

The impact of droughts on sunflower production in the Republic of Moldova

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Abstract

The impact of climate change on agriculture is difficult to assess, but estimating the possible effects generated by the increase in the frequency and intensity of weather-climate risk phenomena is a necessity. The purpose of this study is to highlight the impact of droughts of different intensity and territorial expansion on the sunflower crop in the Republic of Moldova. For this, the data from the last twenty years were analyzed, regarding the area cultivated with sunflowers, the global production and the average yield in the administrative-territorial profile, as well as annual and semi-annual precipitation and temperatures. During the analyzed period, the global sunflower production in the Republic of Moldova registers general growth trends, explained, for the most part, by the constant increase of the cultivated area, but also due to the high productive and qualitative performance of the new hybrids introduced into the crop. The analysis of the relationship between precipitation and temperature, and the sunflower harvest, highlighted the temporal evolution of the parameters and the dependence of the sunflower yield on environmental factors, and the negative influence of the drought on the harvest. The years with the highest droughts had a significant impact on the average harvest per hectare, strongly affecting the yield of sunflowers and reducing it by about 50%. The sunflower harvest was closely related to the precipitation during the growing season and those in the cold half of the year and less to the amount of annual rainfall. In addition, the high temperatures associated with periods of precipitation deficit determined low yields.

Keywords: climate change; drought; precipitation; sunflower; temperature

Introduction

Republic of Moldova is characterized by mild winters, which started to be shorter and warmer, with little snow, as well as long, hot summers, with an insufficient amount of precipitation, which fall predominantly in the form of showers. The average annual amount of precipitation varies between 470 and 620 mm and is characterized by a high instability in time and space (Boian, 2015). The analysis of the data on the regional distribution of the average yield per hectare, but also of the global sunflower yield, shows the prevalence of these indicators in the northern region followed by the southern region. After 2015, the southern region registers an ascent, the analyzed indicators being the highest in the republic (Ulinici and Savga, 2019).

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Drought is a multidimensional stress affecting plants at various levels of their organization, including physiological, biochemical, and genetic processes (Alexandrov *et al.*, 2002), that contribute to the reduction of crop yield globally (Fischer and Turner, 1978; Bosnjak, 2003), including sunflower yield and oilseed production (Dragovic and Maksimovici, 1995; Vanozzi *et al.*, 1999; Petcu *et al.*, 2001; Reddy *et al.*, 2003; Rauf, 2008; Duca *et al.*, 2019). Historically, many of the largest falls in crop productivity have been attributed to anomalously low precipitation events (Kumar *et al.*, 2004). In any case, even small changes in mean annual rainfall can impact on productivity - a change in growing season precipitation by one standard deviation can be associated with as much as a 10% change in production (Lobell and Burke, 2008). However, overall, it does not appear to be possible at the present time to provide a robust assessment of the impacts of anthropogenic climate change on global-scale agricultural productivity (Kumar *et al.*, 2004, Sivakumar *et al.*, 2005).

With climate change, maintaining crop productivity is a challenge, and strengthening the decision-making process to reduce climate and meteorological risks in the agricultural sector remains a pressing need. Drought, as a climate risk factor, can be managed through a combination of agronomic, reproductive and biotechnological approaches. Given that, according to the climate forecasts for the region of the Republic of Moldova, the average air temperature registers increasing trends, and the precipitation registers more and more accentuated spatio-temporal variabilities, the knowledge of their impact on agriculture in general, but also on sunflower, which is one of the most important crops for our country, is of great importance in order to identify as accurate as possible the favorable regions it is the cultivation of this culture, both from the perspective of environmental factors and of the anthropogenic interventions necessary to reduce the impact of droughts. This is the context in which we set out to estimate the impact of droughts of different intensity seen in terms of rainfall scarcity and high average air temperatures on the sunflower crop.

Materials and Methods

Location and working methods

In the present study, the data for the last twenty years (period 2001-2020) were analyzed. The investigations were based on: the data collected from the archive of the State Hydrometeorological Service, regarding the thermal regime and the precipitations, as well as information regarding the meteorological-climatic characterization of the most intensive droughts in the Republic of Moldova for the mentioned period (<http://old.meteo.md/mold/nssezon.btm>); the data collected from the Archive of the General Inspectorate for Emergency Situations, regarding the value of the damages caused by droughts brought to the agricultural households that deal with sunflower growth; the data collected from the National Bureau of Statistics (<https://statbank.statistica.md>) and the archives of the Ministry of Agriculture, Regional Development and Environment, regarding the global harvest and sunflower yield; the primary materials collected from the sunflower fields of the republic regarding the sanitary condition and the reaction of the plants in different phases of development to the drought conditions.

Procedures and organization of research

For the mapping of the spatial distribution of precipitation amounts and the average air temperature, the data for 16 stations on the territory of the country were interpolated by the IDW (Inverse Distance Weighting) method. Also, in order to establish the period of the year when precipitation and temperatures have a greater importance in the development of the sunflower crop, the monthly values of these climatic elements were grouped into two periods: the vegetation period (April-September) and the cold period (October-March). By graphically representing these data, the dry periods were established, which were then overlapping with the data on the productivity of the sunflower crop.

Results and Discussion

Sunflower (*Helianthus annuus* L.) is one of the strategic crops in the Republic of Moldova, representing the main source of vegetable oil, both for supplementing domestic consumption and for export. For the development of solid strategies of cultivation and obtaining the expected yields of this agricultural crop, it is inherent and crucial to manage agro-climatic diversity based on integrated interdisciplinary studies, advanced information technologies and spatial analysis tools, in order to identify target environmental factors and their share of influence on global productivity and harvest.

According to FAO, in the last decade, the area sown with sunflowers globally has increased by about 20% (Olesen and Bindi, 2002). The same trend is revealed at the level of the Republic of Moldova. The areas sown with sunflowers in the Republic of Moldova have been in a continuous increase - from 208 thousand ha in 2001 to 252 thousand ha in 2010 and 387 thousand ha in 2020, being exceeded of the recommended norms about 2 times. The largest areas sown with sunflowers were recorded in 2003, 2016, 2017 and 2020, when 350-385 thousand ha were cultivated annually, which is about 24% of the total sown agricultural areas (Figure 1), while in Ukraine the share of sunflower is 17%, and in Romania - 10% (Anghelache, 2018).

In recent years, there has been a slower growth in sunflower sown areas, but there is a faster increase in global production due to the high performance of new hybrids widely used in production (Bucur, 1996; Cojocari, 2009; Nedealcov, 2012).

During the 2001-2020 the global sunflower harvest had a general growth trend, contributing to the increase of production over 3.2 times. The global sunflower harvest in 2010 and 2011 reached the values of about 382 and 427 thousand tons, respectively. The lowest global sunflower production was recorded in 2007 - only 156 thousand tons. In recent years, there is a tendency to stabilize global sunflower production around 800 thousand tons. Exceptions were the very dry years, when the global production of sunflower decreased considerably, being determined by very intensive and catastrophic droughts (Figure 1).

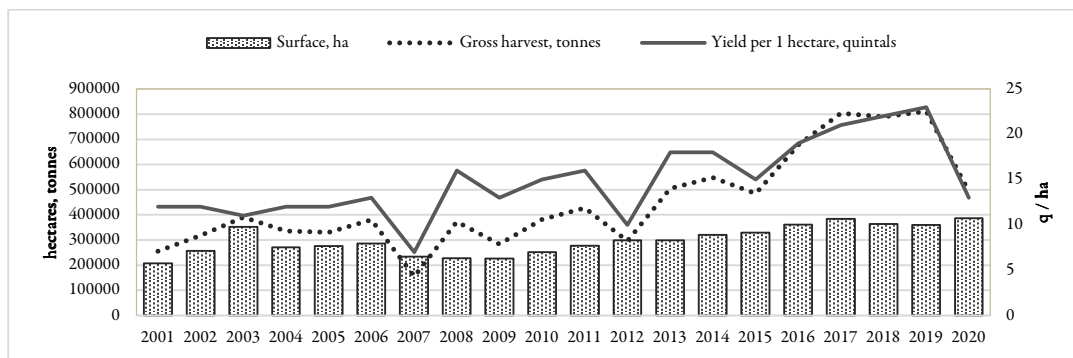


Figure 1. Annual area sown with sunflower, harvest and average yield per hectare in the Republic of Moldova for the period 2001-2020

The average yield per hectare also had a general trend of continuous growth from 12 q/ha recorded in 2001 up to 23 q/ha in 2019, when it was the largest. The lowest average sunflower harvests per hectare were recorded in 2007 - only 7 q/ha, 2012 - 10 q/ha, 2015 - 15 q/ha and 2020 - 13 q/ha (<https://statistica.gov.md/> last accessed 02.08.2021). Starting with 2016, except for 2020 which was very dry, the average harvest per hectare of sunflower in the Republic of Moldova increased significantly compared to the previous period (Figure 1).

The spatial distribution of areas, global harvest and productivity for 2010 and 2019 shows that the southern (districts: Stefan-Voda, Causeni, Cahul and T.A.U Gagauzia) and northern (districts: Drochia, Floresti, Singerei, Riscani, Soroca, Glodeni) areas of the Republic of Moldova are the most intensively exploited for sunflower cultivation. Over 10 years, sown areas have increased considerably (by 110%) in the South and

moderately in the North (by 33.5%) and Centre (by 39%). Similar to the sown areas, the global harvest has increased. But based on the average harvest per hectare, the most profitable is considered the northern area (Figure 2), which even in the conditions of the drought maintains a high level of crop productivity.

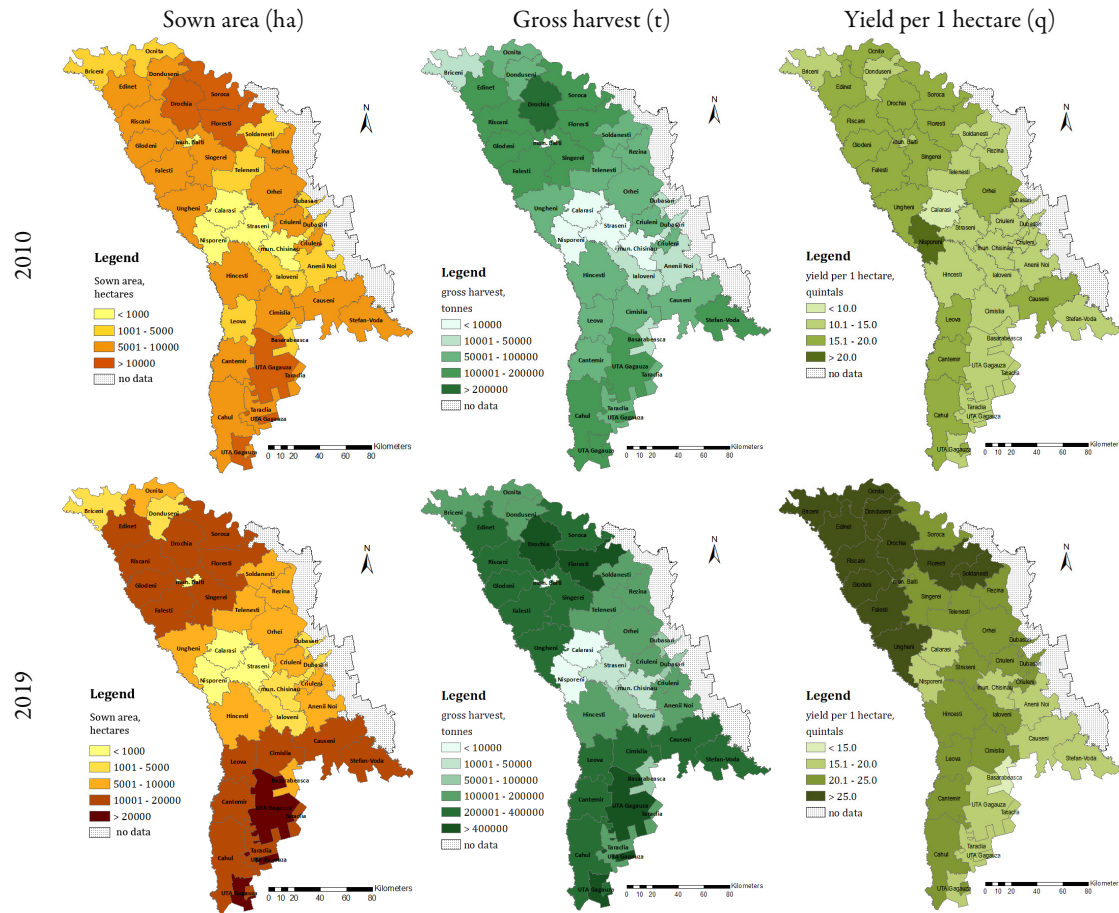


Figure 2. The spatial distribution in administrative-territorial profile the area sown with sunflower, the harvest and the average harvest obtained per hectare

At the regional level, during 2001-2019, the highest value of the average yield per hectare of sunflower was attested in Edinet district - 21 q/ha, and the lowest values of this index were registered in Calarasi district (11 q/ha). For 2010 (Figure 2), the highest sunflower productivity (over 20 q/ha) was registered in the district Nisporeni, followed by practically all the districts in the northern area, as well as the districts of Causeni, Leova, Cantemir and Cahul in the southern part of the republic, with an average yield of 15-20 q/ha. Smaller average of sunflower seeds (10 -15 q/ha) were collected in the districts located in the central and south-eastern part of the country. The lowest average yield was registered in Calarasi district (below 10 q/ha).

In general, the average yield per hectare of sunflower is usually higher in the Northern Development Region, due to the more favorable climatic and relief conditions. However, in some years, depending on the distribution of rainfall, a higher average yield per hectare was obtained in the southern region.

Over last 20 years (2001-2020) on the territory of the Republic of Moldova, there was a continuous trend of increasing temperatures, both in summer and winter, which according to existing scenarios, can last until 2050. These years were practically the warmest of the whole period of instrumented observations. At the same time, in general, during this period, the amount of precipitation was within the limit's characteristic of

the area or insignificantly higher, compared to previous years. The average annual air temperature in the years 2001-2020 ranged from 9.6 °C to 11.9 °C (Figure 3), being 0.7 °C-1.6 °C higher compared to the extreme values of the average annual temperature of air from the previous period (1981-2000). As a result, the average air temperature in the cold semester during the study period ranged between 0.2 and 5.7 °C heat, being 1.6-3.5 °C higher compared to the extreme values of the average annual temperature in the cold semester for the previous period.

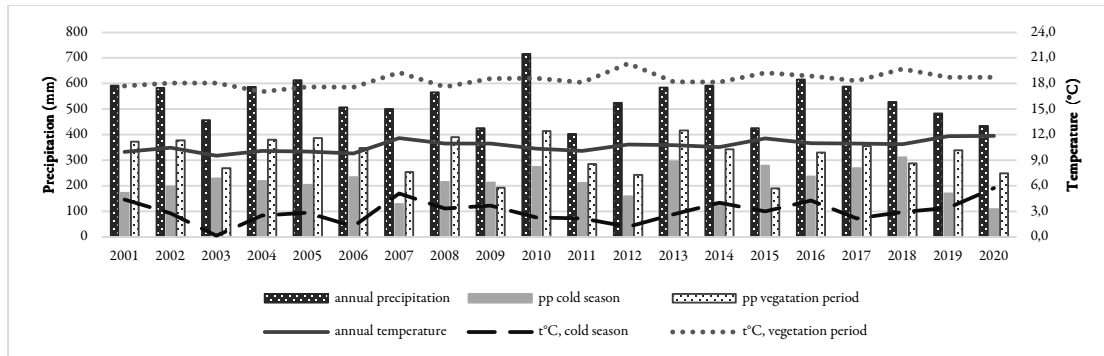


Figure 3. Dynamics of average air temperature and amount of precipitation during 2001-2020 for time intervals: year, cold semester of the year (months: X-III), vegetation period (months: IV-IX)

The average air temperature in the vegetation period during the 2001-2020 years ranged between 17.1 and 20.4 °C, being 0.6-1.1 °C higher compared to the extreme values of the average annual temperature in the vegetation period for the previous period (1981-2000). The highest averages of air temperature during the vegetation period were recorded in the years - 2012 (21.1 °C), 2018 (20.4 °C), 2007 (20.1 °C), 2015 (20.1 °C), 2019 (19.4 °C), and 2020 (19.4 °C).

The average annual rainfall in the period 2001-2020 amounted to at least 350 mm, satisfying the lower limit for the growth and development of sunflower and ranged from 403 mm to 715 mm. This amount was 5-43 mm higher compared to the average annual rainfall in the previous period, when these values ranged from 360 to 710 mm. The same pattern was manifested both in the case of the average amounts of precipitation in the cold semester of the year, and in the case of the average amounts of precipitation in the vegetation period. As a result, the average amounts of atmospheric precipitation in 2001-2020 ranged between 108 and 313 mm in the cold period and between 190 and 416 mm during the vegetation period, being insignificantly higher compared to the respective amounts of precipitation in the previous period (1981-2000).

The highest amounts of annual precipitation were recorded in 2001, 2002, 2004, 2005, 2006, 2008, 2010, 2012, 2013, 2014, 2016, 2017, 2018, and 2019, being greater than 450 mm, thus framing within the limits of variation of optimal precipitation to ensure the realization of the genetic potential of hybrids (Duca, 2018). The other six years (2003, 2007, 2009, 2011, 2012, 2015, 2020) were characterized by annual rainfall within the limits of 350-450 mm. In these six years as well as in 2012 and 2018, the amount of precipitation during the vegetation period was less than 300 mm, which mainly determines and influences the productivity of the sunflower.

Most of the agricultural land in the Republic of Moldova is located in the area of insufficient humidity, and droughts are gradually becoming more systematic in the context of regional and global climate change, being reported more and more frequently. Thus, data analysis from 1890-2020, indicates that on average the frequency of droughts in the northern part of the country is 1-2, in the central part it is 2-3 and in the south of the republic 5-6 droughts at every ten years. If we consider that during this period there were also conditions close to drought, then we can mention that the aridity on the territory of the country appears once in three years (Nedealcov, 2012).

According to the analyzed data during the studied period it was established, that the high thermal regime (2007, 2012, 2015, 2018, 2019, 2020) and the critical insufficiency of precipitation favored the installation of 10 droughts of different intensity (2001, 2003, 2007, 2009, 2011, 2012, 2015, 2018, 2019, 2020), causing enormous damages to the agricultural sector of the country. The probability of occurrence of high intensity (catastrophic) droughts (<50% of the climatic norm of precipitation), in certain months of the vegetation period, is increasing from 11% to 41% (from a case in 9 years to a case in 2 years) (Nedealcov, 2012).

In the very dry years (2001, 2007, 2020), the insufficiency of atmospheric precipitation was accentuated in the cold semester of the year, prior to the vegetation period. These droughts, unlike the droughts mentioned in other years of the study period, had the highest intensity, being very strong and catastrophic (about 80-90% of the territory of the republic), taking place according to the same scenario. The maximum amplitude of the intensity of these droughts overlapped with the critical period of development of the main agricultural crops. Droughts in 2003 and 2020 lasted throughout the growing season (months IV-IX), in the rest of the year's droughts were reported more in summer and early autumn. For these reasons, for more detailed analyzes, the droughts that manifested themselves in 2007, 2012 and 2020 were selected (Figure 4).

The 2007 drought affected over 80% of the republic's territory (catastrophic drought), which according to the main agro-meteorological indices, even surpassed the 1946 drought. This drought practically started in the autumn of 2006, the situation worsening to the maximum during May-July 2007, when the amount of precipitation made up only 30% of the norm. The amount of precipitation falling on most of the territory was 45-145 mm (25-65% of the norm), isolated: 175-268 mm (80-115% of the norm). The uninterrupted interval without precipitation during this period varied from 28 to 73 days, 55-78 days of which had the relative humidity of the air $\leq 30\%$, exceeding 3-4 times the climatic norm (Boian, 2015). The amount of precipitation that fell during July in most of the central and northern districts was 10-45 mm (10-55% of the monthly norm), isolated in some northern districts - 65-120 mm (80-145% of the monthly norm). In most of the southern districts the amount of precipitation reached 1-5 mm (2-8% of the monthly norm). During May-July 2007, the average air temperature in the territory was $+21.0\text{ }^{\circ}\text{C} \dots +23.0\text{ }^{\circ}\text{C}$, being 3-4 $^{\circ}\text{C}$ higher than the norm (record). The number of days with maximum temperatures $\geq 30\text{ }^{\circ}\text{C}$ constituted, in the territory 36-45 days, exceeding the norm 3 times, and the number of days with maximum temperatures $\geq 35\text{ }^{\circ}\text{C}$, respectively 10-12 days. The deviation from the norm was exceeded 10-12 times. On July 21, a record maximum air temperature of $41.5\text{ }^{\circ}\text{C}$ (Camenca Weather Station) was recorded. The average air temperature during July in a large part of the territory of the republic was higher than the norm by 4-5 $^{\circ}\text{C}$ and was $+24.0\text{ }^{\circ}\text{C} \dots +26.0\text{ }^{\circ}\text{C}$, signaling for the first time in the whole period of instrumental observations.

The maximum air temperature over a large part of the territory of the republic (except for the extreme northern districts) was $+38.4\text{ }^{\circ}\text{C} \dots +41.5\text{ }^{\circ}\text{C}$. The summer of 2012 in the Republic of Moldova was abnormally hot and dry. A strong (in terms of intensity) and catastrophic (in term of affected areas: over 90% of the country and 79% of the sunflower area) drought was reported. This drought was the most severe drought for the entire previous period of instrumental measurements, surpassing even the droughts of 1946 and 2007. The amount of precipitation that fell in the country during the summer period ranged from 70 mm to 145 mm (35-70% of the norm). 60 days without precipitation were found, and the longest uninterrupted period with such conditions was 26 days (Leova).

The record number of days with the relative humidity of 30% and lower was 33-58 days (the norm: 4-14 days). July 2012 was the warmest and with a very large rainfall deficit. During July, rainfall fell very unevenly. On 55% of the country their quantity was 25-45 mm (30-70% of the monthly norm), and on 45% of the territory - 55-95 mm (80-135% of the monthly norm).

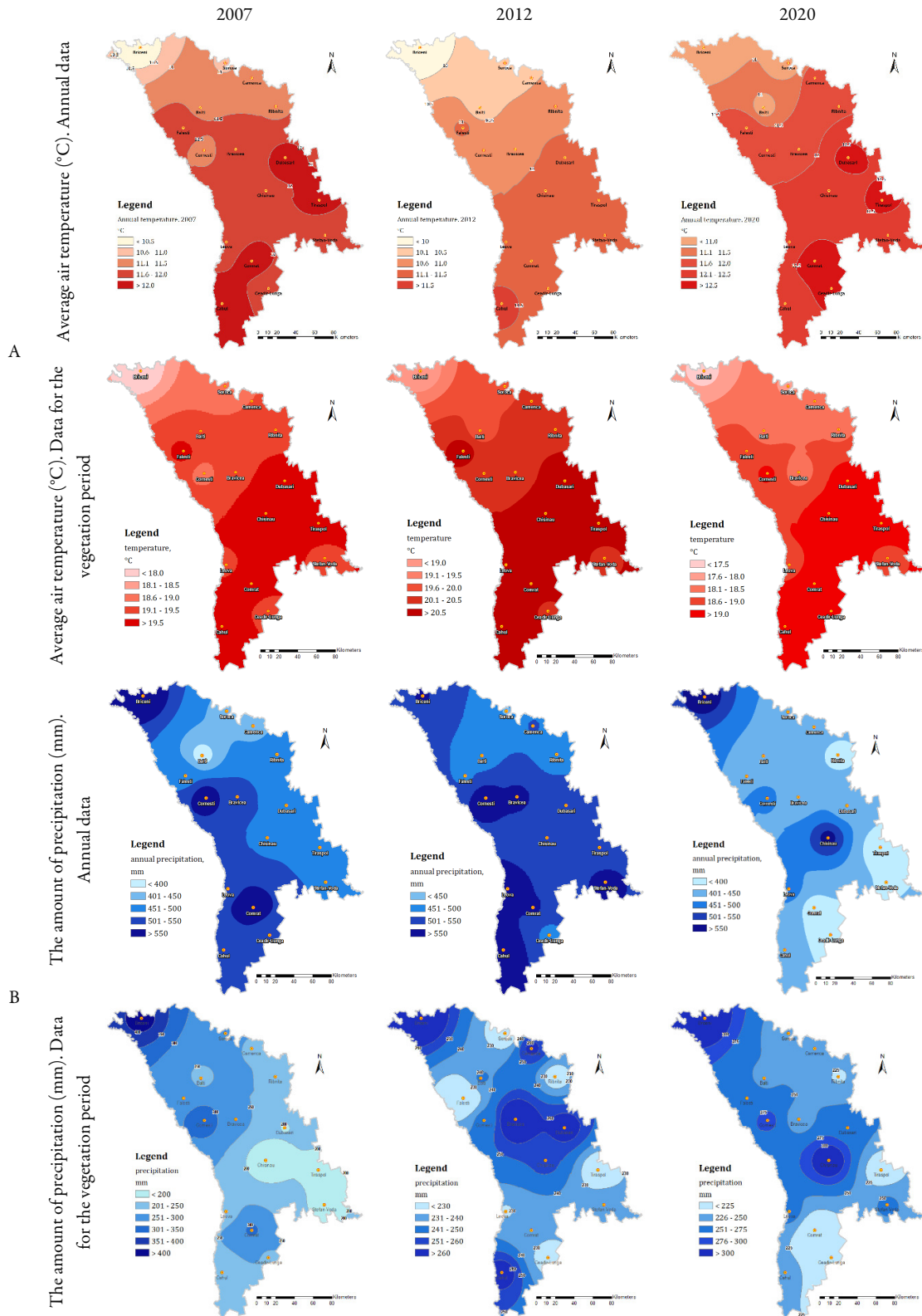


Figure 4. Characterization of the climatic conditions of the Republic of Moldova (A - temperature; B - amount of rainfall) in very dry years - 2007, 2012 and 2020

By the end of July, the reserves of productive moisture on the sunflower lands were very low. As of July 28, 2012, in the soil layer with a thickness of 0.5 m, the productive moisture reserves constituted 5-30 mm (10-55% of the norm), and in the soil layer with a thickness of 1 m, the productive moisture reserves constituted 5-60 mm (5-55% of the norm). The average air temperature for the period June - August was higher than the norm values by 3.0-4.5 °C and was +21.7 °C ... +24.8 °C (Boian, 2015). At the surface of the soil in the summer of 2012, the maximum temperature reached values of +71 °C (July, SM Cornesti). The number of days with a maximum air temperature of +30 °C and higher for the summer season was 39-62 days (the norm is 8-27 days), being reported for the first time. The number of days with a temperature of +35 °C and higher was generally 16-35 days (the norm is 1-2 days), which was also recorded for the first time. The average air temperature in July was +23.7 °C ... +26.6 °C, exceeding the norm by 4.3-5.7 °C, which was reported for the first time.

The summer of 2020 in the Republic of Moldova was very hot and basically with a very large rainfall deficit. Compared to the summer of 2019, this season was analogous to the average seasonal air temperature, but with much less rainfall (basically 20-100 mm). The amount of precipitation in 75% of the country's territory was 80-140 mm (40-75% of the norm). During July 2020, inhomogeneous weather with a large deficit of precipitation was reported. Atmospheric precipitation fell very unevenly. On 70% of the country's territory, they were basically 20-40 mm (30-60% of the norm). In the rest of the territory, predominantly in the southern half of the country, the amount of precipitation fell by 45-90 mm (75-140% of the norm). The average air temperature for this season in the territory was +20.7 °C ... +23.7 °C, being generally 1.9-2.9 °C higher than the norm. The maximum air temperature during the summer rose to +38 °C (August, SM Tiraspol, Stefan-Voda). The average monthly air temperature was +20.5 °C ... +24.5 °C, higher than the norm values by 1.5-3.0 °C. The number of days with a maximum air temperature of +30 °C and more during July 2020 varied from 7 days in the north of the country to 24 days in the south (the norm: 3-11 days) and the maximum air temperature of +35 °C and more was 1-6 days (the norm: 1 day).

The consequences of these droughts on the agricultural sector in general and on concrete crops are also different. In-depth knowledge of these details can greatly facilitate the decision-making process on the implementation of mitigation measures for each type of drought. These droughts have a different negative impact on the agricultural sector in general as well as sunflower crop in particular. The losses in the republic's agriculture amounted to about 3 billion Moldovan lei, of which 2.5 billion lei in the phytotechnical sector and 0.5 billion lei - in horticulture (Boian, 2015).

The analysis of the data on the impact of annual, the cold semester of the year; and the vegetation period precipitation on the global annual sunflower production, demonstrates a strong dependence. The lower amount of rainfall in those periods of the year, the more significant the decrease in the overall annual yield. However, this direct negative dependence is more strongly related to the amount of precipitation during the vegetation period, then to the amount of precipitation in the cold semester of the year preceding the vegetation period, followed by the smaller influence of the annual amount of atmospheric precipitation. More clearly, this dependence is revealed for the dry years 2003, 2007, 2009, 2012, 2015 and 2020 (Figure 5 A). However, changes in seasonal precipitation may be more relevant to agriculture than annual mean changes (Nedealcov, 2012)

It is known that changes in short-term *temperature extremes* can be critical, especially if they coincide with key stages of development. Only a few days of extreme temperature (greater than 32 °C) at the flowering stage of many crops can drastically reduce yield (Wheeler *et al.*, 2000). The analysis of the data for the 20 years included in the study showed that the average air temperature in the cold period of the year does not influence either the global annual sunflower yield or the harvest per hectare. In the conditions of climate change an increase in mean temperature can be confidently expected, but the impact on productivity may depend more on the magnitude and timing of extreme temperatures.

Regarding the impact of the average annual air temperature and the average one during the vegetation period, a direct dependence was found, although statistically insignificant, including: the higher these average temperatures, the lower the overall yield and productivity. More obviously, this dependence is observed for the

dry years 2007, 2012, 2015 and 2020. We can assume that the average annual air temperatures and those of the vegetation period influence the global sunflower yield and the average harvest per hectare, more indirectly by increasing evapotranspiration, and diminishing soil moisture reserves (Figure 5B). We can also see that the average annual air temperatures and those of the vegetation period influence more indirectly on the global sunflower productivity, by increasing evapotranspiration and decreasing soil moisture reserves, and the average air temperature in the cold period of the year does not in any way influence the overall annual sunflower harvest.

The analysis of the impact of climatic indices, analyzed for different intervals of the year, on the productivity (q/ha) of sunflower in the Republic of Moldova showed that the magnitude of the negative impact was strongly determined by the insufficient amount of precipitation during the vegetation period, but also of the insufficient amount of precipitation, fallen in the cold semester of the year, and less of the annual amount of precipitation. We can also see that the average annual air temperatures and those of the vegetation period influence more indirectly on the global sunflower production, by increasing evapotranspiration and decreasing soil moisture reserves.

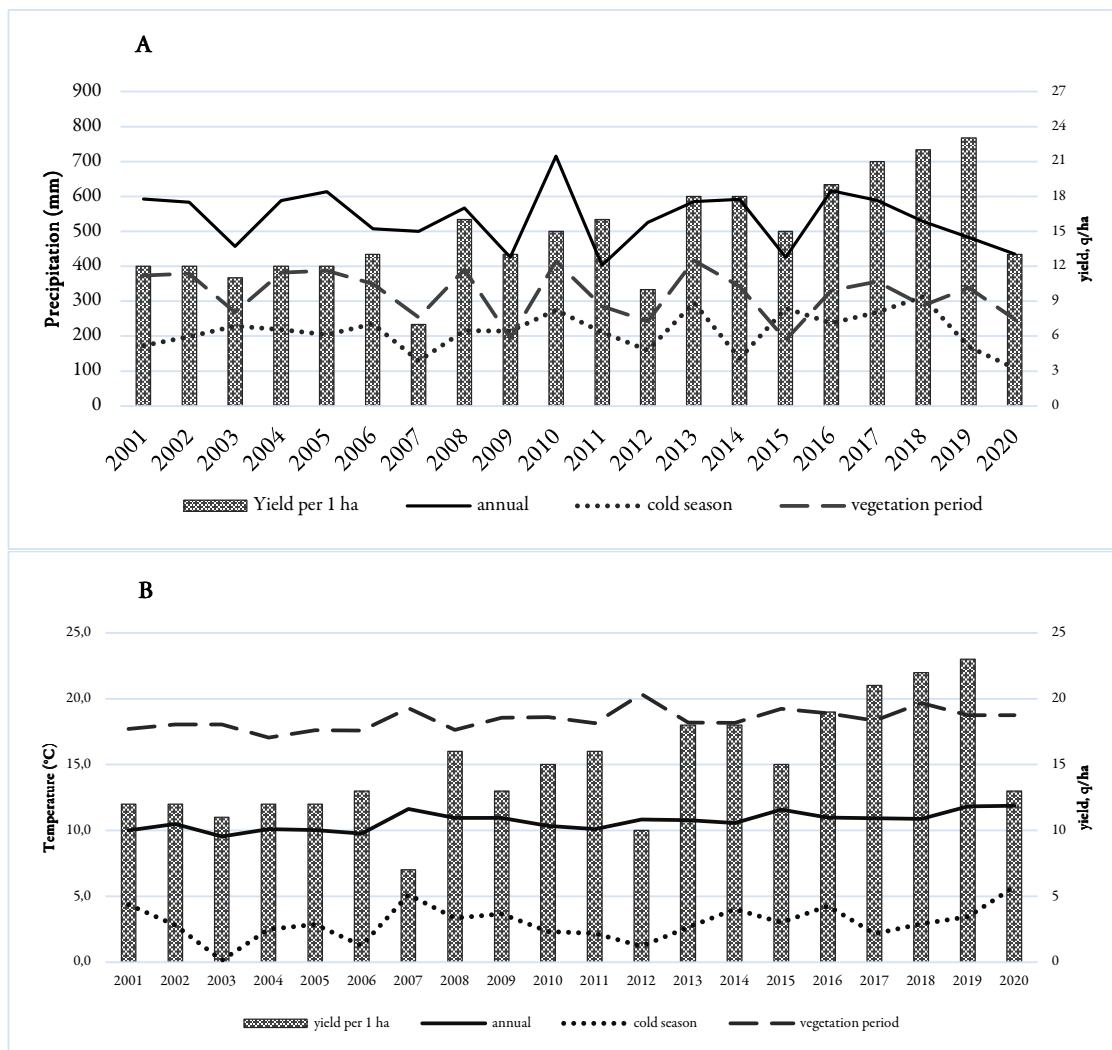


Figure 5. Impact of the amount of precipitation (A) and the air temperature (B) in the time intervals: year, cold semester of the year (months: X-III), vegetation period (months: IV-IX), on the average harvest per hectare of sunflower during 2001-2020

From the agrometeorological point of view the years 2007, 2012 and 2020 are considered as a very dry years, with very strong droughts. These droughts had a significant impact on the average harvest per hectare, strongly affecting production of sunflower reducing it by about 50%.

According to official information, in 2007 on the territory of the Republic of Moldova were sown 234 000 ha of sunflower (380 000 ha in 2006), and the global production was only 156 000 tons (compared to 287 000 tons in 2006). The development of the sunflower occurred 1-2 weeks earlier than the usual terms, at the beginning of July, signaling the flowering and seed formation. The average seed yield in 2007 in the country was 7 q/ha, with 6 q/ha lower than in 2006. The decrease of the average seed yield in 2007 compared to 2006 was about 54%, and compared to the average seed yield per 1 ha in the last 10 years was about 42% (Table 1).

The catastrophic drought of 2012 affected over 90% of the territory of the republic and 79% of the area occupied by the sunflower, being the most severe drought for the entire previous period of instrumental measurements. According to the main agro-meteorological indices, this drought surpassed even the droughts of 1946 and 2007, bringing enormous damage to the national economy. The losses in the republic's agriculture amounted to about 3 billion Moldovan lei, of which 2.5 billion lei in the phytotechnical sector and 0.5 billion lei - in horticulture (Boian, 2015).

Table 1. The variability of agro-climatic conditions from the Republic of Moldova and their impact on the yield per hectare in very dry years 2007, 2012, 2020

Year	Territory	The amount of precipitation (mm)			Temperature (°C)			Yield per hectare (quintals)	Degree of crop diminution (%)	
		Annual quantity	Cold season	Vegetation period	Annual average	Cold season	Vegetation period		Compared to the previous year	Compared to the average for 10 previous years
2007	Whole country	500	129	202	11,6	5,1	22,4	6,9	46	58
	North	467	108	209	11,2	4,7	21,9	9,7	31	48
	Centre	509	140	183	11,9	5,4	22,8	6,3	52	58
	South	532	143	213	11,9	5,3	22,7	4,0	66	74
2012	Whole country	525	159	210	10,8	1,2	22,6	10,3	33	38
	North	487	144	214	10,3	0,8	22,1	13,3	25	29
	Centre	543	167	209	11,1	1,4	22,9	8,1	42	46
	South	553	170	205	11,3	1,5	23,0	8,5	39	44
2020	Whole country	435	108	204	11,9	5,7	20,2	13,1	43	21
	North	450	119	209	11,2	5,1	19,4	17,5	34	6
	Centre	444	102	161	12,3	6,1	20,6	11,0	51	27
	South	408	101	177	12,3	6,1	20,8	10,5	48	31

In 2012 on the territory of the Republic of Moldova were sown 299 000 ha of sunflower (277 000 ha in 2011), and the global production was 296 000 tons (427 000 tons in 2011). The average seed yield in 2012 was 10 q/ha, with 6 q/ha lower than in 2011. The decrease of the average seed yield in 2012 compared to 2011 was about 30%, and compared to the average seed yield in the last 10 years - about 62%.

The negative impact of the very arid conditions in July 2007 on the formation of sunflower seeds was very strong, when the plants reached the critical phase of development during the period of drought with the highest intensity. The catastrophic drought of 2020 affected over 80% of the area occupied by the sunflower, causing enormous damage to the national economy. In 2020 on the territory of the Republic of Moldova were planted 387 000 ha of sunflower compared to 359 000 ha in 2019. The global production in 2020 was 493 000 tons of seeds, compared to 811 000 tons in 2019. The average seed yield in 2020 in the country was 13 q/ha, 10 q/ha lower than the average yield per ha in 2019. The decrease of the average seed yield in 2020 compared to 2019 was about 43%, and compared to the average seed yield in the last 10 years, the decrease was about 21%.

The analysis of data in administrative-territorial profile demonstrated that the average yield of 1 ha of sunflower is highly dependent on the spatial and temporal distribution of temperature and precipitations and allowed to establish the degree of droughts damage to the territory of the Republic of Moldova.

The average sunflower yield per hectare had a very large variation in administrative-territorial profile, being determined by the agrometeorological conditions during the vegetation period, but also by the moisture reserves accumulated in the soil during the winter and spring seasons (Figure 6).

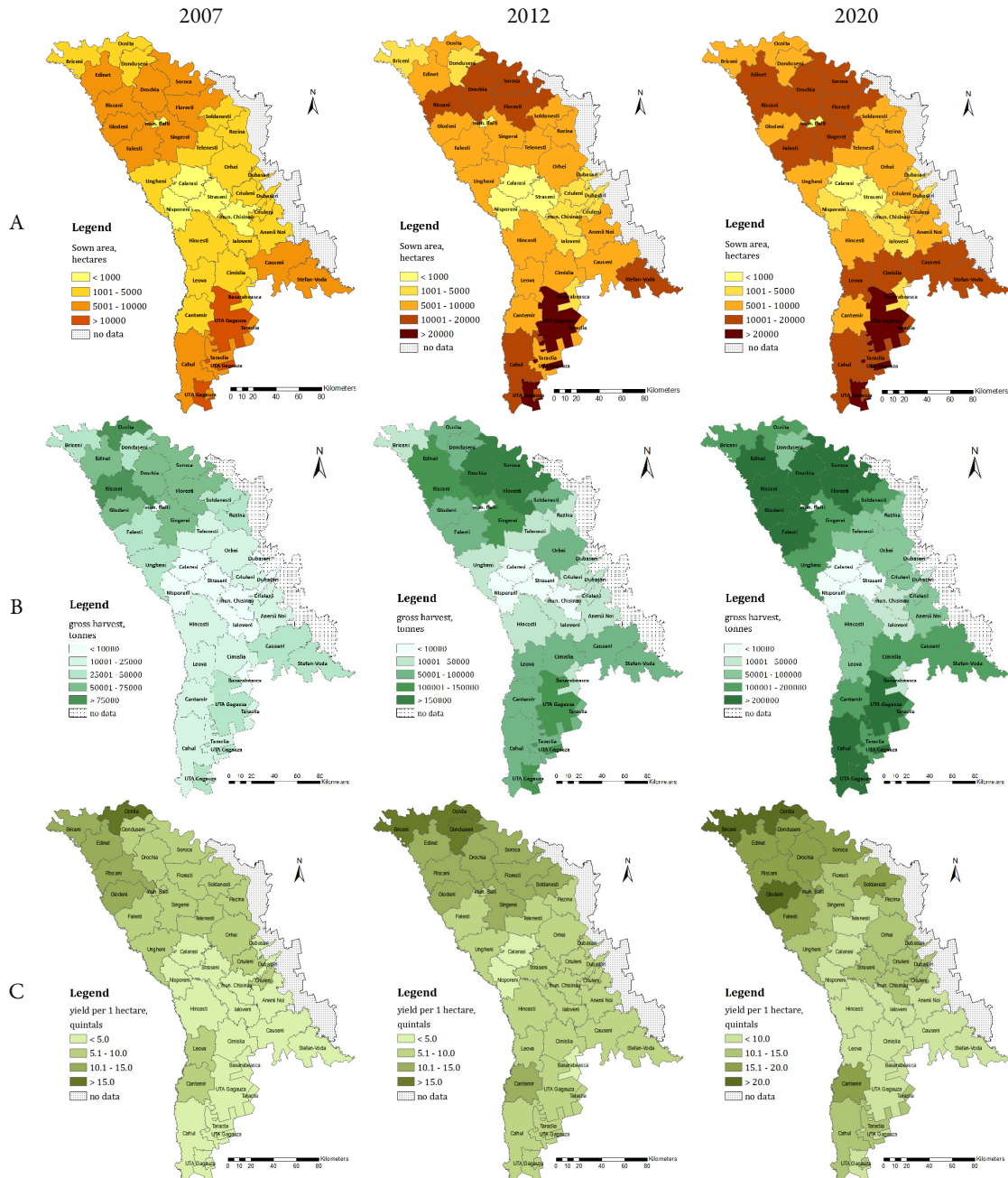


Figure 6. The variation of areas sown with sunflower in the territory of the Republic of Moldova, the global and average harvest per hectare in very dry years 2007, 2012 and 2020; A – Cultivated area (ha); B – Global harvest (q); Average yield per hectare (q/ha)

According to the National Bureau of Statistics of the Republic of Moldova, the highest value of the average yield per hectare in 2007 (over 15 q/ha) was registered only in Ocnita district, followed by the districts in the northwestern part of the country - Briceni, Edinet, Riscani and Glodeni with an average yield of 10-15 q/ha (<https://statistica.gov.md>, 21.07.2021). In the other districts in the northern, as well as in the districts of Ungheni, Orhei, Criuleni, Leova and Cantemir, the average yield was 5-10 q/ha. The highest value of the average yield per hectare in 2012 (over 15 q/ha) was recorded in the extreme northern districts (Briceni, Ocnita and Donduseni), after which the followed districts, located further north of Falesti, Telenesti and Rezina districts (as well as Cantemir district), with an average yield of 10-15 q/ha. Average yields between 5 and 10 q/ha were collected in most districts located in the central, southern and southeastern part of the country, and less than 5.1 q/ha - in the districts of Calarasi, Nisporeni and Basarabasca.

The higher value of the average yield per hectare in 2020 (over 20 q/ha) was registered in the extreme northern districts (Briceni and Ocnita), as well as in Glodeni, followed by the districts further south until at the line of Floresti, Sangerei and Ungheni districts (as well as Soldanesti and Cantemir districts), with an average yield of 15-20 q/ha (<https://statistica.gov.md>, 21.07.2021). Average yields between 10 and 15 q/ha were collected in the central districts of the Northern Region, in the eastern districts of the Central Region, and in the southern districts of the Southern Region. The productivity smaller than 10 q/ha were identified in most central districts of the Central Region, in the central and south-eastern districts of the Southern Region (Figure 6).

Final considerations

Based on this study, several considerations can be highlighted. Thus, droughts represent a specific feature of the regional climate and one of the most dangerous natural phenomena in the Republic of Moldova. During the study period (1890-2020), due to arid regional climate and process of warming, the droughts frequency has grown considerably. In the last 20 years different type of droughts of varying intensity, which occurred at different times of the year (vegetation period - 2003, 2020, summer - 2001, 2007, 2012, 2015, autumn - 2009, 2011, 2018, 2019) were established. The most severe droughts (2007, 2012 and 2020) have affected 80-90% of the Republic of Moldova, overcoming the drought of 1946. In those three years the average annual air temperature exceeded by 2.0-2.6 °C in 2007, by 1.1-1.8 °C in 2012 and by 2.6-3.7 °C in 2020 the climate norm, while average air temperature during the period of sunflower vegetation was significantly higher (+19.3 °C in 2007; +20.4 °C in 2012 and +18.7 °C in 2020). The annual amount of atmospheric precipitation in 2007 and 2012 was practically within the norm, and in 2020 - below the norm, but the amount of atmospheric precipitation during the sunflower vegetation period was well below the norm (254 mm in 2007, 243 mm in 2012 and 248 mm in 2020).

The analysis of the impact of climatic factors, for different intervals of the year, on the productivity (q/ha) of sunflower in the Republic of Moldova showed that the magnitude of the negative impact was strongly determined by the insufficient amount of rainfall during the vegetation period, as well as by the insufficient amount of precipitation, that fell in the cold semester of the year, and less - by the annual amount of precipitation. The productivity of sunflowers on the territory of the Republic of Moldova during the study period (2001-2020) allowed us to establish a general trend of continuous growth of it, from 12 q/ha recorded in 2001 to 23 q/ha in 2019. The greatest deviations towards the decrease in the average harvest per hectare were caused by the very intensive droughts in 2007, 2012 and 2020, when the average harvest amounted to 7 q/ha, 10 q/ha and 13 q/ha respectively.

The elaboration of the map set with the use of GIS technologies, regarding the sown areas, the global production, the average harvest per hectare and their overlapping with the maps on the spatial distribution of precipitation and air temperature allowed the delimitation of the adaptation areas specific to the flora-sun and the highlighting of the areas with different degrees of profitability for the cultivation of sunflower. Thus, the average yield per hectare of sunflower is usually higher in the North Development Region, due to the more

favorable climatic and relief conditions. However, in a few years, depending on the distribution of precipitation, a higher average yield per hectare was achieved in the southern region.

The current situation of climatic factors has shown that Moldova was seriously affected by drought in 2022 as well. The biggest problems and damage to the harvest were recorded both in sunflowers and in cereals. In addition, river flows have greatly decreased and the country's water reserves are depleting. Heatwave episodes in June and July have worsened an already critical situation, following severe winter and spring rainfall deficits. Thus, the pedological drought affected dozens of hectares of agricultural crops, with forecasts indicating a decrease in the sunflower and corn harvest, by up to 50%. Imports, including those from Argentina, are needed to ensure the seed requirement.

Concerns regarding sunflower crops in the context of climate change

In the case of a changing climate, drought is the main factor limiting crop production, and it is anticipated that it will become more intense in the future. With an 8% share of global oilseed production, sunflower is a significant oilseed crop. Although it is a crop that tolerates moderate amounts of drought, extreme drought lowers the production of seeds and oil. Therefore, it is crucial to comprehend the relationship between the physiological, biochemical, genetic, and agronomic bases of drought for its sustainable management in order to ensure sustainable sunflower and oil production (Hussain *et al.*, 2018; Farook *et al.*, 2019; Giannini *et al.*, 2022).

It is evident that human activities and population growth have contributed to global warming and the amplification of abiotic stress factors, including drought. Sunflower is a species with a high impact on human food security that is susceptible to drought stress (Smaeili *et al.*, 2022). The problems caused by the sunflower drought are evident not only in the Republic of Moldova, but also in various countries in its geographical vicinity (Harsányi *et al.*, 2021; Mimić *et al.*, 2022). However, in order to sustainably increase sunflower yield and oil quality under drought stress and future climate change, extensive research on the integration of different management options, including agronomic management, traditional breeding, and modern biotechnological advances, is required. In the case of a changing climate, drought is the main factor limiting crop production, and it is anticipated that it will become more intense in the future (Giannini *et al.*, 2022). With an 8% share of global oilseed production, sunflower is a significant oilseed crop. Although it is a crop that tolerates moderate amounts of drought, extreme drought lowers the production of seeds and oil. Numerous management techniques have been proposed to mitigate the effects of drought, including soil nutrient management, seed treatment, exogenous application of hormones and osmoprotectants, and breeding for drought tolerance. Therefore, it is crucial to comprehend the relationship between the physiological, biochemical, genetic, and agronomic bases of drought for its sustainable management in order to ensure sustainable sunflower and oil production (Hussain *et al.*, 2018; Ilyas *et al.*, 2021).

Numerous management techniques have been proposed to mitigate the effects of drought, including soil nutrient management, seed treatment, exogenous application of hormones and osmoprotectants, and breeding for drought tolerance (Farooq *et al.*, 2019; Adeleke and Babalola, 2020). The cultivation and productivity of sunflowers must be viewed in the context of an uncertain geopolitical and climate change scenario (Giannini *et al.*, 2022). Nevertheless, sunflower improvement must be taken into account regardless of the anticipated perspectives in order to enhance quality traits and tolerance to biotic and abiotic stress. By anticipating sowing dates and scheduling irrigation according to a crop's phenological phases, future agronomic practices must guarantee an increase in crop resistance. By investigating new farming areas at higher latitudes, extensive development may also continue to be of interest (Giannini *et al.*, 2022). However, in order to sustainably increase sunflower yield and oil quality under drought stress and future climate change, extensive research on the integration of different management options, including agronomic management, traditional breeding, and modern biotechnological advances, is required.

Conclusions

In recent years, the Republic of Moldova's sunflower production has been plagued by real challenges and significant losses as a direct result of drought. The production of sunflowers is shown to be highly variable from one year to the next, according to the findings of a study that spanned a period of 20 years. This variation was found to be significantly influenced by shifts in the climatic conditions, in particular the occurrence of extreme weather phenomena and by drought. When selecting cultivated varieties, it is necessary to establish a correlation between the local environmental conditions and the degree to which the genotypes are resistant to the limiting effects of drought.

Authors' Contributions

All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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