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ORIGINAL ARTICLE

The influence of climate changes on crop yields in Western Ukraine

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Increasing the heat resource and limiting the rainfall in the North-Western Forest Steppe of Ukraine resource contributed to a rapid increase in the yield of winter wheat, thermophilic soybeans, and, in particular, maize and other dominant crops. The acreage of these and other thermophilic crops is now larger than in 2000. The purpose of our work was to find out the trends of temperature and humidity in the climate, which determined the crop restructuring and yields in the Ukrainian North-Western Forest Steppe. We use paleoclimatology and paleoecology methodologies with verbal and graphic models and weather data for the Rivne (Ukraine) weather station and data on the structure of acreage and crop yields of the Main Directorate of Statistics of Ukraine in the Rivne region. We conducted field research during 1985–2018 in a stationary field of the Institute of Agriculture of Western Polissya NAAS (Ukraine). The heat supply of landscape agroecosystems has improved significantly. The average annual air temperature has been growing, especially in the period 2003–2018. The analysis of the sums of effective temperatures above 5 and 10 °C since 1961 over five years shows their steady growth. We noted an increase in annual rainfall from 1988 to 1992. They reached 634 mm during 1998–2007, which is 65 mm or 11.4% more than the climatic norm. However, their number decreased in 2013–2018, and in 2018 they were below the norm of 569 mm by 29%. The rapid increase in the sums of effective temperatures created favorable conditions for the cultivation of thermophilic crops such as corn, soybeans, and sunflowers in the Northwestern Forest Steppe. As these crops are rapidly expanding, the acreage structure and the general agro-landscapes in the region are very similar to the Southern Right-Bank Forest Steppe.
Keywords: climate change, temperature, rainfall, moisture content, thermophilic crops, yield.

Introduction

Climate change on Earth is progressing rapidly (Williams & Jackson, 2007; Right to development, 2015). It is probably because of global geomatic and astrophysical processes (Petit et al., 1999; Petit & Delmonte, 2009; Albani et al., 2018; Schneider et al., 2016; Schneider et al., 2017; Ziese et al., 2018). Today, this change is perhaps one of the least studied causes of the dynamics and evolution of biome and landscape ecosystems (Williams & Jackson, 2007), prospects for agro-industrial development (Olesen et al., 2011; White et al., 2011; Shi et al., 2012; Climate Change and Land, 2020), directions of transformations in the economy and development of the human society (Right to development, 2015; Hnativ, 2016; Hnativ & Snintynskyy, 2017).
Fundamental palaeoclimatic studies (Rapp, 2019) and many graphical models (Fig. 1) indicate that Holocene had a much more rapid rise in the surface-atmosphere temperature than we observe today. The magnitude of the current challenges in the global population of 7.7 billion can be judged because different predictive models have been developed for both global (White et al., 2011) and biome (Olesen et al., 2011) climate change even for the next 50–100 years old, and they are not straightforward or optimistic.
In particular, they consider agriculture in Ukraine the industry most dependent on agro-climatic conditions (Boychenko et al., 2016; Osadchyy & Babichenko, 2012; Petrychenko et al., 2013; Tarariko et al., 2016). They require the systematic study of the characteristics and trends of changes in agroclimatic resources components to substantiate sustainable agricultural development strategies (Memorized agroecosystems, 2017; Veremeienko et al., 2016). Petrychenko et al. (2013) and Osadchyy & Babichenko (2012) believe that the speed of adaptation to climate change depends on the rational use of heat resources in agriculture. However, the development of practical measures for the adaptation of the agricultural sector in the regions is constrained by the unformed scientific basis for solving this problem and the limited results of monitoring studies of the processes occurring in the agro- and natural ecosystems under the influence of local climate warming.
The purpose of our work is to determine the relationship between the parameters of western Ukraine's climate and crops restructuring and yields in the North-Western Forest-Steppe.

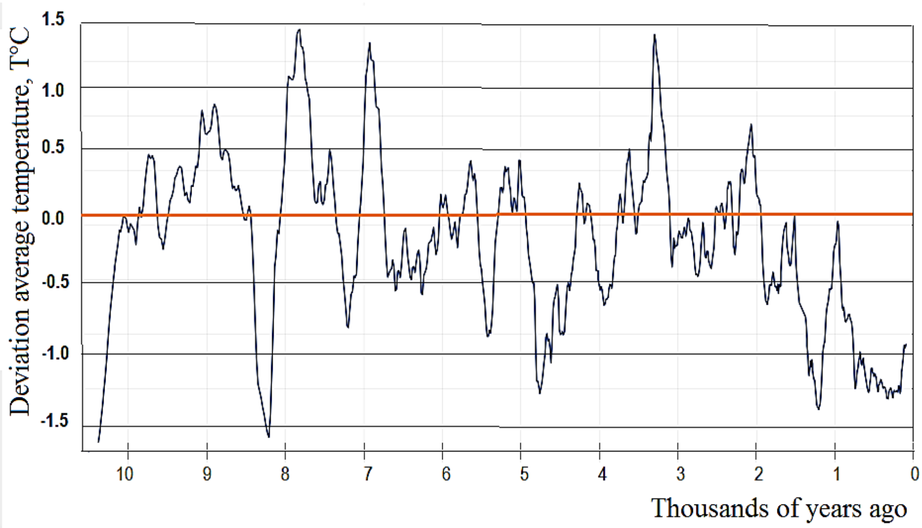


Fig. 1. Graphical model of Eurasian air temperature dynamics in Holocene, °C (Rapp, 2019)

Materials and Methods

We use paleoclimatology and paleoecology methodologies to reconstruct climate change in verbal and graphic models (Schönwiese, 2008; Fagan, 2008; Birks et al., 2010; Braconnot et al., 2012; Easterbrook, 2014; Rapp, 2019). We also used weather data of the weather station of Rivne (Ukraine) and data on the structure of acreage and crop yields of the Main Directorate of Statistics of Ukraine in the Rivne region (www.rv.ukrstat.gov.ua).

We conducted field research in the North-Western Forest-Steppe of Ukraine during 1985–2018 in a stationary field experiment of the Institute of Agriculture of western Polissya NAAS (Rivne, Ukraine). We performed laboratory analyzes using standard methods (State Standard..., 2005a; 2005b; 2015a; 2015b).

Results and Discussion

The western regions of Ukraine belong to the area with the most active growth of heat supply. The average annual air temperature exceeded 7 °C during 1987–1992 (Fig. 2). The average air temperature increased linearly. Thus, it was 8.3 in 1988–1992, and it dropped to 7.3 °C in 1993–1997 (Fig. 2).

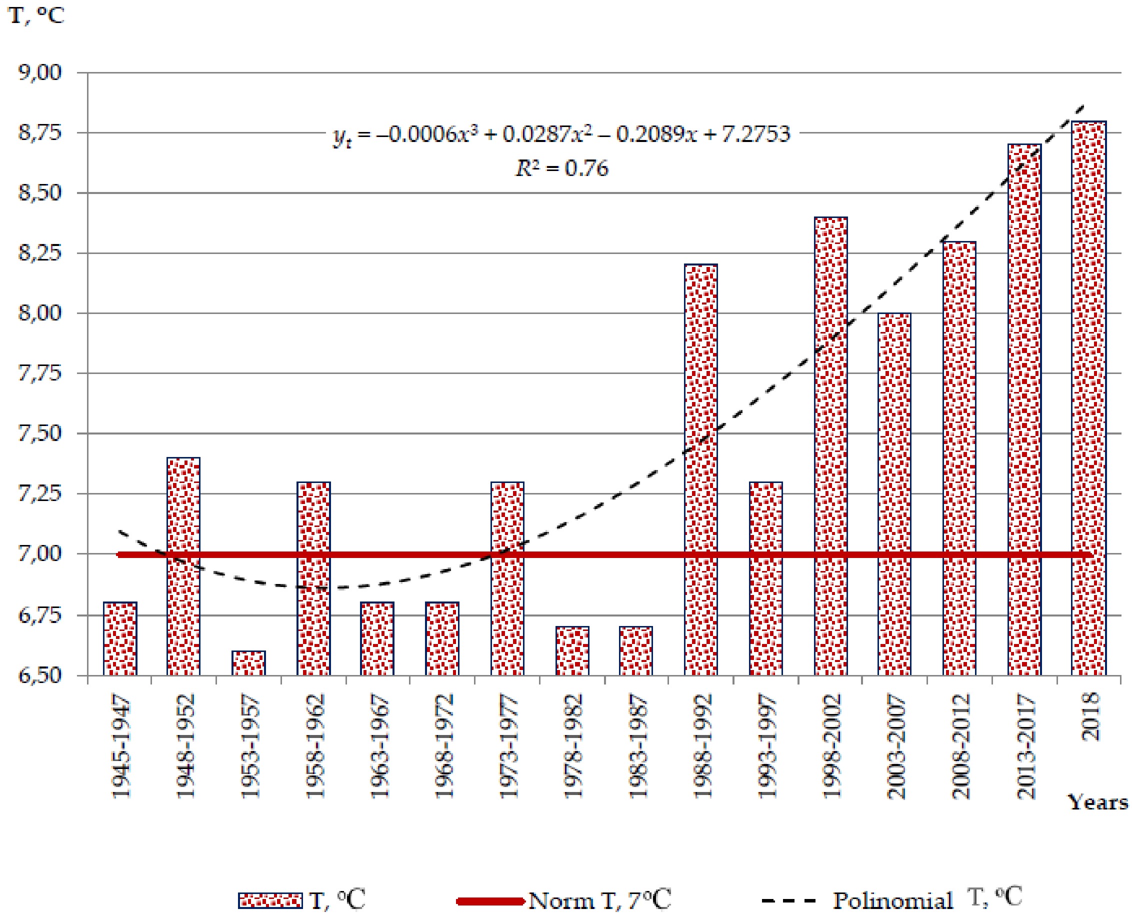


Fig. 2. Regression model of dynamics and reliability of approximation of the trend of average annual air temperature for the period 1945–2018 according to the meteorological station in Rivne, °C

The average annual temperature has continuously been rising during 2003-2018, reaching 8.8 °C for 2018, and it has exceeded the norm by almost 1.8 °C. It is important to note that the average annual temperature increase was primarily because of the warming of the summer months, though the winter months were also somewhat warmer.

The third-degree polynomial model, $y_t = -0.0006x^3 + 0.0287x^2 - 0.2089x + 7.2753$, whose curve has a high coefficient of approximation $R^2 = 0.76$ to the actual course of indicators most accurately describe the long-term dynamics of the average monthly temperature of the terrestrial atmosphere.

The sum of effective temperatures during the growing season is one of the major criteria for assessing the optimality of cultivation of individual crops, their varieties and hybrids with different timing of the grain ripening phase. Naturally, it increased in proportion to the increase in average air temperature (Fig. 3).

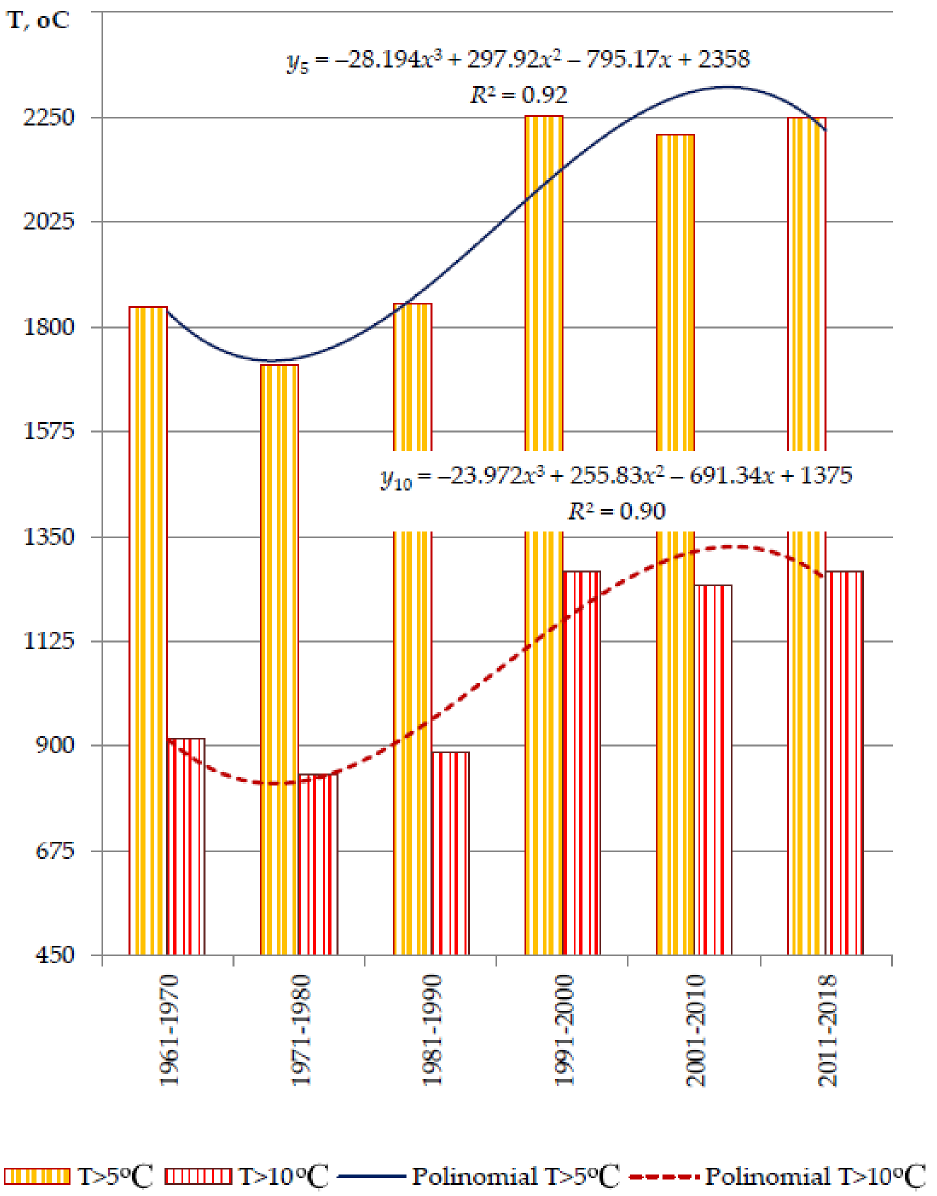


Fig. 3. Regression model and the reliability of approximation of the trend of long-term dynamics of the sum of active (> 5 °C) and effective (>10 °C) temperatures in 1961–2018 according to the weather station in Rivne (Ukraine), °C.

The analysis of the sums of effective temperatures above 5 and 10 °C since 1961 over five-year periods show their steady growth. Thus, the sum of effective temperatures >5°C in 1971–1980 was 1718 °C, and it increased to 2248 °C in 2011–2018 (the growth was 30.8%). The sum of effective temperatures >10 °C during this period increased from 840 °C to 1277 °C, or by 52.0%. Before the onset of rapid warming, the sum of effective temperatures >10 °C was characteristic of the Southern (warm) Podillya mezoclimate (Vinnytsia region, Ukraine).

Polynomial models of the third degree: $y_5 = -28.194x^3 + 297.92x^2 - 795.17x + 2358$, whose curve has a very high coefficient of approximation $R^2 = 0{,}91$ to the actual course of indicators and $y_{10} = -23.972x^3 + 255.83x^2 - 691.34x + 1375$, whose curve also has a very high coefficient of approximation $R^2 = 0.90$, most accurately describes the long-term dynamics of the sum of active (>5 °C) and effective (>10 °C) temperatures in 1961–2018.

The influence of weather on plant growth and development is primarily manifested through soil moisture availability and, the crops moisture content (Schneider et al., 2016; 2017; Ziese et al., 2018).

There is a close correlation between soil moisture, annual rainfall, and monthly dynamics (Schönwiese, 2008). Over the last 20 years, we have noticed an increase in the annual rainfall. It was 634 mm in 1998–2007 (65 mm, or 11.4% more than the norm) and 602 mm in 2008-2017, which was 33 mm (5.8%) higher than the norm. However, the rainfall decreased in 2013–2018, and in 2018 it was 569 mm or 29% below the norm (Fig. 4).

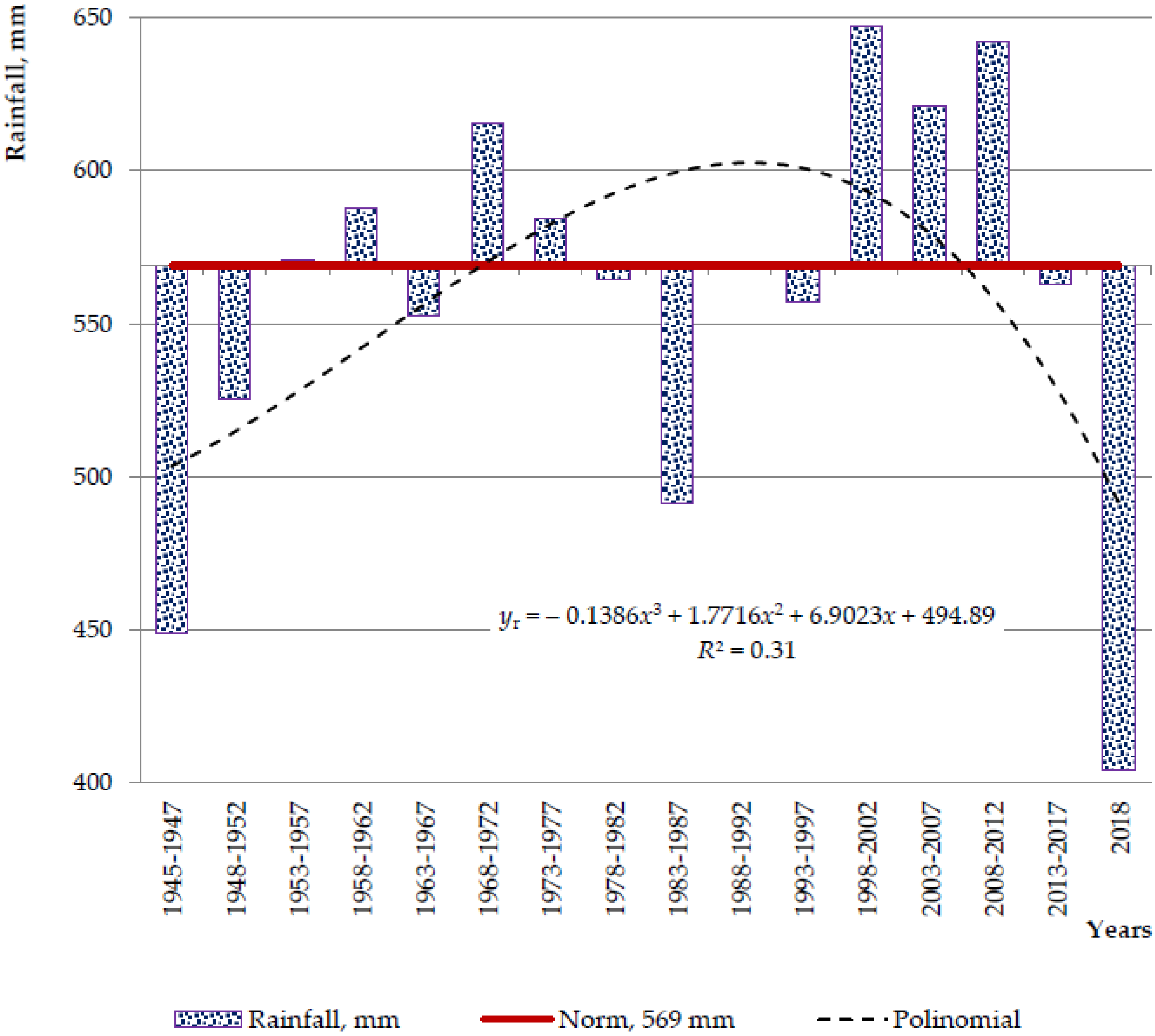


Fig. 4. Comparison of the dynamics of stocks of productive moisture under winter wheat during 1985–1990 and 2013–2018,

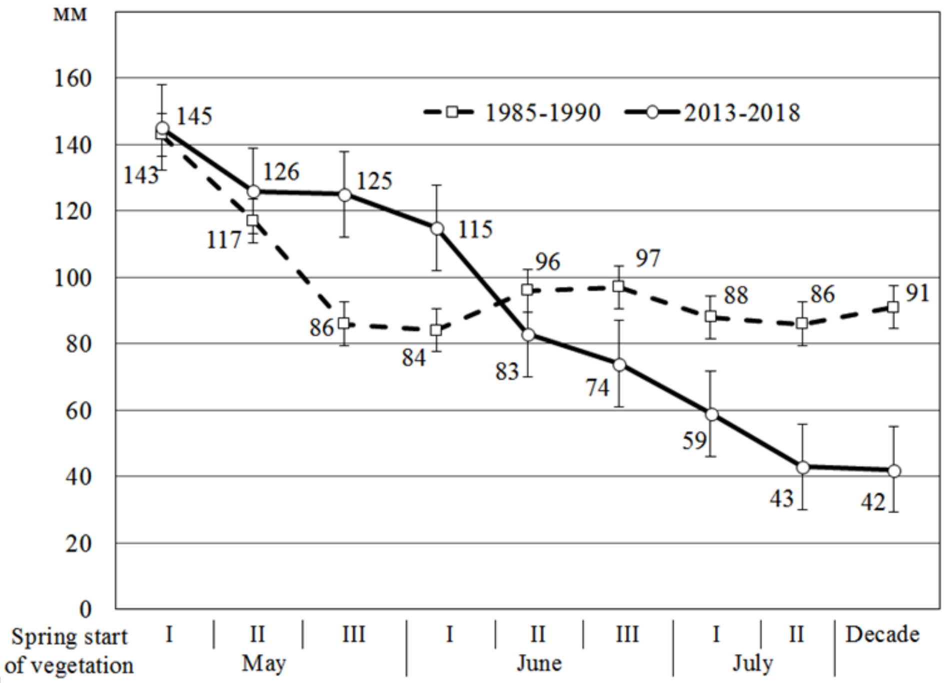
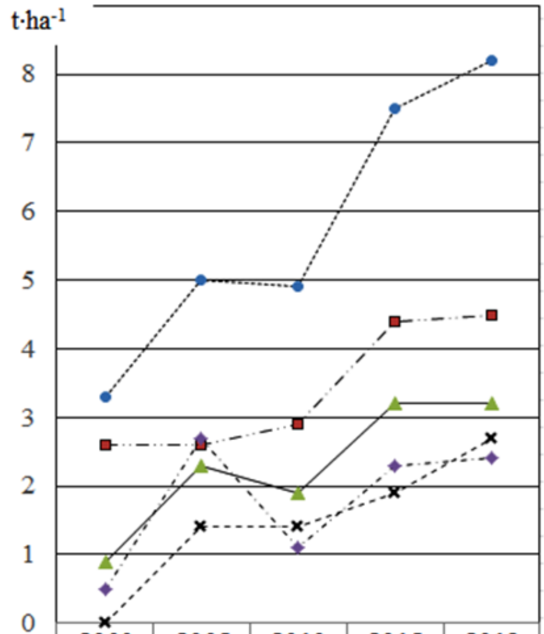


Fig. 5. Comparison of the dynamics of stocks of productive moisture under winter wheat during 1985–1990 and 2013–2018, mm

However, the statistical cumulative annual rainfall and the growing season cannot be self-sufficient basic criteria for assessing the actual moisture supply of crops during their growth and development. We compared their dynamics under winter wheat for 1986-1990 and 2014-2018 to assess climate change's impact on soil moisture supplies (Fig. 5).
The above data show the processes caused by the warming in the panic-western forest-steppe of Ukraine have significantly reduced the plants' water supply. We found that the reserves of productive moisture under winter wheat in the 0–100 cm soil layer in June-July 2013–2018 were two times smaller than in 1985–1990. These data show a gradual aridization of the climate in the landscape of Western Ukraine.
Third-degree polynomial model $y_r = -0.1386x^3 + 1.7716x^2 + 6.9023x + 494.89$, whose curve has an approximation factor of $R^2 = 0.31$ to the actual course of indicators describes the most accurate long-term dynamics of the average annual rainfall in 1945–2018.
Although early spring moisture reserves are increasing because of increasing winter rainfall and better soil absorption due to slight freezing, there are declining trends in the summer. Therefore, there has been a rapid decline in soil moisture since June. They recover only in the second half of autumn. Increasing the air and soil temperature during the growing season of crops, combined with increased winds and a decrease in relative humidity, significantly increases the evaporation of moisture. This causes a worse moisture content of the plants, even if rainfall does not decrease.
If we evaluate hydrothermal resources' potential concerning particular natural and climatic zones, we can reasonably justify the acreage structure's prospective variants (Tarariko et al., 2016). The rapid increase in the sums of effective temperatures has created favorable conditions for the cultivation of such thermophilic crops, such as corn, soybeans, sunflowers, and others, in the Northwestern Forest-Steppe area. Their crops are rapidly expanding. For this reason, the structure of the acreage and the general agro-landscapes in the region are very similar to the Southern Right-Bank Forest Steppe.
Maize was grown in the Rivne region's agricultural enterprises, in 2000, only 3.9 thousand hectares were coopupied with mmmaize, which amounted to 0.9% in the acreage structure. Soybean and sunflower were practically not cultivated. The acreage of these crops was 50.5, respectively; 72.8 and 24.2 thousand hectares, or 17.9; 25.8% and 8.6% in acreage area in 2018. Together, these crops accounted for 52.3% of the acreage of the Rivne region (Ukraine).
Climate change in landscapes, a new structure of acreage combined with the introduction of the latest technical means, fertilizers, plant protection products, and breeding proposals make it necessary to modernize the scientific bases of plant growing according to zonal principles.
Crop yields are shaped not only by the weather but also by a variety of technological techniques. The analysis of indicators of 2010–2018 indicates a trend of increasing crop yields (Fig. 6). Winter wheat yield increased from 2.9 to 4.6 t·ha^{-1}, corn – from 4.9 to 8.2 t·ha^{-1}, soybeans – from 1.4 to 2.7 t·ha^{-1}, winter rapeseed – from 2.3 to 3.8 t·ha^{-1}, sunflower – from 1.1 to 2.4 t·ha^{-1}.



	2000	2005	2010	2015	2019
Maize	3,3	5,0	4,9	7,5	8,2
Winter wheat	2,6	2,6	2,9	4,4	4,5
Coy	0,9	2,3	1,9	3,2	3,2
Sunflower	0,5	2,7	1,1	2,3	2,4
Winter rapeseed	0,0	1,4	1,4	1,9	2,7

Fig. 6. Dynamics of the yield of basic crops in the farms of Rivne region (Ukraine), t·ha^{-1} (Crop production of Ukraine, 2019)

It is difficult to determine the particle sizes of all the components that led to such a rapid increase in yield. First, this is explained by agriculture's innovative development. The farmers widely use the best domestic and foreign scientific assets, including the latest technologies, varieties and hybrids, machinery, fertilizers, and plant protection products obtained because of the economy's globalization. However, it is indisputable to contribute to improving crop productivity, improving the heat supply of landscapes, and possibly increasing the air's carbon dioxide content.

Despite significant achievements, the prospects for further improvement of crop production in Ukraine are less optimistic because of the gradual deterioration of crops' moisture content. This factor could significantly limit some crops' growth soon.

Conclusions

Regional changes in the mezoclimate have occurred because of global trends in geomatics and astrophysics over the last few decades in the Northwestern Steppe of Ukraine. The heat supply of landscape agroecosystems has improved significantly, which has led to the dominance of corn, soybeans, and sunflowers in the acreage structure. Annual rainfall has declined sharply in the last five years, significantly limiting soil moisture resources, especially since June, when plants use rapidly their moisture reserves and begin replenishing only in the second half of autumn.

However, climate warming and modern technologies sped up the productivity of winter wheat, thermophilic soybeans, and corn in the Northwestern Forest-Steppe of Ukraine. It is crucial to determine the soil chemical changes in the North-Western Forest Steppe of Ukraine and their impact on crops' productivity.

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