

## Irrigation Needs in Ukraine According to Current Aridity Level

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### ABSTRACT

Global climate change has led to significant shifts in local climatic conditions of Ukraine with the trend to aridity aggravation. Sustainable crop production is at risk due to the aridity level increase. The study is aimed to evaluate aridity index in Ukraine (on the whole country and individual regions' scales) and the needs in irrigation using hydro-meteorological data of the key regional stations for the periods of 1961–1990 and 2010–2020. The results of hydro-meteorological evaluation were supported by the data on the soil moisture regimes provided by Soil Explorer service. The general trend to aridity aggravation in Ukraine was proved. It was found out that modern climate in most territory of Ukraine is semi-arid, dry subhumid and humid zones are observed in the western regions only. Humid soil moisture regimes (ustic and udic) are observed in the West and the North of the country. As a result of combined analysis of both aridity index and soil moisture regimes the conclusion was drawn that 46.05% of Ukrainian croplands cannot provide sustainable crop production without irrigation, 42.65% need irrigation for the cultivation of crops with high water use, and just 11.30% of the arable land require little or no irrigation.

**Keywords:** aridity index; evapotranspiration; humidification; precipitation; soil moisture regime.

### INTRODUCTION

Global climate change, which is usually referred to as global warming, affects different spheres of life and industry. One of the most sensitive areas to climate change is agriculture as it is strongly dependent on weather patterns including distribution of precipitation, air and land surface temperature, wind, frosts, droughts, other extreme weather phenomena, etc. Agricultural activity is inseparably linked with environment, in which it is conducted, and they have mutual effect on each other. Therefore, deterioration of environmental conditions will certainly lead to a decrease in agricultural productivity, especially, in the field of crop production.

The main concern connected with global warming is gradual desertification, which is currently observed due to the climate change and irrational industrial activities in some regions of the Earth [Cherlet et al., 2018]. Most severely drought-affected regions are in Arab countries and in the North of Africa, but the trend

to enlargement of semi-arid areas in Australia, Central Asia, Central Africa, Eastern Europe, North America, etc., is evident. If we refer to the source [Kassas, 2008], we will find that in 1992 47.2% of terrestrial areas on the Earth were classified as drylands, while 19.6% belonged to extremely arid and arid climate zones. And the figure is growing each year.

The risks of desertification and aridity increase over the world have been pointing out since the late 90s' of the XX century. Little changes in precipitation amounts, which is sometimes accompanied by the increased unevenness of their distribution in time, under simultaneous increase in air temperatures by 0.5–1.0 °C and even more led to significant shifts in the humidity of climate, especially in most vulnerable territories [Le Houerou, 1996]. Climate change will result in change of natural vegetation cover, which is extremely sensitive to weather patterns, and, of course, it will change the situation in crop production [Von Handenberg et al., 2001]. The impact of global warming

on agricultural production is undebatable fact. Most concerns relate to uncertainty in irrigation water demands for different crops in different regions, because while some crop production zones and some types of crops could ripen the benefits due to climate change [Woznicki et al., 2015], other regions could be doomed to failure if no sufficient water for irrigation would be available. For example, the projection for wheat and corn production in Turkey forecasts the increased demand for irrigation in wheat and the decreased one for corn [Yano et al., 2007]. However, most studies claim that irrigation demands are more likely to increase due to the climate change in many agricultural districts of the world [Elgaali et al., 2007; Fischer et al., 2007; Rehana & Mujumdar, 2013]. But the evidence is for that fact that humidification and irrigation water demand change differently in different areas of the world, so there is no universal pattern. Therefore, nowadays the issue of determining possible shifts in humidification regime in the certain crop production area is relevant because it is the question of food safety guarantee.

Ukraine is one of the leading agricultural countries in Europe [Chryniewicz et al., 2016]. Agriculture is a powerful sector of the economy in Ukraine, however, there is the evidence that recent climate change is challenging for national

crop producers because it resulted in dramatical shift in the crop cultivation technology, and previously substantiated irrigation requirements for most crops are out of date now because of huge change in natural humidification conditions. The goal of our study is to determine the change in natural humidification in the territory of Ukraine and revise the demand for irrigation in the country in modern climate conditions.

## MATERIALS AND METHODS

The study was carried out for the territory of Ukraine (Figure 1) using historical meteorological data from the key stations of each oblast, which were averaged for the periods of January 1st – December 31st of 1961–1990 and 2010–2020 years.

Historical monthly meteorological data, including sunshine duration in hours, minimum, mean, and maximum air temperature, mean relative humidity, and wind speed were processed using ETo Calculator software by FAO to calculate potential evapotranspiration (PET) rates for each region of the country [Raes & Munoz, 2009]. Further, the obtained PET values were averaged for each of the studied period and the Aridity Index (AI) was calculated using the formula (1) [Haider & Adnan, 2014]:



Figure 1. Ukraine in the map of Eastern Europe

$$AI = P / PET \quad (1)$$

where: *P* is precipitation amount, mm; *PET* is potential evapotranspiration, mm.

The classification of climate by the values of AI was conducted using the guidelines by Colantoni et al. [2015] (Table 1).

Soil moisture regimes were studied using the information provided by Soil Explorer

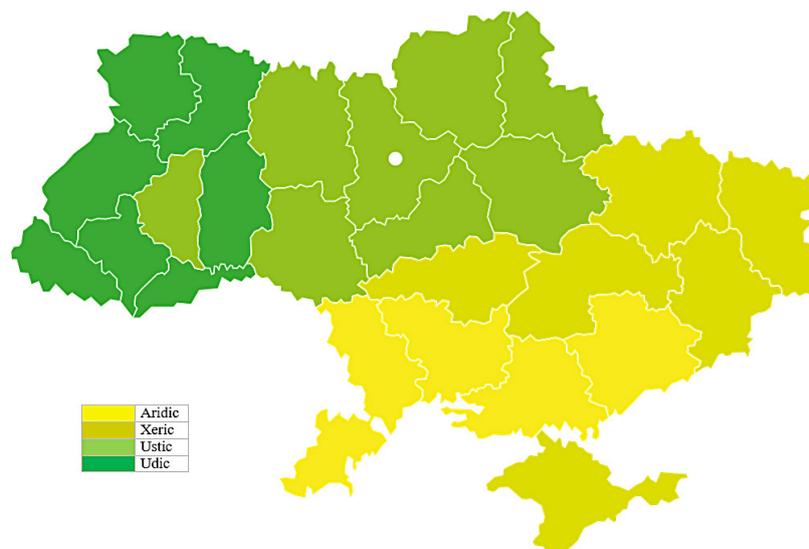
service, which is based on specialized interpretations of the USA’s massive SSURGO database [Miller et al., 2018]. Humid soil moisture regimes are udic and ustic, while arid ones are xeric and aridic. The detailed map of soil moisture regimes was transformed into the simplified one by the prevailing soil moisture regime type in each oblast of Ukraine (Figure 2).

Classification of the territory by the demand for irrigation was performed using the developed methodology, explained in the Table 2, which involves the combined estimation both of soil moisture regime and climate type of each oblast.

To sum up the results of the study, the mapping of the AI and irrigation demands in the territory of Ukraine in the two studied time periods was performed to visualize the trend to aridity increase. The share of croplands, which need irrigation, was calculated based on the surveys of cropland areas

**Table 1.** Aridity Index (AI) values and type of climate

Aridity Index (AI) values	Climate type
<0.05	Hyper arid
0.05–0.20	Arid
0.20–0.50	Semi-arid
0.50–0.65	Dry subhumid
0.65–0.75	Humid
>0.75	Hyper humid



**Figure 2.** Prevailing soil moisture regimes in the territory of Ukraine

**Table 2.** Methodology of classification of the territory of Ukraine by the demand for irrigation

Soil moisture regime	Climate type	Demands for irrigation
Aridic	Semi-arid	Mandatory
Xeric	Semi-arid	Mandatory
Xeric	Dry subhumid	Advisable for the crops with high water use rates
Ustic	Semi-arid	Advisable for the crops with high water use rates
Ustic	Dry subhumid	Required for some highly demanding for water crops
Ustic	Humid	Not needed
Ustic	Hyper humid	Not needed
Udic	Semi-arid	Advisable for the crops with high water use rates
Udic	Dry subhumid	Required for some highly demanding for water crops
Udic	Humid	Not needed
Udic	Hyper humid	Not needed

in the country dated 2019 (with accordance to State Statistical Service Yearbook) [Verner, 2019].

It should be mentioned that due to the course of political change, Luhans'ka and Donets'ka oblasts are no more under control of Ukraine since April 27th, 2014. Besides, the autonomic republic of Crimea is under the control of Russian Federation since March 21st, 2014, and it is not the zone of Ukraine's economic activity at present. Therefore, the evaluation of climate indices for Luhans'ka and Donets'ka oblasts for the period of 2010–2020 was impossible, and they are marked gray in the maps. The data for Crimea was obtained, however, this peninsula cannot be considered as a part of the territory of Ukraine anymore. Therefore, the calculation of the share of croplands, which need irrigation, was performed for both studied periods excluding the above-mentioned regions from the accounted area.

## RESULTS AND DISCUSSION

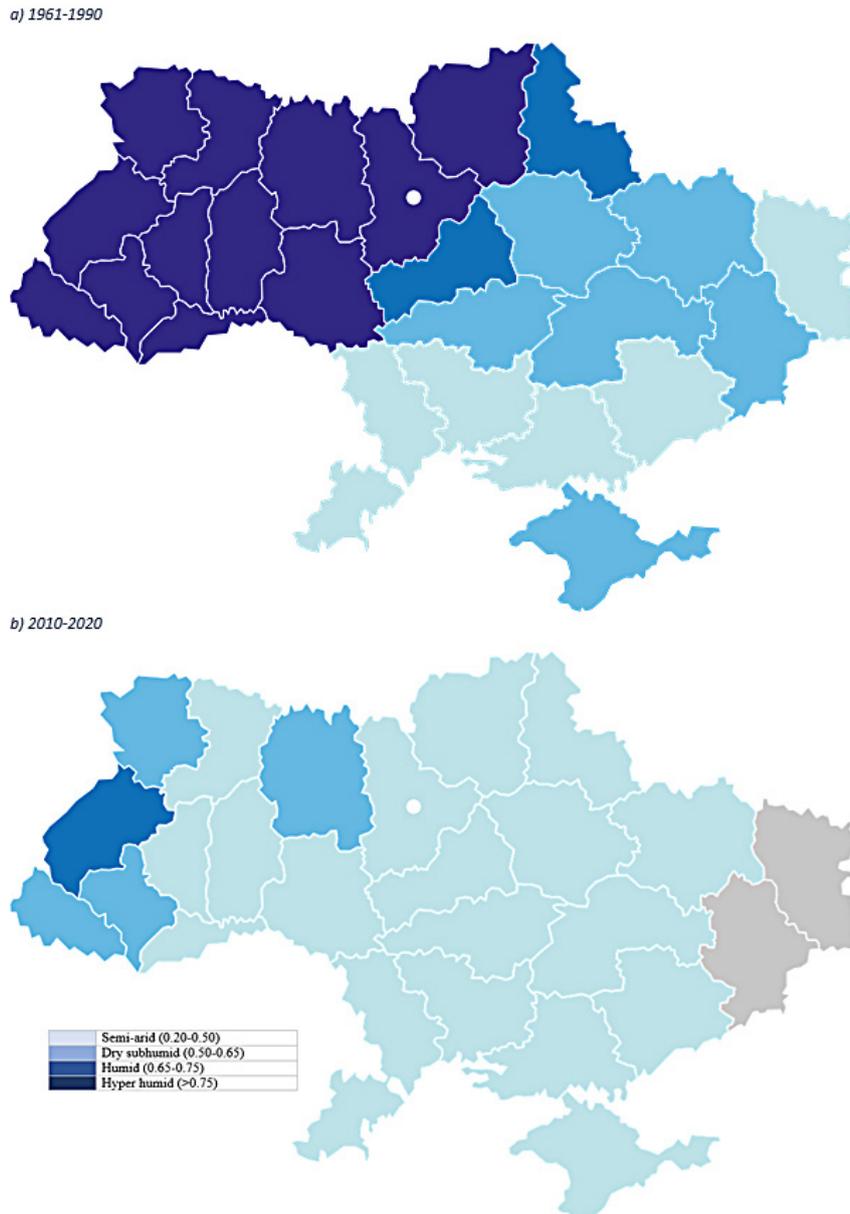
In the result of the Aridity Index computations, the climate peculiarities for every oblast of Ukraine were obtained, which were visualized on the map of the country to provide better understanding of the dynamics in climate patterns change (Table 3, Figure 3).

As the study results testify, the difference in the average AI for the whole territory of Ukraine between the studied periods is  $-0.30$ , that is the territory of the country gradually becomes significantly more arid than it used to be 30 years ago (Table 4). The greatest level of aridity increase is observed in the western regions of the country, Kyivs'ka and Vinnyts'ka oblasts – the difference for these regions is within the range of  $-0.37$ – $0.47$  (the greatest for Ternopils'ka oblast). At the same time, initially

**Table 3.** Climate peculiarities and soil moisture regimes in the territory of Ukraine according to the Aridity Index and Soil Explorer surveys for the periods of 1961–1990 and 2010–2020

Oblast	Soil moisture regime	Aridity Index (1961-1990)	Climate type (1961-1990)	Aridity Index (2010-2020)	Climate type (2010-2020)
Cherkas'ka	Ustic	0.67	Humid	0.42	Semi-arid
Chernivets'ka	Udic	0.85	Hyper humid	0.46	Semi-arid
Chernihivs'ka	Ustic	0.81	Hyper humid	0.48	Semi-arid
Dnipropetrovs'ka	Xeric	0.56	Dry subhumid	0.35	Semi-arid
Ivano-Frankivs'ka	Udic	0.93	Hyper humid	0.54	Dry subhumid
Kharkivs'ka	Xeric	0.57	Dry subhumid	0.36	Semi-arid
Khersons'ka	Aridic	0.40	Semi-arid	0.30	Semi-arid
Khmelnyts'ka	Udic	0.86	Hyper humid	0.46	Semi-arid
Kirovohrads'ka	Xeric	0.56	Dry subhumid	0.32	Semi-arid
Kyivs'ka	Ustic	0.88	Hyper humid	0.46	Semi-arid
Lvivs'ka	Udic	1.08	Hyper humid	0.66	Humid
Volyns'ka	Udic	0.80	Hyper humid	0.57	Dry subhumid
Mykolaivs'ka	Aridic	0.47	Semi-arid	0.34	Semi-arid
Odes'ka	Aridic	0.45	Semi-arid	0.48	Semi-arid
Poltavs'ka	Ustic	0.60	Dry subhumid	0.43	Semi-arid
Rivnens'ka	Udic	0.81	Hyper humid	0.44	Semi-arid
Sums'ka	Ustic	0.74	Humid	0.41	Semi-arid
Ternopils'ka	Ustic	0.90	Hyper humid	0.43	Semi-arid
Zakarpats'ka	Udic	0.90	Hyper humid	0.58	Dry subhumid
Vinnyts'ka	Ustic	0.80	Hyper humid	0.40	Semi-arid
Zaporiz'ka	Aridic	0.49	Semi-arid	0.42	Semi-arid
Zhytomyrs'ka	Ustic	0.83	Hyper humid	0.60	Dry subhumid
Crimea*	Xeric	0.54	Dry subhumid	0.37	Semi-arid
Luhans'ka**	Xeric	0.43	Semi-arid	–	–
Donets'ka**	Xeric	0.54	Dry subhumid	–	–

\* - Crimea is under the control of Russian Federation since March 21<sup>st</sup>, 2014; \*\* - Luhans'ka and Donets'ka oblasts have separated since April 2014.



**Figure 3.** Dynamics of climate patterns change in the territory of Ukraine according to the values of the aridity Index

semi-arid southern regions of Ukraine demonstrated the least reaction to the climate change (the difference within  $-0.07$ – $-0.13$ ), and even some improvement of natural humidification is observed for Odes'ka oblast ( $+0.03$ ).

By the results of the Aridity Index calculations and soil moisture regimes surveys the demands for irrigation by every oblast of Ukraine was determined and mapped according to the developed methodology of classification (Figure 4).

The trend to the aridity increase resulted in significant enlarge in the territory requiring irrigation for sustainable crop production. The calculation of the share of the territories with

different demands for irrigation testifies that nearly 90% of the territory of Ukraine are currently needing irrigation to grow the full specter of crops, while in the period of 1961–1990 this area shared just about 55% or was nearly twice less (Table 5). Nowadays, just a single region of the country (Lvivs'ka oblast) can cope with crop production under the rainfed conditions. The most vulnerable regions are located in the South of Ukraine (so-called coastal Black Sea area including Khersons'ka, Mykolaivs'ka, Odes'ka and Zaporiz'ka oblasts) and in the center of the country (Dnipropetrovs'ka, Kirovohrads'ka oblasts). Sufficient natural humidification and favorable

**Table 4.** Change in the Aridity Index in the territory of Ukraine in the period of 2010–2020 in comparison to the period of 1961–1990

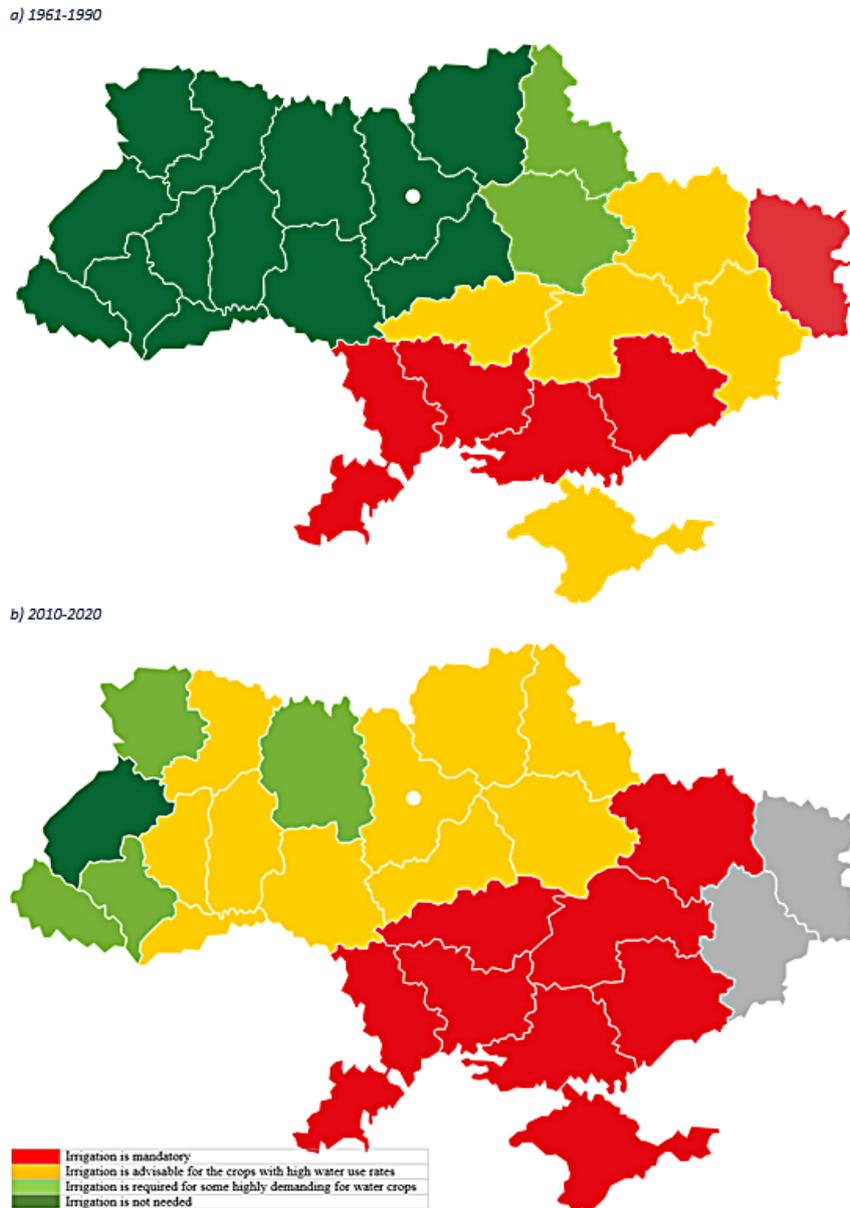
Oblast	Aridity Index (1961-1990)	Aridity Index (2010-2020)	Difference ( $\pm\Delta$ )
Cherkas'ka	0.67	0.42	-0.25
Chernivets'ka	0.85	0.46	-0.39
Chernihivs'ka	0.81	0.48	-0.33
Dnipropetrovs'ka	0.56	0.35	-0.21
Ivano-Frankivs'ka	0.93	0.54	-0.39
Kharkivs'ka	0.57	0.36	-0.21
Khersons'ka	0.40	0.30	-0.10
Khmelnys'ka	0.86	0.46	-0.40
Kirovohrads'ka	0.56	0.32	-0.24
Kyivs'ka	0.88	0.46	-0.42
Lvivs'ka	1.08	0.66	-0.42
Volyns'ka	0.80	0.57	-0.23
Mykolaivs'ka	0.47	0.34	-0.13
Odes'ka	0.45	0.48	+0.03
Poltavs'ka	0.60	0.43	-0.17
Rivnens'ka	0.81	0.44	-0.37
Sums'ka	0.74	0.41	-0.33
Ternopils'ka	0.90	0.43	-0.47
Zakarpats'ka	0.90	0.58	-0.32
Vinnys'ka	0.80	0.40	-0.40
Zaporiz'ka	0.49	0.42	-0.07
Zhytomyrs'ka	0.83	0.60	-0.23
Crimea*	0.54	0.37	-0.17
Luhans'ka**	0.43	–	–
Donets'ka**	0.54	–	–
Average for the whole country			-0.30

\* - Crimea is under the control of Russian Federation since March 21<sup>st</sup>, 2014; \*\* - Luhans'ka and Donets'ka oblasts have separated since April 2014.

water balance according to the results of the study is observed only in five oblasts, which are concentrated in North-Western part of the country, while in 1961–1990 period there were fifteen (thrice more) regions, which were characterized with favorable water supply.

The results of our study are supported by the results obtained for the previous (1991–2016) period by Romashchenko et al. [2017], who first pointed out the problem of growing increase in the aridity in the territory of Ukraine, testifying that the area of hyper humid and humid zones of the country decreased by 10.0%, and the territory of insufficiently humid, dry, and extremely dry areas increased by 13.0% in comparison to 1961–1990. But now (for the period 2010–2020) it is evident that the aridity level of the Ukraine's territory is on the pace to greater increase in the severity of

aridity in the country even compared to the period of 1991–2016. The work by Vozhegova & Kokovikhin [2018] also claims that to provide for competitiveness and stability of Ukrainian crop production irrigation development is urgent, and steps for the reconstruction of present and building new irrigation systems is required to satisfy the demands for water in agricultural sector of the economy. Such ideas were also proposed by another domestic Ukrainian scientists, but they mainly focused their attention on the zone of the South of Ukraine [Maliarchuk et al., 2018], [Vozhehova et al., 2020]. But not only domestic scientists are calling for steps to diminish negative impacts of climate change on agriculture. It is highlighted that water balance modeling testifies that the trend to an increase in water demands for crop production is obvious reality for all the



**Figure 4.** Irrigation requirements in the territory of Ukraine according to the Aridity Index and soil moisture regime

**Table 5.** Demands for irrigation in the territory of Ukraine in the periods of 1961–1990 and 2010–2020 according to the climate change patterns, share of the total croplands area

1961-1990	2010-2020	Demands for irrigation
25.07%	46.05%	Mandatory
20.97%	42.65%	Advisable for the crops with high water use rates
11.10%	8.64%	Required for some highly demanding for water crops
42.86%	2.66%	Not needed

countries of Mediterranean basin [Gorguner & Kavvas, 2020]. Therefore, it is urgent not only to ensure the satisfaction of crops’ demands for irrigation water in the regions where irrigation systems are readily available, but also it is needed to

find the ways of irrigation water supply in the territories where irrigation was not previously present, e.g., the West and the North of Ukraine. Besides, transfer from old (furrow, surface, sprinkler) ways of irrigation to modern water-saving ones (drip,

drip subsurface, micro-sprinkler) should be done to save water resources and provide the best out pay of them [Wang et al., 2021].

## CONCLUSIONS

The study on the climate change and consequent change in irrigation demand in Ukraine discovered the main regularities and trends in this process. Current climate change in Ukraine shows an obvious trend to aridity increase on the whole territory, excluding just coastal region of Odes'ka oblast. Increased aridity of the climate requires revision of irrigation demand in the country, which embraces the change in the areas needing irrigation for sustainable crop production. As for the period of 2010–2020, 46.05% of Ukrainian croplands require mandatory irrigation, 51.29% require irrigation for some crops, and only 2.66% of the croplands might remain rainfed. Coping with current climate change challenge requires extension of irrigation systems in Ukraine and transferring to water-saving cultivation and irrigation techniques to guarantee satisfactory level of provision of crop production with water.

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