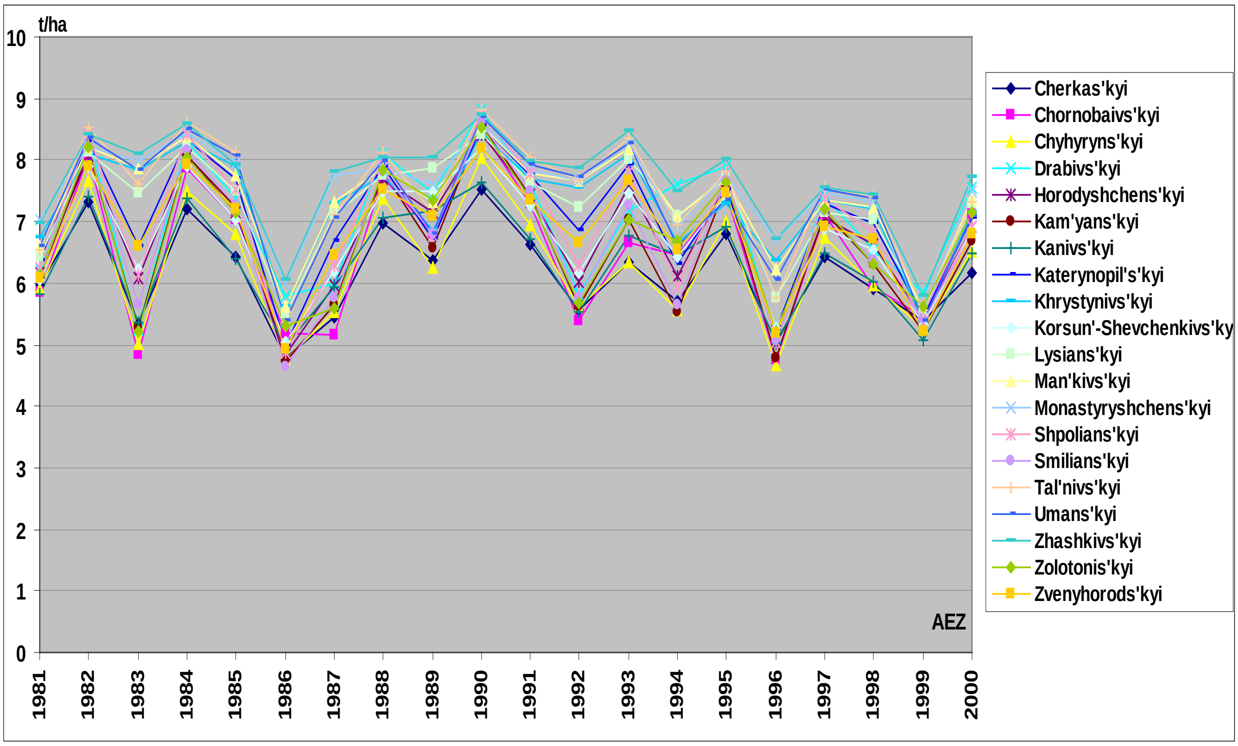


Figure 2a. Estimated potential yields of winter wheat at rayon's level, Cherkas'ka oblast' (1981-2000)

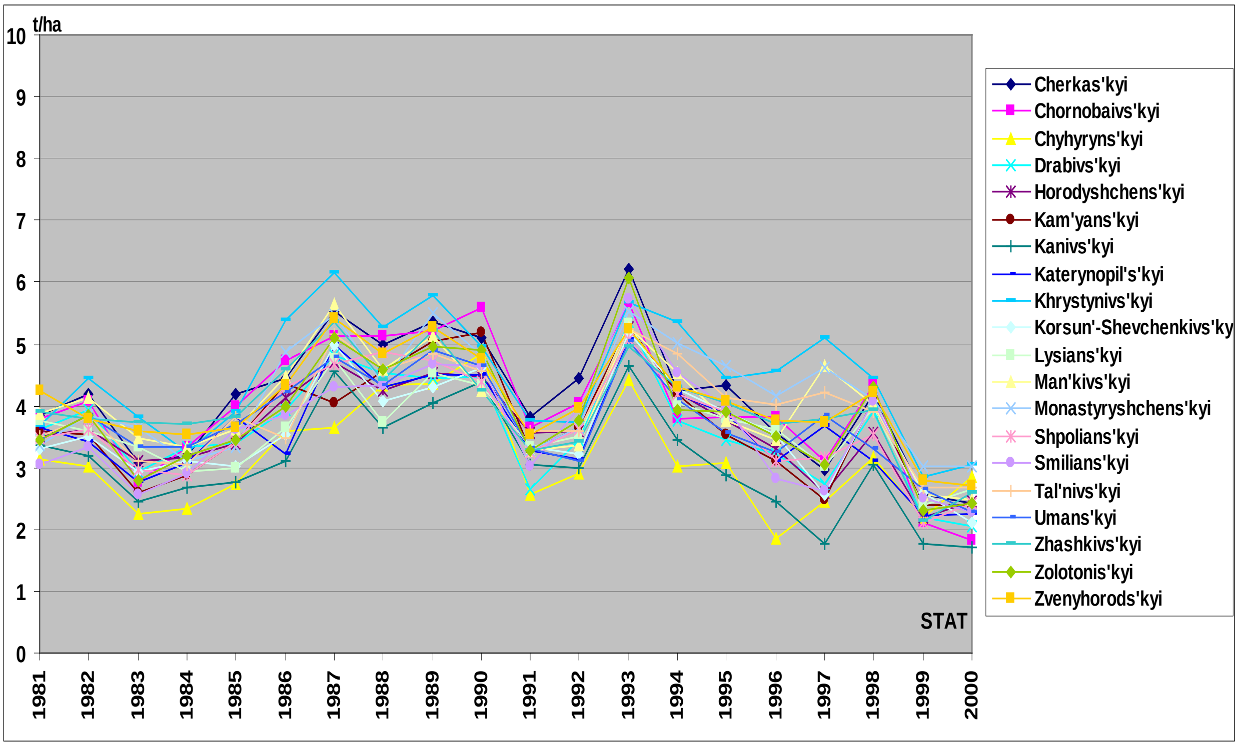


Figure 2b. Observed yields of winter wheat at rayon's level, Cherkas'ka oblast' (1981-2000)

Table 2c. Changes in means and variability of winter wheat estimated and observed yields at rayon's level, Cherkas'ka oblast' (1981-2000)

	National statistic (calculated on year-by-year basis)				AEZ (calculated on year-by-year basis)			
	Average yield (t/ha)		Coefficient of variation (%)		Average potential yield (t/ha)		Coefficient of variation (%)	
	1981-1990	1991-2000	1981-1990	1991-2000	1981-1990	1991-2000	1981-1990	1991-2000
Cherkas'kyi	4,4	3,9	19,6	28,7	6,3	6,0	14,8	9,6
Chornobaivs'kyi	4,4	3,6	21,2	30,2	6,7	6,4	20,2	14,7
Chyhyryns'kyi	3,4	2,9	25,8	24,2	6,5	6,1	18,0	12,8
Drabivs'kyi	3,9	3,3	15,7	29,6	7,2	6,9	17,7	14,1
Horodyshchens'kyi	3,9	3,5	15,4	26,2	7,0	6,6	16,6	13,3
Kam'yans'kyi	3,9	3,4	22,2	27,1	6,8	6,3	19,8	15,7
Kanivs'kyi	3,4	2,8	21,2	32,7	6,5	6,1	14,4	11,4
Katerynopil's'kyi	3,8	3,4	19,0	25,4	7,2	6,8	15,7	13,4
Khrystynivs'kyi	4,7	4,3	21,2	22,0	7,5	7,1	11,7	11,0
Korsun'-Shevchenkivs'ky	3,7	3,5	19,1	26,4	6,9	6,6	14,7	12,0
Lysians'kyi	3,8	3,6	16,4	22,9	7,4	7,0	12,0	11,2
Man'kivs'kyi	4,3	3,7	17,3	24,0	7,5	7,2	11,8	10,8
Monastyryshchens'kyi	4,2	4,1	21,3	20,8	7,7	7,3	9,7	10,4
Shpolians'kyi	3,9	3,4	18,9	24,6	7,1	6,7	17,9	15,2
Smilians'kyi	3,7	3,6	20,2	30,8	6,9	6,5	19,1	14,6
Tal'nivs'kyi	4,0	3,9	18,7	21,0	7,6	7,2	14,3	12,7
Umans'kyi	4,1	3,4	14,8	22,2	7,5	7,1	13,8	12,4
Zhashkivs'kyi	4,3	3,6	14,2	22,5	7,9	7,5	10,2	10,1
Zolotonis'kyi	4,0	3,7	20,3	29,3	6,9	6,6	18,3	12,8
Zvenyhorods'kyi	4,3	3,8	16,1	19,2	7,0	6,7	14,3	12,7
Cherkas'ka	**4,0**	**3,6**	**17,4**	**22,8**	**7,1**	**6,7**	**14,4**	**11,4**

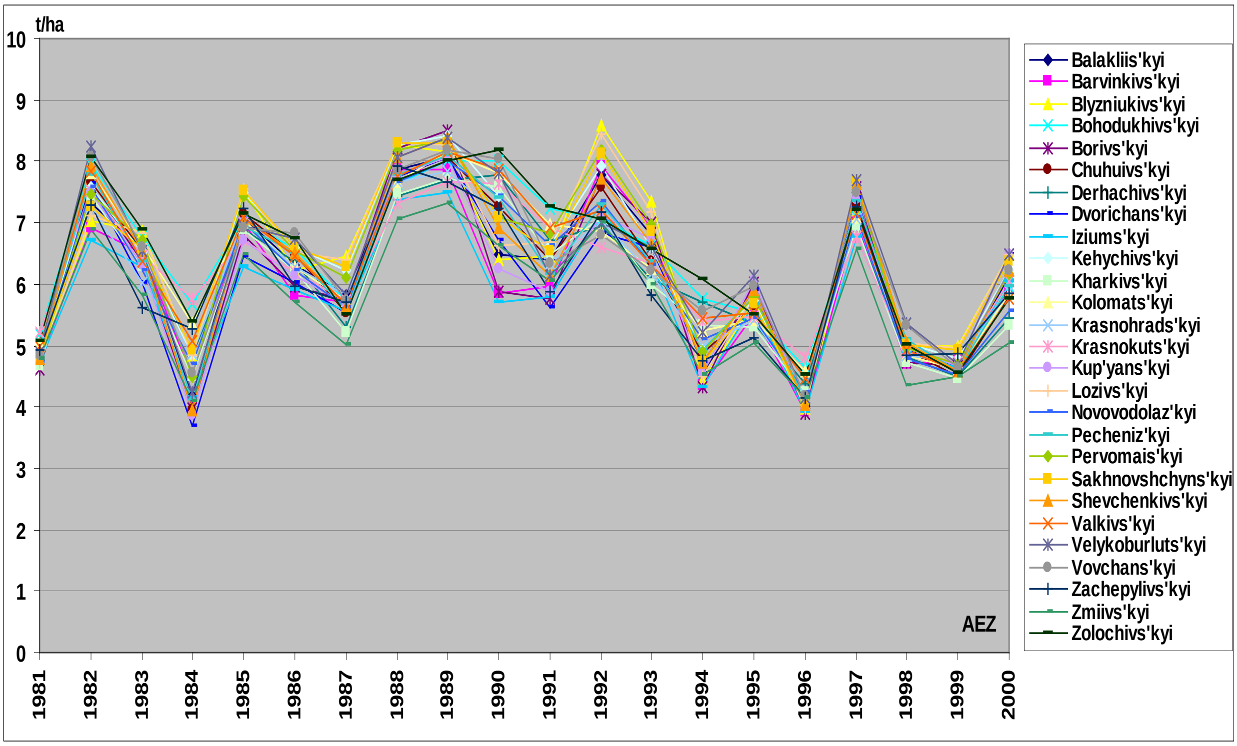


Figure 3a. Estimated potential yields of winter wheat at rayon's level, Khar'kivs'ka oblast' (1981-2000)

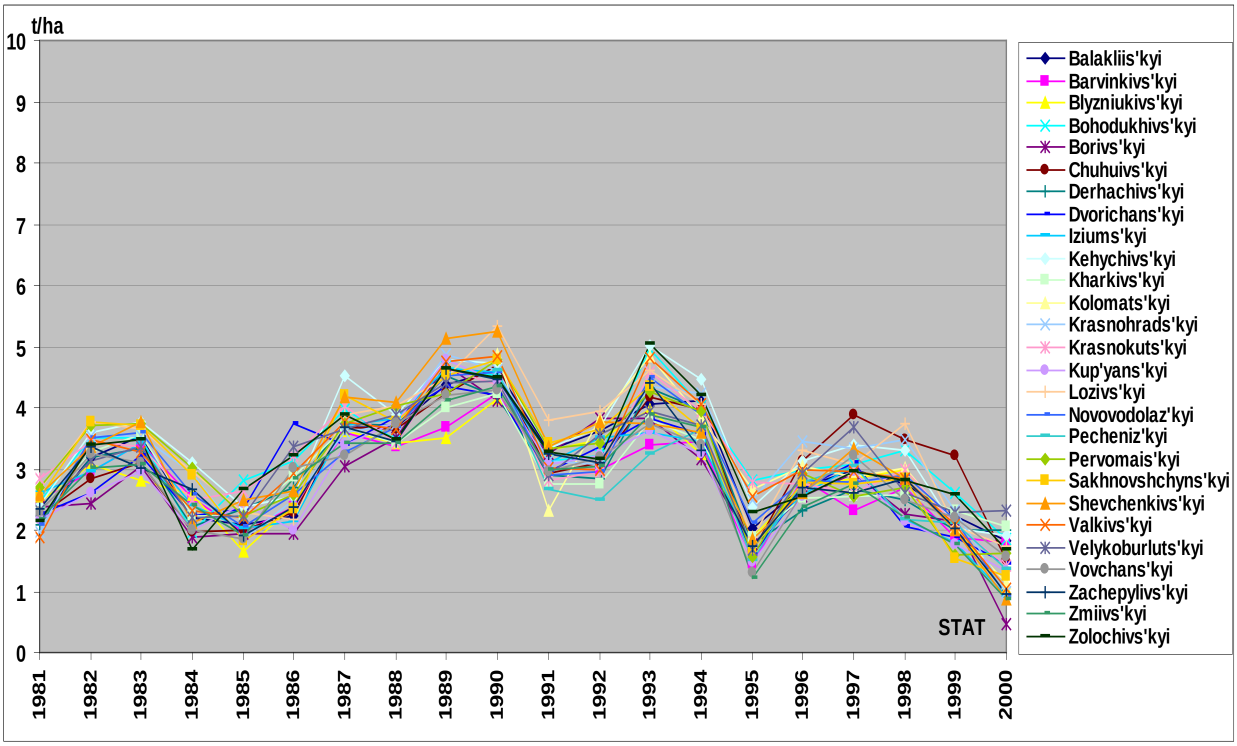


Figure 3b. Observed yields of winter wheat at rayon's level, Khar'kivs'ka oblast' (1981-2000)

Table 3c. Changes in means and variability of winter wheat estimated and observed yields at rayon's level, Khar'kivs'ka oblast' (1981-2000)

	National statistic (calculated on year-by-year basis)				AEZ (calculated on year-by-year basis)			
	Average yield (t/ha)		Coefficient of variation (%)		Average potential yield (t/ha)		Coefficient of variation (%)	
	1981-1990	1991-2000	1981-1990	1991-2000	1981-1990	1991-2000	1981-1990	1991-2000
Balakliis'kyi	3,2	3,0	29,9	27,4	6,4	5,8	19,6	21,9
Barvinkivs'kyi	3,1	2,6	23,2	26,7	6,3	5,7	18,6	22,7
Blyzniukivs'kyi	3,0	2,8	24,7	31,7	6,7	6,0	17,9	24,2
Bohodukhivs'kyi	3,4	3,2	25,3	25,9	6,9	6,0	15,4	17,0
Borivs'kyi	2,9	2,6	33,8	39,1	6,4	5,8	22,9	23,8
Chuhuivs'kyi	3,1	3,1	31,5	28,9	6,5	5,7	21,0	20,4
Derhachivs'kyi	3,2	2,7	27,1	30,8	6,5	5,7	18,0	17,1
Dvorichans'kyi	3,2	2,6	25,2	32,4	6,3	5,7	22,0	19,4
Iziums'kyi	3,2	2,6	29,4	34,9	6,0	5,6	17,6	19,4
Kehychivs'kyi	3,6	3,3	26,3	30,5	6,8	6,0	18,4	21,1
Kharkivs'kyi	3,2	2,7	23,4	22,0	6,4	5,6	19,2	17,9
Kolomats'kyi	…	3,0	…	35,0	6,8	5,8	16,6	16,9
Krasnohrads'kyi	3,3	3,1	30,5	31,7	6,5	5,7	16,5	17,5
Krasnokuts'kyi	3,4	2,9	20,9	30,2	6,6	5,8	13,5	14,6
Kup'yans'kyi	3,1	2,5	32,9	32,1	6,3	5,8	20,8	20,2
Lozivs'kyi	3,5	3,2	28,5	31,3	6,7	6,1	18,2	23,9
Novovodolaz'kyi	3,2	2,8	28,0	34,4	6,5	5,7	18,6	19,1
Pecheniz'kyi	…	2,5	…	29,1	6,5	5,8	20,4	18,8
Pervomais'kyi	3,5	2,8	23,4	34,9	6,7	6,0	19,3	22,6
Sakhnovshchyns'kyi	3,4	2,8	28,7	37,0	6,8	6,0	17,8	22,4
Shevchenkivs'kyi	3,6	2,8	31,2	34,2	6,6	5,9	21,8	21,5
Valkivs'kyi	3,3	2,9	30,4	34,6	6,7	5,8	17,7	17,7
Velykoburluts'kyi	3,3	3,0	25,6	25,1	6,8	6,0	21,2	18,3
Vovchans'kyi	3,1	2,7	27,3	29,7	6,8	5,9	19,9	16,7
Zachepylivs'kyi	3,2	2,7	28,2	35,3	6,5	5,6	16,9	18,5
Zmiivs'kyi	3,1	2,5	25,7	39,9	6,0	5,3	18,1	19,0
Zolochivs'kyi	3,3	3,1	28,5	31,4	6,9	6,0	17,2	17,7
Kharkivs'ka	**3,2**	**2,8**	**27,0**	**28,7**	**6,9**	**6,1**	**19,3**	**20,8**

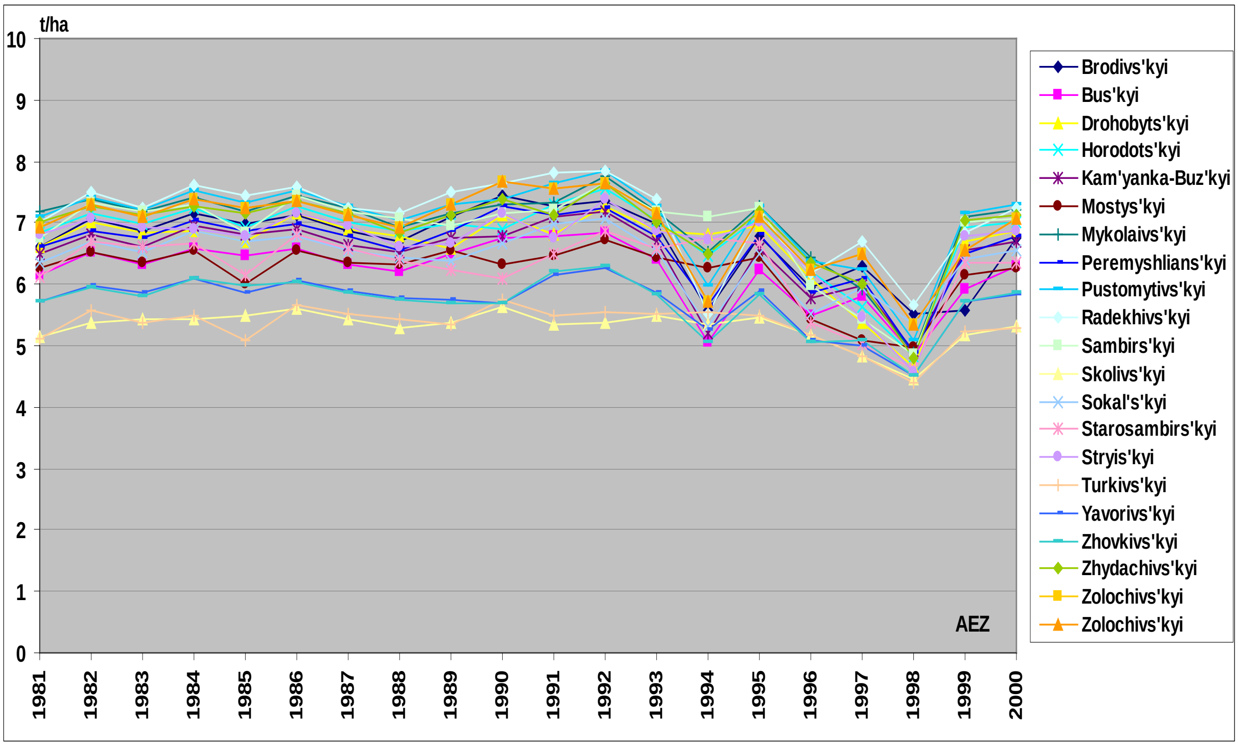


Figure 4a. Estimated potential yields of winter wheat at rayon's level, L'vivs'ka oblast' (1981-2000)

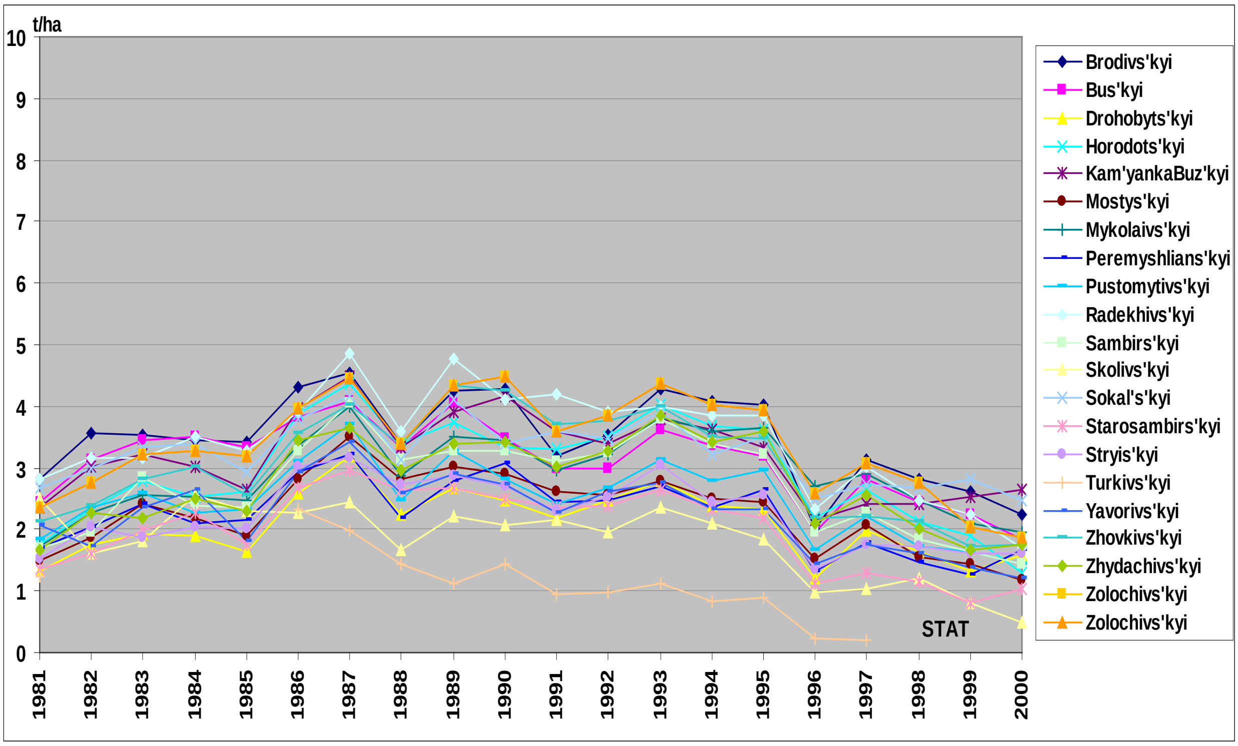


Figure 4b. Observed yields of winter wheat at rayon's level, L'vivs'ka oblast' (1981-2000)

Table 4c. Changes in means and variability of winter wheat estimated and observed yields at rayon's level, L'vivs'ka oblast' (1981-2000)

	National statistic (calculated on year-by-year basis)				AEZ (calculated on year-by-year basis)			
	Average yield (t/ha)		Coefficient of variation (%)		Average potential yield (t/ha)		Coefficient of variation (%)	
	1981-1990	1991-2000	1981-1990	1991-2000	1981-1990	1991-2000	1981-1990	1991-2000
Brodivs'kyi	7,0	6,4	3,5	11,1	3,8	3,2	14,6	24,6
Bus'kyi	6,4	6,0	2,9	11,3	3,5	2,7	13,9	22,0
Drohobyts'kyi	6,9	6,4	2,9	12,8	2,2	2,0	26,3	26,7
Horodots'kyi	7,0	6,6	2,2	12,8	3,1	2,8	26,3	32,4
Kam'yanka-Buz'kyi	6,7	6,3	2,3	12,3	3,4	3,0	20,3	20,5
Mostys'kyi	6,4	6,0	2,7	10,3	2,5	2,1	25,1	28,4
Mykolaivs'kyi	7,2	6,8	2,1	12,5	2,9	2,9	24,0	22,1
Peremyshlians'kyi	6,9	6,4	3,0	11,6	2,5	2,0	20,8	28,3
Pustomytivs'kyi	7,3	6,8	2,2	12,7	2,7	2,3	20,6	27,3
Radekhivs'kyi	7,4	6,8	2,9	12,0	3,7	3,2	18,4	28,8
Sambirs'kyi	7,1	6,7	3,1	13,7	2,8	2,6	25,4	32,8
Skolivs'kyi	5,4	5,2	2,6	6,3	2,1	1,5	16,0	44,3
Sokal's'kyi	6,6	6,2	2,6	10,4	3,4	3,1	14,7	16,6
Starosambirs'kyi	6,4	6,1	4,1	13,0	2,2	1,7	24,0	40,7
Stryis'kyi	6,9	6,5	2,7	13,0	2,4	2,1	23,6	26,4
Turkivs'kyi	5,4	5,3	4,0	7,1	1,6	0,7	29,7	50,3
Yavorivs'kyi	5,9	5,6	2,4	10,3	2,5	2,0	21,3	28,1
Zhovkivs'kyi	5,9	5,5	2,5	10,6	3,2	2,8	24,3	32,1
Zhydachivs'kyi	7,2	6,7	2,3	12,2	2,8	2,7	24,4	29,7
Zolochivs'kyi	7,2	6,7	3,1	11,3	3,5	3,2	20,8	27,3
L'vivs'ka	**6,7**	**6,3**	**2,2**	**10,6**	**2,8**	**2,8**	**20,0**	**18,6**

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IIASA—the International Institute for Applied Systems Analysis—located in Laxenburg, Austria, is an international, interdisciplinary research institution sponsored by a consortium of National Member Organizations in Asia, Africa, Europe, and North America. The Institute's research focuses on sustainability and the human dimensions of global change. Its studies are international and interdisciplinary, providing timely and relevant insights for the scientific community, policymakers, and the public. Research at IIASA addresses three core themes: Energy and Technology, Environment and Natural Resources, and Population and Society. Within these broad themes, projects focus on specific areas, such as energy, dynamic systems, new technologies, evolution, ecology, land use, forestry, transboundary air pollution, population, risk and vulnerability.

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