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Kinga Biró * and Erik Kovács

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Impact of the 2022 Drought Shock on the Adaptive Capacity of Hungarian Agriculture

Kinga Biró [1,*] and Erik Kovács [1]

[1] Mathias Corvinus Collegium, Climate Policy Institute, Hungary; kovacs.erik@mcc.hu
* Correspondence: biro.kinga@mcc.hu

Abstract: Globally and in Hungary, agriculture is one of the most vulnerable sectors to weather and climate extremes. Intense temperature rises, spatial and temporal variations in precipitation, and significant changes in extreme climatological and weather parameters have contributed to changes in the conditions of cropland, crop losses, and crop quality in recent years. The aim of the research is to describe the transformation of the domestic agricultural sector due to the extreme drought shock of 2022 and to explore the adaptation strategies applied. The studies are based on their own agro-climate database and crop data. The results can help smallholders effectively reduce the adverse impacts, thereby increasing their adaptation to similar shocks.

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1. Introduction

Climate change and its extremes are one of the most significant challenges of the 21st century [1,2,3]. The intense rise in temperature and the spatial and temporal changes in precipitation in the middle latitudes of the Northern Hemisphere are increasingly disrupting the traditional and usual variety-climate-soil balance [4,5,6]. Already in the 1980s, researchers drew attention to the fact that increasing emissions of GHGs will induce irreversible processes in the atmospheric system at the beginning of the 21st century [7,8]. One of the signs of this was shown in 2021 and 2022 in Europe, especially the agricultural sector was adversely affected [9].

In 2022, a drought warning was in effect in nearly two-thirds of Europe [10]. The 2022 European drought was the worst in at least 500 years [11]. Europe's average temperature in both August and June–August 2022 was the highest ever recorded on the continent [12,13]. The dry period of the last 20-24 months was simultaneously caused by the weakening of the jet stream, the persistent negative phase of ENSO (La Niña), the persistently strengthening of blocking anticyclones, and the absence of tropical cyclones [14]. All of this resulted in insufficient saturated water vapor arriving in the northern hemisphere, which is deficient in atmospheric moisture, so precipitation could not form. Most of the water vapor was in an unsaturated state in the atmosphere, resulting in a secondary greenhouse effect. Together, these caused heat and lack of precipitation, which may become more frequent in the future [15,16].

Events like last year's record drought in terms of volume and intensity may become the new norm in the future [17]. There is currently no scenario that presents an optimistic forecast for the 21st century [18]. Evaporation, the water cycle, and macro-circulation processes increase and change with climate change, which is why droughts, storms, and floods will become more frequent and intense at the same time in Europe [19]. Farmers around the world are trying different methods to adapt to changing climatic conditions. Drought is a serious threat to agricultural production, including livestock numbers. The death of livestock has a negative impact on food security. A study assessed the strategies adopted by households in livestock production in times of food security shocks [20]. Life cycle assessment has been used to investigate the environmental impacts of livestock production to propose an effective solution for sectoral adaptation to climate change [21]. Agriculture depends mostly on the availability of water, therefore, the pressure on water resources is increasing worldwide [22]. There are regions (e.g., the Mediterranean area, Hungarian and Romanian lowlands) where surface and soil water resources have already sunk below a critical level in the long term [23]. Irrigation helps protect farmers from climate extremes and increases crop yields, but also puts significant pressure on water resources [24]. Despite this, no significant relationship has yet been shown between the modern irrigation technologies appearing in field crop production and water saving, and according to the FAO study, these lead to an increase in water consumption [25].

In Europe, the agricultural production of nations is significantly affected by the fact that 60% of water catchment areas are in transnational regions, which makes effective cross-border cooperation essential [26]. More than 10% of the water resources of 20 European countries depend on other countries, and more than 75% of the water resources of five countries come from rivers coming from abroad [27]. The annual water runoff of rivers decreases in Central, Southern, and South-Eastern Europe, and increases in Northern and North-Eastern Europe due to climate change [28]. The decreasing and growing precipitation, as well as changing water flows and groundwater levels, affected the yield difference in the European agro-regions [29]. While crop production increased in Northern Europe, it decreased significantly in South-Southeastern Europe. Several assessments of climate change impact on crop yields. At more intense global warming, strong yield losses are predicted in lower latitudes especially [30].

2. Materials and Methods

In this paper, the shock effects of droughts are approached from two directions. First, the agro-climatological features of Hungary (temperature, precipitation, radio thermal index, etc.) are analyzed with a 30-year data series, and secondly, the analysis of the effects of the changing climate and increasing droughts is focused on three selected varieties (wheat, corn, grape wine). The agro-climatological data come from the National Meteorological Service (OMSZ) and from their own measurements. Each private station was calibrated annually. The results of the RegCM regional climate model, the HUCLIM, and CARPATCLIM databases were used for the climatological study. During the research, temperature, and precipitation were examined on an annual basis, during the growing season and the dormancy period. The relationship between radio thermal index (including effects of both temperature and radiation) and the length of the main crops, growing season were analyzed based on several year-long meteorological and phenological data series.

The research also assessed Hungary's drought sensitivity using the Atmospheric Drought Index (ADI). Physiological changes occur in plants as a result of atmospheric dryness, which can often lead to the complete destruction of certain parts of the plant (flowers, shoots, clusters, stems). For this, the temperature must rise above 25 ºC and the air humidity must fall below 40% [31].

$$ADI = \frac{T}{25} * \frac{40}{RT13h} \quad (1)$$

where T is the daily mean temperature, $RT13h$ is the relative air humidity measured at 13 hours (1 pm).

Table 1. Values of ADI and water supply level.

Values of ADI	Water supply of plants
0.0 < ADI < 0.2	favorable water supply
0.2 < ADI < 0.4	satisfactory water supply
0.4 < ADI < 0.6	moderately unfavorable, intermittent water supply
0.6 < ADI < 0.8	strong atmospheric dryness
0.8 < ADI < 1	severe atmospheric drought, disruption of plant water balance
1 < ADI	extreme atmospheric dryness, plant death, water stress

Not only the atmospheric dryness but also the soil-air dryness should be examined, for which the Pálfai drought index (PAI) was used [32].

$$PAI = \frac{t_{IV-VIII}}{P_{X-VIII}} k_t k_p k_{gw} \quad (2)$$

where PAI is the drought index °C/100 mm,

$t_{IV-VIII}$ is the mean temperature of the period between April and August,

P_{X-VIII} is the weighted sum of precipitation (mm) between October and August,

k_t, kp, k_{gw} are temperature, precipitation, and the correction factor for soil humidity.

The analysis of the quantity and quality of the crops was based on official data from the Hungarian Chamber of Agriculture, village farmers, and the Hungarian Central Statistical Office. The statistical data sets were checked by t-test, mean, median, standard deviation, and Mann-Kendall (MK) trend test.

3. Results

3.1. Agro-climate aspects focused on precipitation and drought

Based on the evaluation of long-term and short-term data, it is clear that climate change and its extremes have a negative and, to a lesser extent, a positive impact on Hungarian agriculture. Precipitation is a very variable meteorological element, not only in space but also in time, both in the Carpathian Basin and in Hungary. The average annual precipitation is around 620 mm in the country, usually between 550 and 700 mm. In the wettest years, values above 800 mm also occur, while the driest years, which tend to occur in recent decades, have been below 430 mm over the last 30 years. In the long term, a slight decrease in annual precipitation is observed, but not significant (Figure 1).

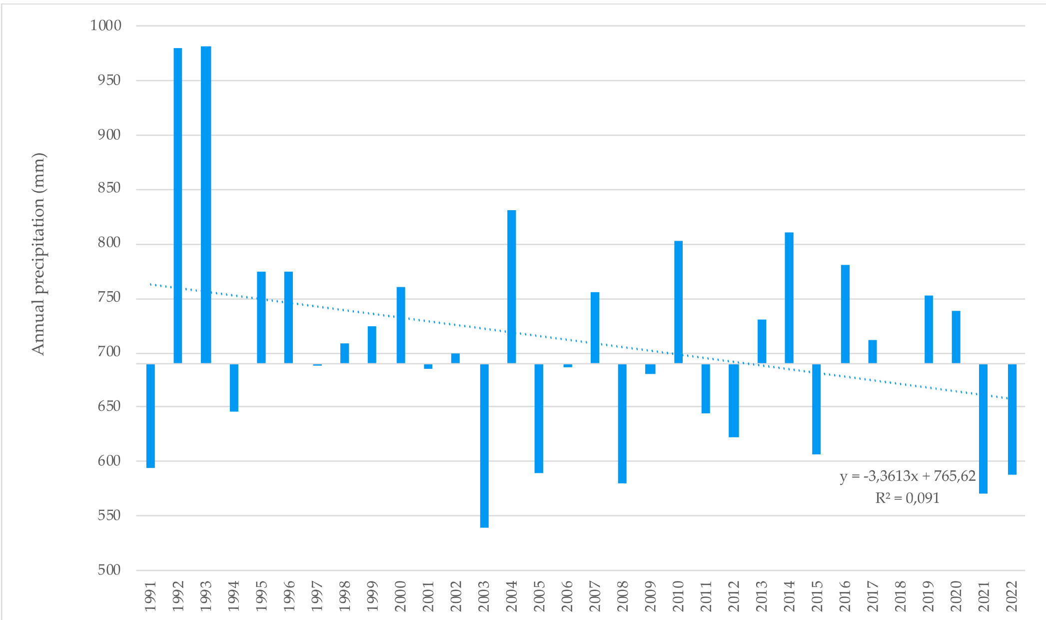

Figure 1. Annual precipitation - based on homogenized and interpolated data.

In Hungary, a drier or wetter year occurs on average every two years during the 1991-2020 climate normal period. Drier (avg. prec. -15%) or wetter (avg. prec. +15%) years also occur irregularly, which is a feature of the region. On average, the southwestern part of Hungary receives 150-200 mm more precipitation falls than the south-eastern part. According to meteorological station data, the difference rarely exceeds 300 mm. In some cases, even larger differences, up to 600-700 mm, can occur within the country, e.g. in 2022. In the last 30 years, there have been prolonged a permanently dry periods, for example between 1992 and 1994, as well as in 2011 and 2012. The most severe drought began in 2021 and ended in the early fall of 2022.

The change in precipitation is not significant if only examined on an annual basis. However, it can already be seen as significant changes from season to season. In the climate period between 1991-2020, it decreased significantly between May and September (-15-20%), while it increased by 16-18%

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in the months from October to April. The results of the climate simulations show further significant precipitation patterns similar to this for Hungary until 2100.

Hungary's exposure to climate change is very significant, which is reflected in the number, duration, and intensity of heat waves. In the case of heat waves, there is a shift towards early onset, but there are also examples of the heat period starting in August and extending into the first days of September, or an independent heat period forming at the beginning of autumn. In the climate period between 1991-2020, the number of summers and early autumn heat wave days increased by more than 100 percent. The steepest increase occurred in August, by nearly 300 percent compared to the period between 1961-1990 (Table 2). In the last 30 years, 2019 and 2022 were the years with the most heatwave days in Hungary. Both years had 150-200% more heatwave days than the 30-year average.

Table 2. The occurrence of days above 27 °C between May 15 and September 15 (Σ day/3 decades).

Climate normal	June	July	August	September
1901-1930	5	41	26	0
1931-1960	3	64	40	0
1961-1990	0	51	28	0
1991-2020	18	128	115	3
2022	6	8	17	0

Source: Authors' elaboration.

In the summer, due to the increasing number and intensity of anticyclones, decreasing cloud cover, and intense warming, the country's heat and radiation supply continues to improve. While previously the western half of the country was not ideal in terms of heat and radiation supply for some varieties, today the region's capabilities have improved, but based on all climate simulations, from the middle of the century due to temperature extremes, the eastern and southern thirds of the country will become less and less suitable for agricultural activities in the current form.

3.1.1. Drought assessment based on ADI and PAI data

Based on the data for the period 1991-2022, every second year is below 1, which means that every second year was a drought. The ADI value for the 2010 decade is 0.5-0.6. Different grades of dryness can be observed, among which 2003, 2007, 2012, 2021, and 2022 stand out. In these years a particularly severe drought was typical. The most extreme drought was typical in 2009 and 2022 according to the drought indices. The correlation matrix of the available 30-year crop series and the drought indicators produced for the growing season is shown in Table 3.

Table 3. Correlation matrix of drought indicators for each plant.

Varieties	ADI	PAI	Level of significance (α)
wheat	0.19	0.05	NS
corn	0.71	0.68	$p < 0.001$
barley	0.62	0.70	$p < 0.001$
sugar beet	0.23	0.42	$p < 0.01$
apple	0.61	0.58	$p < 0.1$
grapevine	0.23	0.09	NS
sunflower	0.60	0.63	$p < 0.001$
potato	0.18	0.11	NS

Source: Authors' elaboration.

A strong correlation was observed between drought indices and an average yield of each plant. The correlation is strong for corn (r=0.71), barley (r=0.62), and apples (r=0.61). The correlation is weak for wheat (r=0.19). The statistical correlations also clearly indicate that drought and aridity particularly impact late season varieties.

3.2. Drought shock of 2022

In the Carpathian Basin, the 2022 drought had caused almost 1.6-2 billion euros in damages and crop losses, according to data received from official institutions and domestic agriculture participants. The most significant yield losses are observed in late-ripening varieties such as corn, apple, grapevine, etc. The main reason is that the extreme drought occurred in July and August so cell development was delayed in these crops due to lack of rain. The livestock sector has also been extremely negatively affected by the decline in fodder crops. Hungarian agriculture was not prepared for such an extraordinary drought. The soils of agricultural areas are overused, and in many cases, there is a lack of organic matter replacement. Another problem is that 90% of the former floodplains have disappeared from the country and in some regions, groundwater has sunk by 100-200 cm (own observation).

4. Discussion

The new technological solutions must be found as soon as possible for targeted surface and groundwater storage and for the utilization of stocks for agricultural and drinking water supply. Both surface and soil water reservoirs are still waiting to be established in the country. Since 2010, more than 18 rainwater reservoirs have been built in the country, but due to the changing climate, at least three or four times as many would be needed, especially in the Hungarian Great Plain, which is prone to aridity. In Hungary, 4.3-4.4 million hectares are currently under cultivation, of which slightly over 2%, roughly 100.000 hectares are irrigated - based on the regional database of the Hungarian Central Statistical Office. The most ambitious plans would increase the ratio to two or three times, which means 200-300 thousand hectares, more than that could not realistically be included, therefore, the water demand of the soil is taken care of by precipitation and groundwater.

Climate change is causing increasingly extreme weather in Hungary, and with present cultivation technologies, it will be impossible to grow crops efficiently in the future. Field cultivation must be shifted from drought regions to less arid ones, e.g. from the Hungarian Great Plain to the Little Plain or the Transdanubia region. In the case of current industrial crops, the re-establishment of less productive but more stress-tolerant varieties with a short growing season brings a "renaissance" (e.g. short breeding season soybean, buckwheat, etc.). Corn is currently grown in 6-8% of Hungarian fields. As this crop is extremely sensitive to precipitation and the number of rainy days in the country decreases significantly in summer, it will increasingly decline in Hungary. In arid regions (e.g. Homokhátság, Kiskunság), sorghum can be one of the main alternatives to corn, as it is much better able to tolerate heat stress and drought stress. It was widespread in the country until the 1920s and 1930s, but in the last 50-60 years, its production area has shrunk.

However, variety selection in itself is only a partial success; the overall technological system needs to be transformed, from soil cultivation to intelligent farm management and crop protection. The key is the soil: if it can retain water, plants can survive periods of rainfall deficit with less damage.

5. Conclusions

The increasingly extreme effects of global warming and climate change are posing ever greater challenges for Hungarian agriculture. The combination of a warming atmosphere, a significant decrease in summer rainfall, and an increase in drought are causing more frequent droughts in the country. The peak of this so far occurred in 2022. Technological developments and the achievements of digitalization must be brought closer to farmers so that they can manage changes in a flexible way, and support them in investing in sustainable innovation and its practical application. To achieve sustainable agricultural and rural development in Hungary, preparing for the expected impacts of

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climate change, including the transformation of the agricultural sector, is crucial and strongly supports EU climate policy objectives and national recovery and resilience-building plans. Changing climatological conditions will require a complete transformation of agriculture, from growing conditions to digitalization and crop varieties. We expect a new agricultural revolution to begin in Hungary, driven by climate change rather than technological progress.

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