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Drought events in Hungary and farmers' attitudes towards sustainable irrigation

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Abstract— Among the different forms of agricultural damage in Hungary, drought poses a remarkably high risk according to the reported drought events, the area affected, and the level of mitigation payments. This study explores drought damage based on the 2018–2020 data of the Hungarian Agricultural Risk Management System. Owing to eligibility criteria, slightly more than half of the members of the scheme who reported drought damage received mitigation payments, but for them, the value of compensation significantly exceeded the mitigation contribution. According to our results, most of the damaged areas were outside the impact areas of water supply systems or were within the impact area but on non-irrigated fields, which proved that irrigation could be an effective drought mitigation tool. To avoid drought damage, irrigation development is essential, and special attention should be paid to the territory of Szabolcs-Szatmár-Bereg county. This area suffered significant drought damage in the years examined, and currently the impact area of the surface water-based water supply systems is small, while the groundwater resources are already overexploited. At the same time, the risk management system should be modified to transform it into a preventive system which encourages farmers to use water retentive soil cultivation methods, appropriate cropping systems, sustainable water management, and efficient and reasonable levels of irrigation. Accordingly, fewer mitigation benefits would be paid through less drought damage. Based on questionnaire surveys, farmers are open to using water retention practices and sustainable irrigation management.

Key-words: drought, Agricultural Risk Management System, irrigation, water supply systems, crops

1. Introduction

Over the last few decades, damage and losses caused by weather and climate-related extremes, such as floods, droughts, storms, and heatwaves, have increased all over the world. Among these natural disasters, drought is probably the most complex and severe due to its wide-ranging economic, social, and environmental impacts. Droughts can have cascading effects. For example, they reduce water levels in rivers and ground water, stunt tree and crop growth, increase pest attacks and fuel wildfires (EC*,* 2021). Agriculture is assumed to be one of the most drought-vulnerable sectors, as drought can substantially affect crops through many direct and indirect ways (*Musolino et al.,* 2018; *Vogt et al.,* 2018; *Cammalleri et al.,* 2020, *Trnka et al.,* 2022). While in the past the Mediterranean area was a region of major concern in Europe, central and eastern Europe and the Carpathian region have also become drought hotspots in recent decades. Long-term studies revealed that in the period June-August, a drying trend has been typical for the central and southern regions, including Czechia, Slovakia, Hungary, Romania, Moldova, and southern Poland (*Jaagus et al.*, 2021). Moreover, *Spinoni et al.* (2016) found that both drought frequency and severity have increased in the Carpathian region, in particular Hungary and Slovakia.

In recent years, such as 2003, 2007, 2012, 2015, 2017, substantial areas of the Danube River Basin were affected by water scarcity and drought (*Gregorič et al.*, 2019). Extreme droughts in the western and central parts Europe in 2018, 2019 and 2020 caused considerable damage to agriculture. In 2018 alone, agricultural damage amounted to some EUR 2 billion in France, EUR 1.4 billion in the Netherlands, and EUR 770 million in Germany (EC*,* 2021). Using long-term observations, *Hari et al.* (2020) demonstrated that the occurrence of the 2018–2019 consecutive summer droughts across Central Europe was unprecedented in the last 250 years. More than 50% of the region suffered severe drought conditions, and its combined impact on the growing season vegetation activities was stronger compared to the 2003 European drought. The 2020 drought marked the third consecutive year of unexpectedly dry conditions across Europe. Central and Eastern Europe recorded a widespread lack of rainfall in April, less so during May (EDO, 2020).

The IPCC's Sixth Assessment Report (IPCC, 2021) showed that global warming will continue in the coming decades, and changes in extremes will continue to become larger. Future climate projections indicate increasing heat waves, longer warm seasons, shorter cold seasons and, in some regions, increasing agricultural and ecological droughts. Based on the results of the PESETA IV project, with global warming droughts are expected to be more frequent, longer lasting, and more intense in the southern and western parts of Europe, while drought conditions will become less extreme in northern and northeastern Europe. In the central parts of the region (Czechia, Austria, Slovakia, Hungary, eastern part of Germany), drought hazard conditions are projected to reduce slightly, yet uncertainty in the projections is highest here (*Cammalleri et al.*, 2020). Using model simulation for Central Europe, *Hari et al*. (2020) found that under the highest Representative Concentration Pathway (RCP 8.5), a seven-fold increase in the occurrence of consecutive droughts could be expected, with an additional 40 (±5) million hectares of cultivated area being affected by droughts, during the second half of the century. Under low and medium scenarios (RCP 2.6 and RCP 4.5), drought occurrence would be significantly reduced, suggesting that an effective mitigation strategy is needed.

In addition to the different spatial frequency, magnitude, and damage consequences of drought years, the resilience can also vary depending on the geographical and socio-economic conditions (*Blauhut et al.,* 2021). In the case of agricultural damage, crop species are characterized by different water requirements and drought tolerance. Furthermore, it is important to consider that the water demand of the plant species depends on their developmental (phenological) stage. May–June is critical for winter cereals for heading and grain filling, June–August for maize for tasseling and filling, June-July for lucerne after mowing, October for rapeseed for leaf development, and May-June for flowering and setting. Drought during the period of high water demand is the main cause of yield losses (*Antal et al*., 2005). An extensive analysis based on an ensemble of crop models (*Webber et al*., 2018) concluded that maintaining current genotypes, sowing dates, and the mix of rainfed and irrigated land use would result in a 20% decrease of maize yields by 2050. For winter wheat, a yield increase of 4% is projected when CO_2 fertilization is accounted for, versus a 9% decline without. However, for both crops, drought is the larger yield-limiting climatic factor across Europe.

According to the Global Water Partnership Central and Eastern Europe (GWP, 2019), most countries react to droughts as crises requiring emergency interventions, which can be costly. The alternative is to act before droughts occur to reduce the risks and their impacts, and they encourage governments to take this approach. Instruments for financing disaster recovery need to be in place, especially for coping with extraordinary catastrophic losses; however, farmers should be encouraged to invest in preparedness and private insurance instead of the risk and ex-post damage compensation (*Leitner et al*., 2020). As far as possible, a proactive approach should be preferred, such as increasing soil water retention capacity, increased groundwater storage, improvement of irrigation techniques, investment in water-saving technologies, and improvements in water supply (*Musolino et al*., 2018; *Vogt et al.,* 2018; *Kolossváry,* 2021).

A pan-European survey on drought perception and management highlighted that even though the awareness of a future increase of drought risk is prevalent, drought is often still not considered as a risk in Central, Northern and Eastern Europe (*Blauhut et al.,* 2021). This is consistent with the findings of *Mutua Ndue* and *Goda* (2021), that there is no single European Union (EU) Member State whose agricultural sector can be considered as fully climate adapted. Hungary is among those with weak potential for climate change adaptation and, thereby, very exposed to the impacts of climate change.

2. Hungarian climate trends and the agricultural risk management system

In this paper, we focus on Hungary, where agriculture plays a significant role in the economy. Hungary lies in the Carpathian Basin, where the natural conditions (climate, water, soil, and biological resources), particularly in the lowlands and plains, are generally favorable for agriculture. However, these conditions show high spatial and temporal variability. Humid conditions can be observed in the western parts and semiarid conditions dominate in the eastern regions of the country. The spatio-temporal distribution of precipitation is highly irregular and more and more frequently produce extremes.

Owing to the expansion of built-up areas, the productive land area is slowly decreasing, but still over 54% of the total area is used for agriculture (KSH, 2021). About 82% of the agricultural land is arable land (*Fig. 1*), the main crops are maize, wheat, sunflower, and rapeseed.

Under current conditions, crop systems are mainly rainfed and water licenses are underexploited. The share of irrigated (at least once a year) areas in Hungary is very low, with only 2.6%, compared to the EU-28 average of 5.9% (Eurostat, 2019). According to the General Directorate of Water Management (OVF), 3.0–3.7% of arable land is potentially irrigable, but only around 2% is irrigated. For orchards, the irrigable area varies between 11.5 and 12.8%, of which the actual irrigated area varies between 1.9 and 7.7% depending on the year (*Kolossváry,* 2021).

Several studies have been conducted to investigate climate change trends in the Carpathian region and Hungary for the period 1961–2010. According to the results, the first decade of the 21st century was the warmest period since 1901, with two heavy and three moderate drought events, and significant changes in the trends of the annual extreme temperature and precipitation indices can be observed (*Lakatos* and *Bihari*, 2011; *Lakatos et al.*, 2016; *Mezősi et al.*, 2016). For the same period, *Alsafadi et al.* (2020) reported that the north-eastern region was less sensitive to drought despite experiencing the highest duration of total drought. Their results also showed that the eastern part of Hungary was less vulnerable to drought, while the western part was more prone to drought. The southern-western part of the country received more rainfall than the central part, while the central part was more susceptible to rainfall changes and more prone to drought. Spatial analyses of *Szabó et al.* (2019) confirmed the western-eastern difference, with the smallest temperature increase in the Great Hungarian Plain and the largest in the Transdanubian Hills. Accordingly, in areas where the temperature was high, the level of further increase was smaller compared to colder areas in the western part of the country. *Berényi et al.* (2021) confirmed the increase in the frequency and intensity of extreme precipitation events, in the length of dry periods, as well as in the occurrence of extreme weather events in the Great Hungarian Plain for 1951–2019.

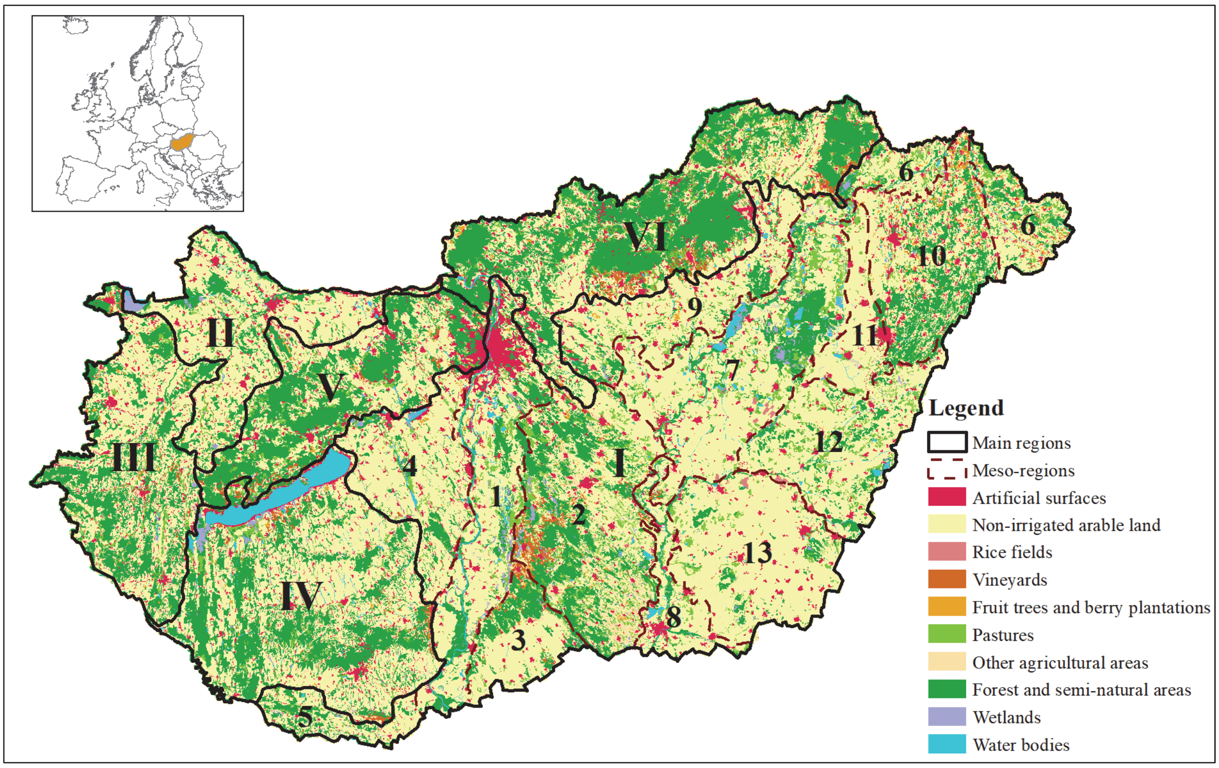

Fig. 1. Location of Hungary within Europe, the land use categories, and the main geographic regions: Great Hungarian Plain (I), Small Hungarian Plain (II), West-Hungarian Borderland (III), Transdanubian Hills (IV), Transdanubian Mountains (V), North Hungarian Mountains (VI). All the main regions can be divided into meso-regions, of which only the 13 meso-regions of the Great Hungarian Plain are highlighted.
Source: own editing based on CORINE 2018

Climate models predict that extremely hot days will become more frequent in the future, and summer rainfall could fall by more than 20% by the end of the century (*Lakatos* and *Zsebeházi*, 2018). Due to the increasing drought hazard and more frequent drought years, agricultural production conditions are expected to worsen throughout the 21st century (*Mezősi et al.,* 2016). The largest increase in the drought hazard by the end of the century is simulated to occur in the Hungarian Great Plain, while it is projected to be lowest in the westernmost part of the country (*Blanka et al*., 2013).

The Hungarian Agricultural Risk Management System (HARMS) has been operating since 2012 to address adverse climate impacts. The system consists of four pillars: (1) the compensation scheme, (2) the subsidized insurance, (3) the National Hail Damage Reduction System, and (4) the Agricultural Crisis Insurance System, which is the most recent income stabilization tool (*Lámfalusi* and *Péter*, 2021).

Pillar 1 provides damage compensation for farmers when winter frost, spring frost, autumn frost, floods, inland inundation, storms, heavy rainfall, hail, or drought damage occurs. There is a mandatory membership of the risk-sharing community in Pillar 1, when the farmers' cultivated area fulfils either:

- 10 ha for arable crops
- 5 ha for field vegetables
- 1 ha for plantations
- 5 ha for plantations combined with field vegetables
- 10 ha for all categories combined.

Smallholders, whose areas do not reach the requirements above are allowed to join voluntarily. The Hungarian single area payment scheme (SAPS) distinguishes approximately 460 crop codes, of which around 300 are relevant for Pillar 1. Forests, meadows, pastures, green manure crops, and some other specified crops are not covered by the compensation scheme. The system covers approximately 3.7 million hectares; plantations have the highest share of area involved (95.3%), followed by arable crops and vegetables (92.9% and 92.5%, respectively). Annual membership contributions are calculated per area unit: HUF 1000 per hectare for arable crops and HUF 3000 per hectare for vegetables production and plantations (from 2021, a 1.5-fold increase has been applied). The main eligibility criteria for compensation are a certified yield loss at minimum damage threshold of 30% and yield value loss at minimum 15% compared to the Olympic average (excluding the highest and lowest value) of the past five years.

Drought events are difficult to characterize, since there is no generally accepted definition for them. Several drought indices have been developed to determine the duration and severity of drought. The Act No. CLXVIII of 2011 on handling of weather-related and other natural risks affecting agricultural production defines the drought as a natural phenomenon, when during the growing season of the crop concerned, at a certain location, the total precipitation is less than ten millimeters for a period of thirty consecutive days, or the precipitation is less than twenty-five millimeters, and the maximum daily temperature exceeds 31 °C for at least fifteen days. As part of the risk management system, the National Meteorological Service (OMSZ) determines the fulfilment of these criteria based on data from around 120 automatic measuring stations and nearly 500 rainfall measuring stations and interpolating to a regular grid using a method specifically designed for meteorological purposes.

Among the different forms of agricultural damage, drought poses a remarkably high risk. According to the data of the Hungarian Agricultural Risk Management System, the amount of contribution paid by members hardly changed in the period 2016–2020, while the amount of compensation paid steadily increased (however, in 2017 the eligibility criteria for payments changed, with the decrease in yield value being considered at crop level instead of at farm level). Drought mitigation payments accounted for 27.5–50.7% of the total payments, except the wetter year in 2016. In 2019–2020, the value of the drought mitigation payments exceeded the total value of contributions paid (*Table 1*).

Table 1. Payments related to drought damage in the period 2016–2020

Indicator	**2016**	**2017**	**2018**	**2019**	**2020**
Damage mitigation contribution (million HUF)	4,185	4,167	4,088	4,121	4,145
Total mitigation payment (million HUF)	4,928	7,160	7,608	13,777	18,680
Drought mitigation payment (million HUF)	7,9	1,971	3,858	6,500	7,582
Ratio of the drought mitigation payment to the total (%)	0.2	27.5	50.7	47.2	40.6

Source: own calculations based on the HARMS database

Several studies have focused on agricultural droughts in Hungary based on long-term datasets of temperature, precipitation, or other climate variables. Drought indices (e.g., *Fiala et al.,* 2014; *Mezősi et al.,* 2016) and vegetation indices, like the normalized difference vegetation index (NDVI) (e.g., *Nagy et al.,* 2019; *Szabó et al.*, 2019) are popular tools for revealing drought trends and severity. The present study explores the relationship between drought damage and irrigation, the spatio-temporal distribution of the drought events, and the affected crops based on the 2018–2020 data of the Hungarian Agricultural Risk Management System. In addition, farmers' attitudes towards irrigation as a mitigation tool are examined.

3. Materials and methods

3.1. Datasets

Analyses were based on the HARMS database. The database contains the type of damage, the date and area damaged, the crop, and the decision to accept or reject the damage at parcel level. These data were obtained from the Damage Assessment Workflow Support System operated by the National Food Chain Safety Office (Nébih). The contribution and mitigation payment data were collected and provided by the Hungarian Paying Agency (MÁK) as the responsible authority for these datasets under Pillar 1 of the compensation scheme. The mitigation contributions were available at parcel level, while the mitigation payments were available at farm level, broken down by crop and type of damage. The designation of the parcels as irrigated or non-irrigated was based on farmers' declarations in the single application database. Data on the date and amount of irrigation water used were not available. Although most of the data were available in the database at parcel level, and the parcel geometry is recorded in the national Land Parcel Information System (LPIS), the latter was not available for us, only larger units, the physical blocks of the LPIS were obtained from the MÁK as shape files.

Most of the irrigated areas are supplied with water through interconnected integrated water supply systems, but irrigation water can also be obtained directly from lakes, reservoirs, and underground wells. Examining the spatial distribution of drought damage, the impact areas of the water supply systems were also considered. Agricultural water is supplied through 68 public irrigation water supply systems. A supply system is generally a large-scale water management and operation unit of the highest order, associated with a main water intake, defined by topography, and connected to a channel system. They are primarily used to meet agricultural water needs, but in many cases also perform other functions, such as the provision of drinking and industrial water, and ecological and recreational water replenishment. The impact areas of these systems are defined by the water management directorates based on technical and water resource management criteria and conditions, which were available in geodata (shape) files.

In addition, monthly and yearly climate reports of the OMSZ were used for the interpretation of the results.

3.2. Methods

The diversity of the analyses carried out required not only several data sources but also different methods and software. The recognized drought affected areas and the areas covered by crops relevant for HARMS were summarized for the LPIS blocks, and the queried data were then appended to the block layers (shape files). Drought-affected blocks in all three years (2018–2020) of the study were selected starting from the 2020 drought layer, from which drought-affected blocks for the other two years were selected (using the Select by Location – Have their centroid in method).

Water supply systems were assigned to blocks based on the largest proportion of their area that overlaps (Spatial join – Largest overlap). One of the supply systems belongs to two water directorates but was treated as one system during the further calculations. The impact areas of these systems vary considerably in size due to technical constraints, and the given boundary is a theoretical line. Therefore, the size of the accepted drought-affected areas was not compared to the size of these impact areas but to the total area of crops relevant for HARMS.

The causes of drought damage on parcels designated as irrigated were investigated by a questionnaire survey. Based on the 2018–2019 data, we selected the HARMS members who had accepted drought damage for their irrigated parcels. The contact details of the members concerned were provided by the MÁK, and farmers were first interviewed by e-mail and then by telephone. The short questionnaire focused on four questions:

- the use of water retention agrotechnical practices,
- taking water requirements into account when selecting the crop species or varieties to be grown,
- the purpose of irrigation,
- the causes of drought damage according to the farmer.

Except for the second question, farmers could check multiple answers from a list and an additional comment was also possible. Another questionnaire survey focused on farmers' current practices and future intentions related to irrigation in Szabolcs-Szatmár-Bereg County, which covers the Nyírség (I/10) and Upper Tisza region (I/6). This survey was carried out in collaboration with the FruitVeb Hungarian Interprofessional Organization for Fruit and Vegetables.

For simple calculations and diagrams, we used Microsoft Excel. Database management and queries were done in a PostgreSQL database, while ArcGIS Desktop was used for geospatial analysis and map visualization.

4. Results

4.1. Spatial distribution of the accepted drought damages

The majority of the 76,201 hectares accepted drought-affected area in 2018 fell in the Nyírség (I/10) and Upper Tisza region (I/6), additionally in the Danube–Tisza interfluve (I/2) (see *Fig. 1* for the numbers of the regions). The drought was more widespread in space and time in 2019 (138,928 ha), and significantly affected the Bácska Plain (I/3), the Körös–Maros interfluve (I/13), the Central Tisza region (I/7), and the Nyírség (I/10), as well as the Small Hungarian Plain (II). The 243,371 hectares of accepted drought-affected area in 2020 were 1.8 times higher than in the previous year and more than three times higher than in 2018. As in the previous year, the drought affected a large area of the Körös-Maros interfluve (I/13), the Central Tisza region (I/7), and the Nyírség (I/10), and covered most of the Small Hungarian Plain (II) (*Fig. 2*).

In all three years, the damaged areas were typically outside the impact areas of the water supply systems (89%, 70%, and 77% over the years) or on parcels covered by water supply systems but designated by farmers as non-irrigated (99%, 95%, and 97%). Areas, where accepted drought damage occurred in all three years were mainly located in the Nyírség (I/10), the Upper Tisza region (I/6), the Central Tisza region (I/7), and the Bácska Plain (I/3) (*Fig. 2*). Within the affected physical blocks – mainly due to crop rotation –, not always the same parcels were damaged.

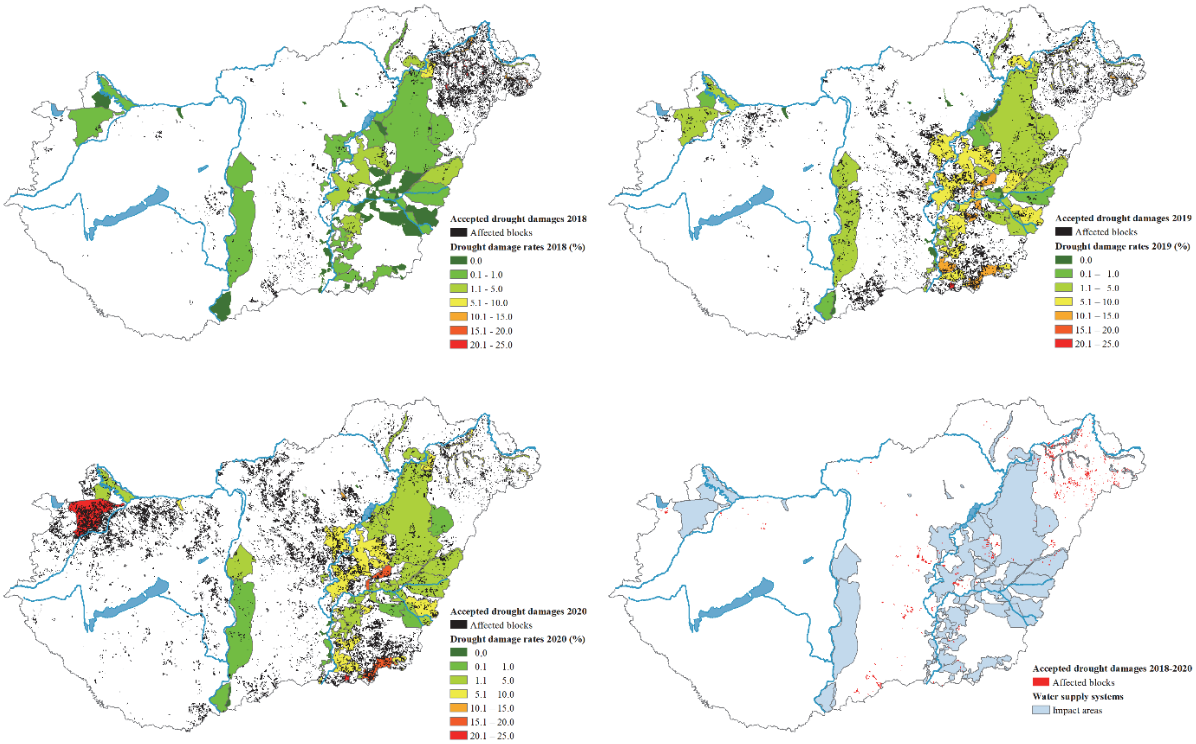

Fig. 2. The water supply systems and the spatial distribution of the accepted drought damages. *Source:* own calculations based on the HARMS database.

The impact areas of the water supply systems vary considerably in size (from 160 hectares to 343.5 thousand hectares) due to technical constraints. Therefore, for each supply system, the size of the accepted drought-affected areas was compared to the total area of crops relevant for HARMS.

In the less drought-prone 2018, 32 of the 67 water supply systems (48%) did not contain any accepted drought-affected area. There were five supply systems with more than 10% of accepted drought areas. These were small water supply systems in Nyírség (I/10) and Upper Tisza region (I/6), with a total of about 3,200 hectares of accepted drought area, of which only 2.5 hectares were on parcels marked as irrigated.

In the drier year 2019, the proportion of accepted claims also increased in areas covered by water supply systems. Of the 67 supply systems, only 12 (18%) had no drought-affected areas accepted, and the number of those with damage rates above 10% increased to eight. These were typically located in the Central Tisza region (I/7) and the south part of the Körös-Maros interfluve (I/13), with a total of almost 7,800 hectares of accepted drought area, of which 423 hectares were on parcels marked as irrigated. For a small supply system, the percentage of accepted drought-affected areas (581 ha) was slightly above 20%, but only non-irrigated parcels were damaged.

Owing to the most extensive drought in 2020, only seven small water supply systems did not contain accepted drought areas. As in the previous year, the 687 hectares damaged in the south part of the Körös-Maros interfluve had the highest percentage of damage (almost 25%), but only non-irrigated areas were damaged. With almost the same proportion (23%), however, more than 13,000 hectares were affected for one of the supply systems in the Small Hungarian Plain (II), but only 57 ha of this area was designated as irrigated. For other supply systems with a higher percentage of accepted damage (15–17%), all the damaged parcels were non-irrigated.

A significant difference is that in the years examined, accepted drought damage affected 35–43% of the non-irrigated areas, while 9–22% of the areas were marked as irrigated.

4.2. Crops affected by drought damage

In the years examined, drought damage showed different patterns, not only in spatial but also in temporal distribution, and these were closely linked to the crops damaged. Owing to cereals being sown in the autumn, the compensation year runs from November 1 of the preceding year to October 31 of the actual year. *Fig. 3* illustrates the temporal distribution of accepted drought areas and the main crops affected, broken down by month. Mitigation payments were paid for more than 100 crops in each year examined (for 106 in 2018, for 115 in 2019, and for 114 in 2020). For the total area, crops with over 500 hectares of damage have been highlighted, while for the irrigated areas, the threshold was 50 hectares. The damaged crops shown in *Fig. 3* reflect the periods of critical water demand for these crops (e.g., May-June for winter cereals, June-August for maize).

According to meteorological data, in 2018, the monthly mean temperature was higher than the 1981–2010 average in every month except February and March. The 4.8 °C difference in April was prominent, but the average temperature in May was also 3.1 °C higher. Precipitation in February and March was more than twice the multi-year average, and in June it was also above average (+35%), except in the eastern part of the country. However, in the other months of the year, there was a lack of rainfall, especially in April and October (37% and 42% less than the long-term average, respectively). Based on the damage events, the lack of rainfall in April was probably compensated by the earlier surplus of rainfall. More than half of the accepted drought areas were reported in August, when several crop species were severely affected by the drought. The October rainfall deficit was reflected in damage to winter cereals and rapeseed in November. The monthly mean temperature in 2019 was above the 1981–2010 average in all months except May. During the year, highest rainfall occurred in May and November, while March was extremely dry, with only 28% of the long-term average. More than 40% of the accepted drought areas were declared in April and mainly affected winter cereals, rapeseed, and lucerne.

As in the previous year, the monthly mean temperature in 2020 was higher than the long-term average in every month except May. The total annual precipitation was slightly higher than the long-term average (102%), but very unevenly distributed. During the year, June and October received outstandingly high rainfall, while April and November were extremely dry. In April, only 25% of the normal rainfall fell, and 54% in May. There were stations where no measurable rainfall fell during the whole month of April. Accordingly, over 61% of the accepted drought-affected areas were declared in May and nearly 25% in June. The drought damage in May affected a particularly large number of crops, with 20 crops having an accepted damage above 500 hectares.

The temporal distribution of the accepted drought damage in the areas designated as irrigated (*Fig. 3*) was essentially similar to that for all damaged areas, with some differences. Overall, the greatest damaged area for apple and Virginia tobacco in 2018 was in August, while the greatest damaged area designated as irrigated was in September. As most of the area under maize, sunflower, lucerne and soybean was non-irrigated, that significantly influenced the temporal distribution of drought damage. A smaller change can be seen in spring for green peas, which was affected by drought over a large area for both irrigated and non-irrigated parcels, but the damage was more severe in May than in the wetter June. The differences seen in July 2019 and August 2020 are due to damage to irrigated hybrid maize.

However, for agricultural risk management, not only the size of the damaged area should be considered, but also the yield loss and the value of the crop affected by the damage event (loss of production value). As a result, the value of the mitigation payment will be in many cases higher for a crop with a high value but smaller area damaged than for a crop with a larger area damaged but a lower price. Therefore, different crops may be considered the most drought-affected according to the accepted drought area, the paid area, and the value of the mitigation payment (*Table 2*). For example, in 2019, hybrid maize was not in the top ten in terms of drought area, while it was ranked fourth in terms of the value of the compensation paid. However, maize and sunflowers, whose critical water demand is in summer, as well as winter cereals and rapeseed, whose critical period is in May-June and which are cultivated over large areas, have been in the top ten in all aspects every year.

Period	2018				2019				2020			
	Total area	min. 500 ha	Irrigated area	min. 50 ha	Total area	min. 500 ha	Irrigated area	min. 50 ha	Total area	min. 500 ha	Irrigated area	min. 50 ha
November	0,0%		0,0%		8,7%	R, W, Sp, B	9,8%	R, W	0,0%		0,0%	
December	0,0%		0,0%		2,0%	W, R	0,0%		0,0%		0,0%	
January	0,0%		0,0%		0,2%		0,0%		0,0%		0,0%	
February	0,0%		0,0%		0,9%	R	0,0%		0,0%		0,0%	
March	0,0%		0,0%		6,4%	W, R, S, L, B	8,5%	R, W	0,0%		0,0%	
April	0,0%		0,0%		41,6%	W, R, B, T, D, L, Ry, Lf, S, X	38,3%	D, W, R, O, Sp, X, B	8,9%	W, R, B, L, T, S, X	1,3%	
May	11,0%	W, T, G, R, Ry, S	20,2%	G	19,1%	W, R, B, D, T	13,7%	W	61,7%	W, R, B, S, L, M, T, D, Ry, G, O, Ms, Bs, Ph, Sp, Su, Or, Cp, Lf, P	56,1%	W, L, Ms, B
June	13,7%	W, R, G, M	7,1%		2,5%	W	1,0%		24,8%	W, R, B, S, M, L, D, T, Bs, Sp, Ms, O	6,9%	L
July	15,6%	M, S, Wm	2,1%		5,1%	M, Ms, Mh, W	27,5%	Mh, R	2,3%	W, M, S	0,0%	
August	50,2%	M, S, A, Ms, L, Vt, Sb	29,9%	A	5,3%	M, S	1,1%		1,0%	M, Mh	34,4%	Mh
September	9,6%	M, S	40,8%	A, Vt	8,1%	M, S, L	0,2%		1,2%	M, S	1,3%	
October	0,0%		0,0%		0,0%		0,0%		0,0%		0,0%	

Fig. 3. Temporal distribution of accepted drought areas and the main crops affected. A - apple, B - winter barley, Bs - spring barley, Cp - purple clover, D - winter durum wheat, G -green peas, L - lucerne, Lf - lucerne fermented fodder, M - maize, Mh - hybrid maize, Ms - silage maize, O - oat, Or - oil radish, P - poppy, Ph - phacelia, R - rapeseed, Ry - rye, S - sunflower, Sb - soybean, Sp - spelt, Su - sugar beet, T - winter triticale, Vt - Virginia tobacco, W - winter wheat, Wm - watermelon, X - mixed culture. *Source:* own calculations based on the HARMS database

Table 2. Ranking of drought-affected crops according to the accepted drought area and the mitigation payment

2018		**2019**		**2020**	
Accepted drought area	**Mitigation payment**	**Accepted drought area**	**Mitigation payment**	**Accepted drought area**	**Mitigation payment**
Maize	Maize	Winter wheat	Rapeseed	Winter wheat	Winter wheat
Sunflower	Sunflower	Rapeseed	Winter wheat	Rapeseed	Rapeseed
Winter wheat	Green peas	Maize	Maize	Winter barley	Sunflower
Apple	Apple	Winter barley	Hybrid maize	Sunflower	Maize
Rapeseed	Watermelon	Winter triticale	Sunflower	Maize	Hybrid maize

Source: calculations based on the HARMS database

Of the more than 100 crops affected by drought mitigation payments, 8–12 crops were associated with payments of more than HUF 100 million, covering 70–80% of the payments, depending on the year. Crops damaged on irrigated fields (e.g., green peas, Virginia tobacco) generally have higher value and price, therefore drought mitigation payments per hectare were much higher than in non-irrigated areas.

Owing to eligibility criteria, slightly more than half of the members who reported drought damage received mitigation payment, but for them, the value of compensation payment significantly (23–31 times) exceeded the mitigation contribution they paid.

4.3. Causes of drought damage on irrigated fields

Based on the 2018–2019 data, 74 farms were identified having drought damage on parcels designated as irrigated, two of which suffered damage in both years. The causes of the damage were investigated by a questionnaire survey. Most farms had one or two damaged crops, but some of them reported drought damage for eight crops marked as irrigated. Some members responded separately for the different crops, resulting in 50 responses from 48 respondents. Of the responses, 70% were related to arable crops and 30% to orchards. Among the cases examined, the damage to apple and Virginia tobacco was prominent in 2018 in terms of the number of members affected as well as the area damaged, while in 2019, most responses were related to winter wheat and rapeseed (according to the results shown in *Fig. 3*). In the followings, we describe the farmers' attitudes toward irrigation and the causes of drought damage according to the farmers.

Most of the respondents use some water retention practices. Of the technologies surveyed, soil loosening is widespread among arable farmers (field crops and field vegetables) but is also used by 20% of responding fruit growers. The use of cover crops and bacterial fertilization were mentioned by almost one third of arable farmers, while the use of cover crops was more common for fruit growers (40%). Other technologies applied included the use of organic fertilizers, as well as shoot-sorting in apple orchards.

Of the respondents, 66% consider the water needs of plants when choosing a plant species or variety. This figure is even higher among arable farmers, where the crop is rotated annually (71%), and slightly lower for longer lifespan orchards. Fruit growing is a special case, where the characteristics of the trees are determined by the combination of the rootstock and the grafted variety. Another problem for apple growers was that when the plantation was established, the weather was not so drought-prone, so this was not a factor in the choice of species.

Most respondents (72%) use irrigation primarily for crop safety, followed by the need to achieve higher yields, which accounted for nearly 50% of all responses, and 80% of fruit growers. Most of the winter wheat growers irrigate occasionally to reduce damage. Additional purposes of irrigation are typical of fruit growers, such as fertilization, in some cases frost prevention or achieving a more uniform fruit size.

Farmers were allowed to provide multiple answers for the effective reasons of drought damage. Of the respondents, 28% indicated that no irrigation had taken place on the field marked as irrigated, but this proportion was slightly higher among arable crop producers (31%) and lower among fruit growers (20%) (*Fig. 4*). In some cases, this was due to a technical problem (e.g., pump failure), in others it was considered that the crop was not worth irrigating – these were generally listed among the other reasons. Among the offered responses, the indications of damage in sensitive phenophase were prominent (51% for arable land and 47% for orchards), while the lack of available water, as a limiting factor, was mentioned by fewer than 15% of respondents.

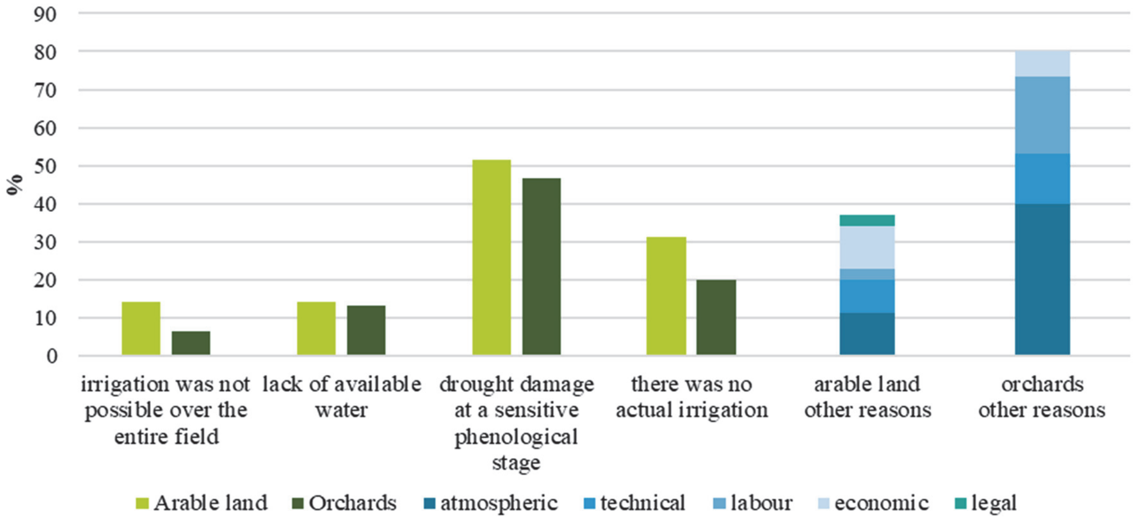

Fig. 4. Causes of drought damage on irrigated fields. *Source:* questionnaire survey.

For this question, farmers had more freedom to give answers other than the few pre-defined options. Half of the respondents took the opportunity to mention other reasons, which were particularly high (80%) among fruit growers. For an easier overview, the answers were grouped into atmospheric, technical (failure, outdated system), economic (operating costs, irrigate something else), labor (lack of labor and/or time), and legal (irrigation period) reasons (*Fig. 4*). There was a high prevalence of atmospheric drought, particularly among fruit growers using drip irrigation and vegetable growers in arable fields. Drip irrigation is not suitable for humidification and, especially in the case of prolonged drought and associated winds, the low humidity in the air will dry out the leaves of the plants despite irrigation. Other reasons mentioned repeatedly included lack of available labor and working time for winding drums and for old pumps requiring supervision. For crops damaged in autumn 2018 (winter cereals, rapeseed, poppy), some mentioned that the dry period fell outside the statutory irrigation season (from 2019 the irrigation season ran from 1 March to 31 October, previously from 15 April to 30 September), therefore they did not irrigate. Off-season irrigation is possible at an extra cost in consultation with the water supplier, but farmers usually do not undertake this. Those with little water available preferred to irrigate other, more water-intensive crops (e.g., vegetables instead of the old orchard) or could only irrigate intermittently. Thus, in several cases, these respondents also indicated that they were unable to irrigate the entire field.

4.4. Farmers' irrigation practices and plans in Szabolcs-Szatmár-Bereg County

Based on the spatial distribution of drought events (*Fig. 2*), Szabolcs-Szatmár-Bereg County, which covers the Nyírség (I/10) and the Upper Tisza region (I/6), was one of the 'hotspot' areas in the years examined. As this is the main fruit-growing region in Hungary, a questionnaire survey focused on current irrigation practices of orchards and farmers' attitudes towards sustainable irrigation development.

A total of 106 fruit growers participated in the survey, whose orchard area covered 7.4% of the total fruit-growing area of the county. More than half (58%) of the growers have irrigation equipment in their orchards. The main irrigated cultures are walnuts, apples, and sour cherries, with a share of irrigated areas above 60%; in addition, plums, cherries, pears, and quince with shares of irrigated areas of 30–40%. However, based on the responses, illegal irrigation (without water licenses) of commercial orchards is estimated at 20–30%. Orchards are irrigated mainly from groundwater (59% from stratum water and 20% from subsoil water), 19% of the areas are irrigated from reservoirs, and only 2% from surface water. The high percentage of stratum water use is unfavorable, because its recharge is much slower than that of subsoil water and raises both water quantity and quality issues. Of the irrigated orchards, 90% are equipped with a water-saving drip system, and most of them (71%) are also suitable for fertilization.

Of the fruit growers who irrigate, 88% have a simple cylindrical rain gauge. Meteorological stations are used by 27% of the growers, while 23% use tensiometers to measure soil moisture. Almost half of them (46%) have also installed water purification units for their irrigation system, while only 23% use irrigation management software. Most of the respondents (89%) do not currently contact an irrigation advisor, and 34% do not plan to do so in the future. All these responses show that irrigation is more based on growers' experience and tradition rather than on objective measurements and control systems.

The limited water supply, the actual status of water bodies, and the protection of groundwater require a change in irrigation practices in the region. Therefore, fruit growers were also asked about their attitudes towards sustainable irrigation management. The vast majority (97%) of the respondents consider irrigation development important and would use water-saving technologies to reduce irrigation restrictions. Almost the same proportion (94%) would use conservation tillage methods, many of them would change to use surface water instead of groundwater (if made available through irrigation development), support or develop the construction of dual-function canals (inland drainage and irrigation) on their field, and would undertake the construction of reservoirs. The willingness to establish irrigation communities is lower than in other instruments, although Hungary now strongly supports this form of cooperation. Respondents are divided on the reuse of wastewater for irrigation purposes (*Fig. 5*).

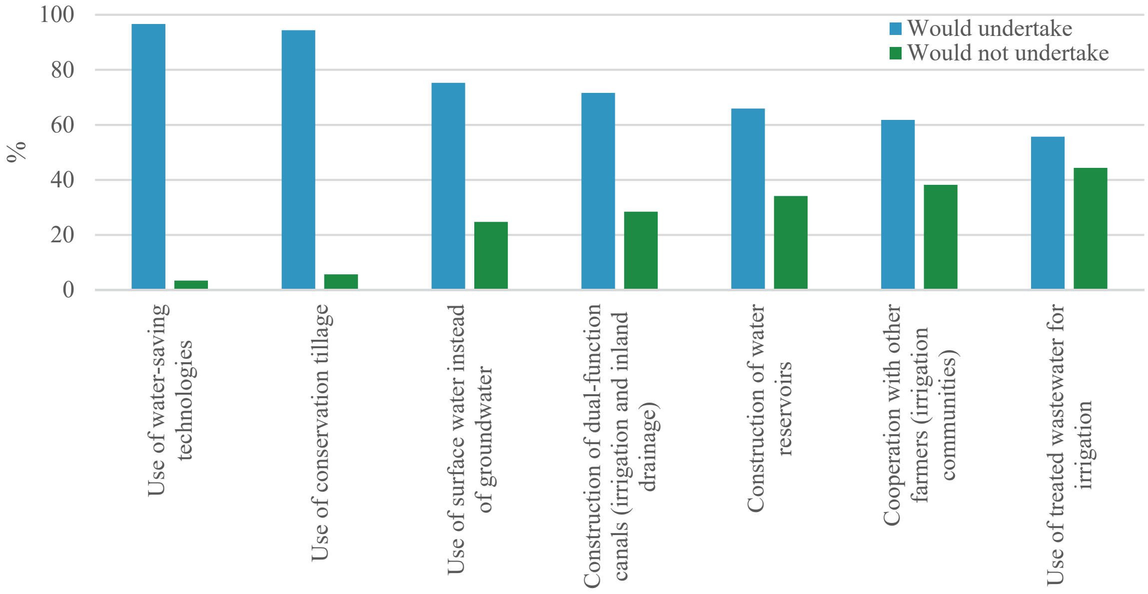

Fig. 5. Attitudes to manage limited irrigation possibilities (number of respondents is 89). *Source*: questionnaire survey.

Most of the respondents (73%) plan some irrigation development (e.g., irrigation well, irrigation equipment, meteorological station, fertilizer unit, soil moisture meter) in the next five years, and more than half of them would require investment support for that purpose. The survey shows that farmers are trying to make water use in their area as efficient as possible with sustainable tools.

5. Discussion

Agriculture is one of the most important sectors in Hungary, therefore, agricultural drought events are a particularly important area to be examined. A significant share of Hungarian agricultural land is already considered to be affected by drought (*Kemény et al.*, 2018) and most farmers experienced now reduced productivity due to drought periods (*Biró et al.*, 2021). In addition, climate models predict a decrease in precipitation and an increase in the frequency and duration of droughts (*Mezősi et al.*, 2016; *Lakatos* and *Zsebeházi,* 2018). One of the main problems of studying drought is its delimitation in space, time, and intensity (*Tamás,* 2017). The present study was based on the 2018–2020 data of the Hungarian Agricultural Risk Management System, and accepted drought-affected parcels were analyzed. Drought damage showed different patterns, not only in spatial but also in temporal distribution, and these were closely linked to the crops damaged. The economic value of drought damage and the mitigation payment depends on the price of the crop. Therefore, different crops may be considered the most drought-affected according to the accepted drought area, the paid area, and the value of the mitigation payment.

Farming systems may play a fundamental role in the adaptation to adverse climatic conditions. Among the adaptation options, changes in crop species, cultivar, sowing date, fertilization, irrigation, use of cover crops, conservation tillage, and precision agriculture technologies seem to be the most appropriate. *Mitter et al.* (2019) found that adaptation intentions are only formed if farmers are aware of effective adaptation measures, accept personal responsibility for their farms, and evaluate adaptation costs positively. According to *Hanger-Kopp* and *Palka* (2021), whether a farmer irrigates or not partly depends on whether water for irrigation and the associated water rights are available. In Hungary, farmers often complain about the lengthy and difficult authorization procedure and the associated high costs. The water licenses are underexploited; only around the half of the potentially irrigable land is irrigated. Crops that are regularly and extensively damaged (e.g., maize, sunflower, and winter cereals) are mainly rain-fed. To avoid drought damage, a proactive approach should be pursued, such as increasing soil water retention capacity, increased groundwater storage, improvement of irrigation techniques, investment in water-saving technologies, and improvements in water supply (*Musolino et al.*, 2018; *Vogt et al.*, 2018). The results showed that irrigated areas have a lower rate of drought damage than non-irrigated areas, demonstrating that irrigation can be an effective drought mitigation tool. Most of the damaged areas were outside the impact areas of the water supply systems, or on parcels covered by water supply systems but designated by farmers as non-irrigated. Based on the questionnaire survey, most of the respondents use irrigation primarily for crop safety. However, planned irrigation management not only mitigates the adverse effects of extreme weather anomalies and reduces yield variability, but can also increase yields and, in most cases, improve product quality. Most of the agricultural experts agree that the increase of irrigated areas could provide a huge potential for field crop production in Hungary (*Kemény et al*., 2018). According to other experts, irrigation is primarily justified when and where other agrotechnological means cannot provide the necessary water for the crops (*Kolossváry,* 2021). Our surveys show that most of the farmers consider the water needs of plants when choosing a plant species or variety, many of them use some water retention practices and are open to use new solutions to manage limited irrigation possibilities. It should be highlighted that the water-saving drip irrigation is not suitable for humidification, and therefore, against prolonged atmospheric drought. This is a serious problem for fruit and vegetable growers.

Hanger-Kopp and *Palka* (2021) found that farmers consider irrigation a strenuous and tedious job, and equipment needs regular checks, therefore, the location (i.e., whether they are close together) and size of the fields may also influence the adoption of irrigation. Technical problems (e.g., pump failure, outdated system), as well as lack of available labor and working time for winding drums and for supervising old pumps were also mentioned by farmers responding the causes of drought damage on irrigated fields. The other survey revealed that automation and use of irrigation management software is not widespread, only 23% of the respondents use it.

Adaptation to climate change is one of the critical points of the long-term sustainability of Hungarian agriculture. According to *Trnka et al*. (2022), to influence the strategic decisions of the farmers positive incentives are needed rather than regulations. The compensation paid through the risk management system is a great help for the farmers, but farmers should be encouraged to invest in preparedness and private insurance instead of the risk and ex-post damage compensation (*Leitner et al*., 2020). Sustainable water management would require the spread of new technologies and digitalization. *Biró et al*., (2021) emphasized that it is necessary to bring technological developments closer to farmers, support them in sustainable innovation investments and practical application. They identified 27 Climate-Smart Agriculture tools, which may strengthen environmental sustainability, among them the drought monitoring system and water-saving smart irrigation systems. *Zubor-Nemes* (2021) analyzed the relationship between crop insurance take-up, technical efficiency, and investment in Hungarian farming. According to her results, total subsidies (including direct payments) decrease technical efficiency, while targeted subsidies, i.e., premium support, encourage crop insurance demand, and investment subsidies stimulate investment significantly. Financial support to help farmers invest in climate-smart practices and technologies is considered important, and there are now such investment support schemes in Hungary (e.g., support for precision agriculture and for irrigation development).

Information about the drought-vulnerable areas and analyses of drought impact on agriculture are crucial to adapt agricultural practices to the weather extremes. Such information will potentially help to adapt irrigation and land management strategies, application of any drought management measures (*Crocetti et al*., 2020; *Drisya* and *Sathish Kumar,* 2022), as well as to establish adequate insurance and mitigation policies. Owing to the different vulnerability and adaptive capacity of different regions, impacts and problems should also be managed in a differentiated way, with customized solutions based on each area and its capabilities. *Buzási et al*. (2021) developed an indicator that categorizes the Hungarian counties based on their drought-related exposure (relative Pálfai drought index), sensitivity (topsoil sand content), and adaptability (irrigation water use). Their results showed that many counties are not adequately prepared for the impacts of drought, despite their high vulnerability index. They found that the drought vulnerability of Szabolcs-Szatmár-Bereg County is in the top quartile, but the county's strategy considers drought in a typical forward-looking response. Our results confirm that this county should receive special attention. This area suffered significant drought damage in the years examined, and the impact area of the surface water-based supply systems is small. The biggest problem in the county is the excessive stratum water use. Reducing the wasteful use of groundwater and protecting the status of aquifers are important to ensure that drinking water needs are met in the long term. The protection of aquifers is not only quantitative but also has a water quality issue, preventing the flow of locally contaminated groundwater into deeper layers. Therefore, only micro-irrigation from stratum water should be allowed.

6. Conclusions

Among the different forms of agricultural damage in Hungary, drought poses a remarkably high risk. In the years examined, drought mitigation payments accounted for 40.6–50.7% of the total payments. In 2019–2020, the value of the drought mitigation payments exceeded the total value of the contributions paid by farmers. The National Water Strategy (Jenő Kvassay Plan) also draws attention to the fact that a substantial proportion of agricultural subsidies is spent on compensation, rather than on more efficient irrigation, which would generate higher revenues and make better use of the water supply (*Reich,* 2019). The current risk management system contributes to mitigating the damage caused by extreme weather events but does not encourage farmers to mitigate risk. The risk management system should be modified to transform it into a preventive system, which encourages farmers to use water retentive soil cultivation methods, appropriate cropping systems, sustainable water management, and efficient and reasonable levels of irrigation. Accordingly, fewer mitigation benefits would be paid through less drought damage. Currently, annual membership contributions are calculated per area unit, but it is recommended to examine whether the amount of contribution may take into account the drought sensitivity of the given area, and the irrigation and water retention agrotechnical practices used by the farmer. Investigations in this direction have started at Institute of Agricultural Economics. In addition to the financial support (subsidized insurance, ex-post damage compensation, investment support), irrigation advisory and knowledge management should be strengthened.

Several initiatives, projects and online tools have been established to facilitate drought monitoring and management in the Pannonian Basin (*Gregorič et al.*, 2019; *Nagy et al.,* 2019, *Szabó et al.*, 2019; *Crocetti et al.*, 2020). The Hungarian Agricultural Risk Management System is based on its own drought definition and the measurements of the OMSZ. However, the OVF has also established a national drought management monitoring system and developed the Hungarian Drought Index. The main purpose of this system is to determine intervention levels and to define precisely the operational activities and related measures for legislative harmonization. Additionally, data are published on a web portal, delivering information for decision makers, professionals, or farmers (*Fiala et al.*, 2018). However, different methodologies show different results, and it would be beneficial to synthesize the research results and create a national drought risk map.

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