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Farmers observations on the impact of excessive rain and flooding on agricultural land in Croatia

Zapažanja poljoprivrednika o utjecaju prekomjerne kiše praćene poplavama na poljoprivredna zemljišta u Hrvatskoj

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ABSTRACT

Extreme events have produced more rain and became more frequent in many regions around the world, and these trends will rise with the warming of the planet. The vulnerable agricultural sectors, directly dependent on the climate, is predicted to be significantly affected by climate change, with an expected decline in future crop yields. We provide data on the effects of floods, because of excessive rain, on the agricultural sector in Croatia, with emphasis on its northern Pannonian region. Data collected for the period 2015-2020 are based on a 34-question survey, conducted among farmers previously reporting on climate-related damages to their crops. With almost 80% of farmers having experienced flooding on their field plots in the last 5 years (mostly short-term flooding, i.e. waterlogging of up to seven days), it is clear that this type of investigation needs further attention. Data suggested that floods most often occurred in the plant germination phase (before the 5th leaf) representing a risk for plant damage and consequent reduction in yields. A combination of mitigation and adaptation measures could minimize water retention in the fields and reduce damage, however, our survey implied that farmers scarcely use such measures. Knowledge gained in this study represents the first step toward understanding potential negative effects of the extreme events on the fragile agricultural sector in Croatia and could help authorities in decision making with the aim to reduce the degree of uncertainty associated with climate change effects.

Keywords: extreme weather events, rain, flooding, agriculture, Croatia, crops

SAŽETAK

Ekstremni vremenski događaji, između kojih su i obilne kiše, postali su sve češća pojava u mnogim dijelovima svijeta. S obzirom na to da se planet nastavlja zagrijavati, očekuje se njihovo povećanje. Predviđa se da će poljoprivredni sektor, koji izravno ovisi o klimi, pretrpjeti velike štete s očekivanim padom prinosa usjeva. Istraživanje je usmjereno na poplave koje nastaju kao posljedice obilnih kiša te njihov utjecaj na poljoprivredni sektor u Hrvatskoj, s naglaskom na njegovu sjevernu Panonsku regiju. Podaci su prikupljeni za razdoblje 2015-2020, a temelje se na anketi od 34 anonimna pitanja provedenom među poljoprivrednicima koji su prethodno prijavljivali klimatske štete na svojim usjevima. Budući da je gotovo 80% sudionika istraživanja u posljednjih 5 godina na svojim proizvodnim površinama imalo poplavu (uglavnom kratkotrajnu tj. poplavljivanje do sedam dana), jasno je da ovoj vrsti problema treba dodatno posvetiti pažnju. Podaci sugeriraju da su se poplave najčešće dogodile u fazi klijanja biljaka (prije 5. lista) što predstavlja rizik za oštećenje biljaka i posljedično smanjenje prinosa. Kombinacija mjera ublažavanja i prilagodbe mogla bi umanjiti zadržavanje vode na poljima i smanjiti štetu, međutim, istraživanje je pokazalo da poljoprivrednici rijetko koriste takve mjere. Znanje stečeno u ovoj studiji predstavlja prvi korak ka razumijevanju potencijalnih negativnih učinaka ekstremnih događaja na krhki poljoprivredni sektor u Hrvatskoj i moglo bi pomoći vlastima u donošenju odluka s ciljem smanjenja posljedica takvih događaja.

Ključne riječi: ekstremni vremenski događaji, obline kiše, poplava, poljoprivreda, Hrvatska, usjevi

INTRODUCTION

Global climate change presents one of the greatest and most complex issues that humankind is facing today. It involves many dimensions including science, economics, society and politics. As stated in the IPCC Fifth Assessment Report from 2014, human influence on the climate system is now clear, with most recent anthropogenic emissions of greenhouse gases being the highest recorded in history (388 ppm CO_2 v/v in 2010, 399 ppm in 2015, and 413 ppm in 2020; NOAA, 2020). Changes in climate have measurable impacts on humankind and ecological systems across our planet. Among an array of indicative signs of global climate change, we are witnesses to more frequent fluctuations in weather conditions, with growing incidents of extreme weather disasters. According to the report of the UN Office for Disaster Risk Reduction, extreme weather events will start to dominate the disaster landscape in the 21st century. In the period of 2000–2019, there were 7,348 major recorded disaster events claiming 1.23 million lives, affecting 4.2 billion people (many on more than one occasion) and resulting in approximately US$2.97 trillion in global economic losses. In to the previous period (1980–1999), lower numbers were recorded (i.e. 4,212 disasters linked to natural hazards/ 1.19 million lives/ affecting 3.25 billion people/ US$1.63 trillion in economic losses). The differences observed between these periods are linked to the rise in numbers of climate-related disasters (from 3,656 between 1980–1999 to 6,681 between 2000–2019), including extreme weather events such as floods and storms, being prevalent events (major floods rose from 1,389 to 3,254 events). As indicated in the IPCC special report on the extremes (Seneviratne et al., 2012), climate changes directly influence water-related variables, including rainfall and snowmelt. Our warming world, i.e. warmer atmosphere, holds more water that is subsequently being dumped onto the Earth surfaces. With each of the last three decades being successively warmer than the previous decade (IPCC, 2014a), experts predict that extreme events will only intensify in the future. The latest evidence shows that the number of days with heavy precipitation over Europe has increased on average by about 45% in the period from 1981–2013 compared to the 1951–1980 period and by about 25% in the model average (Fischer and Knutti, 2016).

Increases in both heavy and total precipitation is directly connected to increases of severe flooding events. The EU Floods Directive defines a flood as a covering of land, which is not normally covered, by water. This can be caused by the overflow of inland waters (rivers and streams) or tidal waters, or by an unusual accumulation of water from heavy rains or dam or levee breaches. Studies suggested that flood risk has greatly increased in Europe in recent years (Blöschl et al., 2017; Slingo et al., 2014). Especially dangerous are flash floods that are greater in magnitude in the Mediterranean countries of Europe than in the inner continental countries (Gaume et al., 2009). Flash floods are extreme weather events characterized by short duration (from less than one hour to 24 hours) and heavy rainfall (more than 100 mm rainfall over a few hours or less). The affected areas are often limited to a few hundred square kilometres, with rapid hydrological responses occurring in less than 6 hours after peak rainfall intensity (Gaume et al., 2016). Extreme flooding can result in great losses induced to infrastructure, human lives but likewise to different economic sectors, including agricultural sector. In the agricultural sector, which is highly dependent on the climatic factors, floods can have considerable negative impact on quantity and quality of food products. Consequently, floods are becoming not only an environmental but also an economic and social problem, posing direct threat to human food security. At the same time, due to the irregularity and rarity of extreme floods, relatively little is known on the long-term impacts of floods on crops, as well as on whole land ecosystems, and its potential for recovery (Hall et al., 2019).

Climate change is considered to be a global issue, with consequences felt on a regional scale, and a need to combat these changes starting at the national level as well. To address the issue of climate change on the national level, in 2020 the Croatian Parliament adopted the “Strategy for Adaptation to Climate Change in the Republic of Croatia for the period until 2040 with an overview on 2070” clearly defining problems associated with climate change in Croatia. In addition, assessment guidelines published in the “Seventh National Communication of the Republic of Croatia under the United Nation Framework Convention on the Climate Change (UNFCCC)" outlined the agricultural sector (alongside forestry, fisheries, energy and tourism) as a climate-related “fragile sector”, that is expected to suffer the greatest damage as a consequence of climatic change in Croatia. Due to the vast hilly-mountainous areas with high rain intensities, wide valleys of lowland watercourses, large cities, valuable goods on potentially endangered areas, and due to insufficiently built and maintained protection systems, the Republic of Croatia is quite vulnerable to floods. It is estimated that floods potentially threaten about 15% of the state’s land territory, much of which is today protected with varying levels of security (Simac and Vitale, 2012).

According to the Disaster statistics report (http://www.emdat.be), floods are designated as the most frequent type of disaster events in Croatia, followed by wildfires and extreme temperatures. Long-term observations (including pre-2000) show that the territory of Croatia is often exposed to river floods (Samardzija et al., 2014), however, at the same time, no consensus data exist on the issue of excessive rain causing short and long-term flooding, i.e. water retention on field plots. These types of events occur randomly and rapidly and therefore their forecasting is faced with great unreliability. Due to the lack of data on this topic, this study was conceived to give insight into occurrence frequency and potential damage of flooding on the agricultural activities in Croatia.

The aim of our study was to consider and evaluate flood risks and flood damage induced to agricultural production in Croatia as a consequence of excessive rain events, solely based on the subjective assessment of selected farmers’ groups. We hypothesized that excessive rain followed by floods are an important climatological events that are significantly affecting farmers in Croatia and their agricultural production. This survey was conducted as a part of the project “Potential of rhizosphere microbiome in adapting agriculture to climate change (PERSPIRE)” funded by the “Scheme to strengthening applied research for proposing measures for climate change adaptation”. This scheme, financed by the European regional fund, aimed to improve the quality and availability of scientific data on the topic of climate change in Croatia, encouraging actions and measures that would allow this “fragile sectors” to adapt to the changing world. The obtained data represent a first step towards understanding the effects of extreme events on the fragile agricultural sector and will allow us, in the future, to better understand the complexity of climate change impacts on agriculture.

MATERIALS AND METHODS

Data were collected with a questionnaire conducted among farmers from selected counties in Croatia, where farmers have been noticing flood-related damages on their crops. With help of a questionnaire, we were able to:

i) identify frequency of the occurrence of short and long-term floods caused by rain in the last 5 years in selected counties in Croatia,
ii) determine plants sensitivity and damage induced by water retention, and
iii) get insight into the adaptation and mitigation measures used by farmers to fight flood-related disasters.

The questionnaire was designed in collaboration with the Croatian Ministry of Agriculture (https://poljoprivreda.gov.hr/) that was also responsible for collecting the data. Survey was conducted by using Google Forms survey administration software included in the Google Docs Editors software suite along with Google Docs, Google Sheets, and Google Slides (https://www.google.com/forms/about/). The survey was sent in electronic form to physical and legal persons registered in the Register of Farmers (active farmers) who are beneficiaries of Sub-measure 13.2. Compensation payment for other areas facing significant natural constraints from Rural Development Programme of the Republic of Croatia for the Period 2014–2020, and are obliged to perform agricultural activity on agricultural land in areas with significant natural constraints. Participants were also selected according to the counties in which their farms are located, including (i) counties with high agricultural production and (ii) counties in the Pannonian part of Croatia with expected higher frequency of rain events, i.e. higher possibility of floods. The questionnaire was designed to refer to one production plot at which flooding was observed as a result of excessive rain. Results presented here correspond to data collected from 101 agricultural plots and are related to the period of 5 years (2015-2020).

The survey consisted of 34 questions with the possibility of marking single or multiple offered answers. It was comprised of different types of questions investigating:

i) frequency of floods observed by the farmers,
ii) length of water retention on their agricultural plots,
iii) information on the stage of the plant at the time of flooding,
iv) assessment of the damage induced to plants by flooding,
v) information on the most commonly grown plants on the examined agricultural plots,
vi) assessment of the plants' sensitivity to floods, and
vii) information on the use of adaptation and mitigation measures by the farmers.

As farmers do not grow on their plots all crops that were provided within the multiple answer list, for such type of multiple-choices questions less than 101 data/per question was received. A complete list of full-length questions, the possibility of multiple answers, and the number of answers per question is provided in the supplement (Supplement material, Table S1). Data were further statistically analyzed using Microsoft Excel 2016 tool.

Plot distribution within the collected data

In general, agricultural land in Croatia is either privately owned or state's land assigned to a large number of farmers. Part-time farming is very common in Croatia (70% of all farms). Survey resulted in data collected for 101 different agricultural plots (1 farmer gave 1 answer corresponding to 1 plot), disseminated throughout 12 Croatian counties (Table 1).

According to the size of the plots, most of the data collected included plots belonging to three categories: category 1 with 1,001–5,000 m^2, category 2 with 5,001–10,000 m^2, and category 3 with 10,001–50,000 m^2 (21–26% data fitting each of the category). Minor percentage of data collected corresponded to plots in categories below 1,000 m^2 and above 50,000 m^2. Also, majority of the data were collected from plots located in the continental part of Croatia (northern Croatia), from 4 counties: Krapina-Zagorje (16.8%), Virovitica-Podravina (15.8%), Brod-Posavina (14.9%), and Varaždin (12.9%) (Figure 1). This so-called Pannonian region (with subregions: Eastern-P1, Central-P2, Western-P3, North-West-P4) covering 46.2% of the Croatian territory, represents the most important and largest agricultural region of Croatia with highly developed intensive arable farming and high yields of crops (Figure 1).

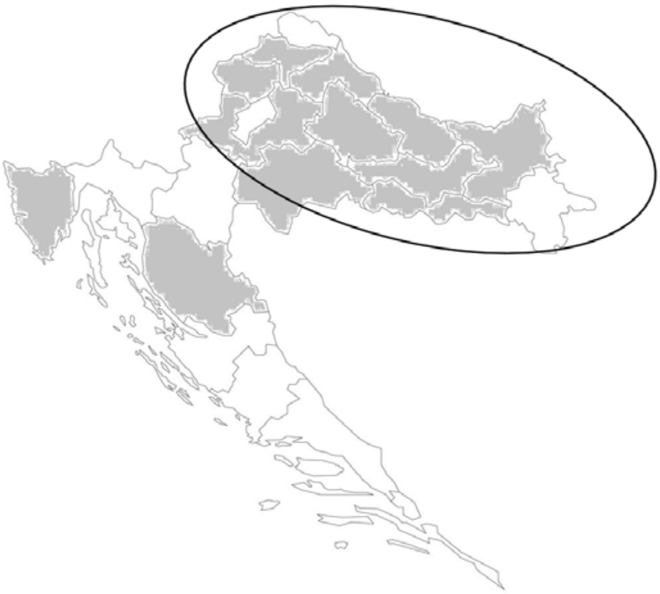

Figure 1. Map of Croatian counties. The counties included in the survey are marked in grey on the map. The Pannonian region is presented in ellipse frame (customized from VectorStock.com)

Table 1. Distribution of plots included in the survey, divided by counties

County	Number of plots	% in total answers
Krapina-Zagorje	17	16.8
Virovitica-Podravina	16	15.8
Brod-Posavina	15	14.9
Varaždin	13	12.9
Bjelovar-Bilogora	9	8.9
Osijek-Baranja	8	7.9
Koprivnica-Križevci	6	5.9
Požega-Slavonia	5	5.0
Istria	4	4.0
Zagreb	4	4.0
Sisak-Moslavina	3	3.0
Lika-Senj	1	1.0
Total answer for plots*	n=101	

* Counties that were not included in the survey includes Primorje-Gorski Kotar, Zadar, Karlovac, Šibenik-Knin, Vukovar-Srijem, Split Dalmatia, Dubrovnik-Neretva, Međimurje county and City of Zagreb

Concerning climate, the Pannonian region is characterized by a temperate continental climate - throughout the whole year it is in a circulation zone of mid-latitudes, with very variable atmospheric conditions resulting in the diversity of weather situations and intense exchanges. For most of the year, precipitation in this area is sufficient for sustainable agricultural growth, with shortage occurring mostly during the summer months (Zaninović et al., 2008). Data however likewise suggest June as the month with most abundant precipitation observed for this part of Croatia. In addition to the Pannonian region, 5% of data were also collected from Istria (Western Croatia) and Lika-Senj counties (Table 1, Figure 1).

RESULTS AND DISCUSSION

Data on type of agricultural production

The survey questions focusing on land-use, showed that farmers use their land for diverse agricultural production, including livestock breeding, permanent lawns, perennial plantations, vegetables growth, and arable land (Figure 2).

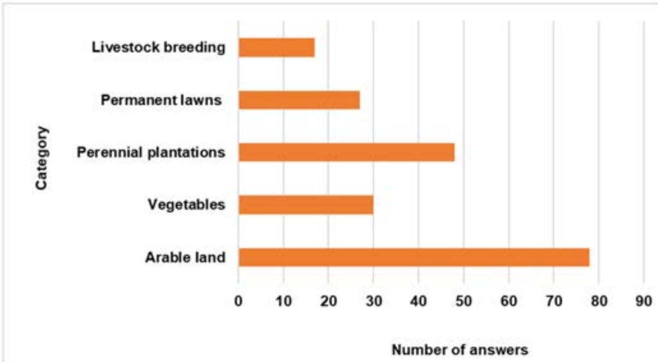

Figure 2. Agricultural production on plots of farmers

Majority use their plots as arable land for growing field crops, followed by perennial plantations and land used for vegetables growth. As expected, based on data on crop production in Croatia, corn was categorised as the most commonly grown crop, grown by 55 of farmers, followed by winter wheat (29 farmers), winter barley (22 farmers), and soybeans (20 farmers). Farmers also consider corn as the crop which is the most sensitive to floods because of excessive rain (rough assessment of farmers, data not shown). Although this information could be to some extent misleading, since most of the collected data are on corn, this crop is generally accepted as a relatively flooding-sensitive crop. Consequently, we did not obtain enough information on the sensitivity of other crops as they are less represented in the collected answers of the survey. Among fruit growers participating in the survey (a total of 52 farmers), the majority are growing apples (25 farmers) followed by plums (21 farmers), cherries (21 farmers), and walnuts (20 farmers) (data not shown). Among fruit growers, farmers identified strawberry as the most sensitive species to floods. Out of 41 vegetable growers, the majority (27 farmers) were growing beans, and half of them also planted tomatoes, onions, cucumbers, and peppers (22–24 farmers). As the most sensitive crop to floods, vegetable growers identified beans. Smaller number of answers was obtained on medicinal and aromatic plants growth (16 farmers), short rotation coppice (8 farmers), and viticulture (7 farmers). These low numbers of farmers did not allow us to give any acceptable conclusion as to which species and varieties are most commonly grown in Croatia and in correlation which of them are the most sensitive to flooding events.

Data obtained in this survey showed good correspondence with the general land-use in Croatia. According to the data of the Croatian Bureau of Statistics (https://www.dzs.hr/) for the year 2019, 1,504,445 ha of land was used for agricultural production, including vegetable gardens, permanent crops, permanent grassland, arable land, and gardens. Among crops, corn (255,887 ha) and wheat (141,602 ha) were grown on the largest part of the arable land, while vegetables (including vegetable gardens) were grown on an area of 11,621 ha.

Frequency and duration of floods observed by surveyed farmers

Analysis of the results obtained on the frequency of flooding events observed by surveyed farmers in the period 2015–2020 showed that around 80% of farmers experienced flooding on their field plots as a consequence of excessive rain (Figure 3).

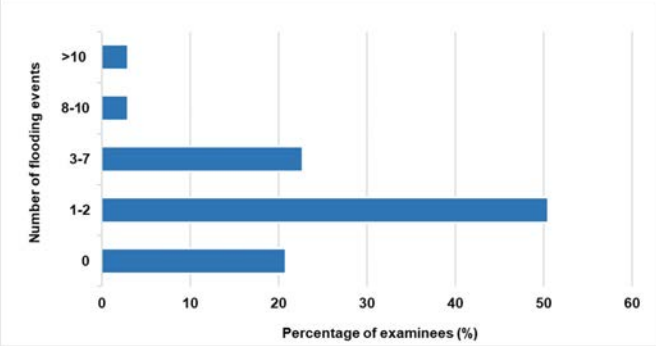

Figure 3. Frequency of flooding events as a result of excessive rain observed by the farmers in the last 5 years on their plots

Half of the farmers (50%) observed 1–2 flooding events, while around 20% experienced 3–7 floods in the last 5 years. Higher number of flooding events (8 to more than 10 times in the last 5 years) was observed by 6% of the farmers and included Krapina-Zagorje County (plots situated in the municipality of Petrovsko and Kraljevec na Sutli), Virovitica-Podravina County (plots situated in Špišić Bukovica, Slatina and Virovitica), and municipality Kalinovec in Koprivnica-Križevci County. Even though, we could not find available data on the floods on the field plots as a consequence of excessive rain specifically for these counties, they do all belong to the Danube river water area. According to the register of flood events (Barbalić et al., 2019) given by the Croatian waters, in the Danube river water area there were 202 flood events recorded in this period from 2015-2018 (last published data) out of which 79 were related to precipitation - 26 of them were caused only by precipitation, while the rest 53 were caused by a combination of precipitation and river flooding. On average, these floods lasted 6 days. In the same period, fewer flood events were recorded in the Adriatic water area (86 flood events). They lasted on average 3 days, and only 4 events where related to precipitation. We can conclude that in Croatia, the Danube River water area is more affected by floods caused by precipitation and will need more adaptation measures with intensification of extreme events in future.

Further analysis of the obtained data suggested that water retained on the fields for different period of time (Figure 4).

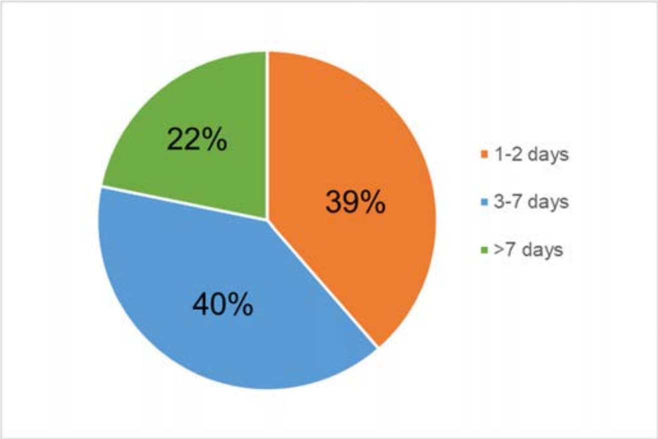

Figure 4. Data on the average water retention as the consequence of excessive rain on the plots as reported by farmers

The majority of farmers (79%) reported that flood retained on their fields for up to seven days (considered as “short-term flooding event”), while remaining (22%) reported “long-term floods” (more than seven days).

Many crops are sensitive to waterlogging (superficial and covers only the root) and complete submergence (water also covers the aerial plan tissues) even during short period of time. Since roots and rhizomes are essentially aerobic organs, the consequences of oxygen depletion due to flooding, can be fatal because levels of energy-rich adenylates drop rapidly, causing a dramatic decline in ion uptake and transport. Damage on the plant is also shown to be dependent on the month in year when flooding occurs. In their paper, Glavan et al. (2020) analysed the relationship between flood event and month of flood occurrence, through agro-economic scenarios. In the worst-case scenario, when all dry detention reservoirs would be full, the authors suggested that there would be minimal or no impact on crop production only during the winter months (December-March). In winter, plants are more resistant in their dormant growing phase unlike spring when plants begin to develop rapidly. In opposite, most severe flood damage in plant production is expected to occur between May and September.

Only few days of flooding can damage plants and result in significant agricultural losses (Perata et al., 2011). For example, two, four and six days of floods, at the time of first irrigation (25-day old plants), lead to significant reduction of wheat height, delayed head emergence, and resulted in a 17%, 29%, and 46% decline in grain yield (Sharma and Swarup, 1988). It is also noticed that corn grain yield decreased with increased waterlogging (2-15 cm above soil surface) and subsurface waterlogging durations (soil moisture exceeded 90%). Ren et al. (2014) noted 32% and 35% grain yield reductions in two cultivars after waterlogging for 6 days at tree leaf stage. With longer water retention (9 days) in the same phase, Tian et al. (2019) reported grain yield decrease of around 65% and 82% in two corn hybrids. Also, great grain yield decrease of 62% and 74% happened after exposing the hybrids to subsurface waterlogging stress at the tree leaf stage for 15 days. Studies on 20 *Brassica* species varieties showed that plants waterlogged 1–2 cm above the soil surface for 7 days led to significant decrease in yield (20% decrease in 65% of tested varieties) (Xu et al., 2015).

Observed stages of plant growth impacted by flooding events

As the impact of flooding on the plant also depends on the stage of plant growth (Biswas and Kalra, 2018), our farmers also reported on the stages of growth at which plants were exposed to flooding (Figure 5). Results showed that 40% of the floods occurred before seeding, with the remaining floods occurred in different stages of plant growth: 31% of farmers reported that the incident occurred in the plant germination phase, i.e. before the appearance of the 5th leaf, 15% in the stage of “up to 10th” leaf, and 14% of farmers reported incident in the stage “after 10th leaf”.

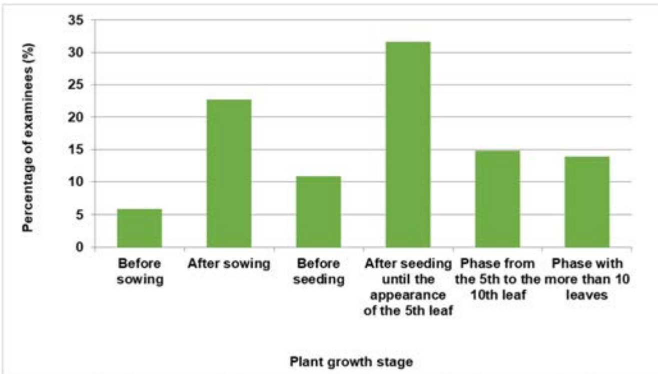

Figure 5. Stages of the plant growth at which farmers reported to be subjected to waterlogging event

Literature overview suggests that, according to crop, different sensitivity levels to flooding event are observed. For winter wheat and corn, studies demonstrated (Tian et al., 2019; Cannell et al., 1980; Collaku and Harrison, 2002) that flooding has greatest detrimental effect when it occurs at germination or in the early vegetative stages. In addition, Ploschuk et al. (2018) suggested that wheat leaf physiology and shoot growth are significantly affected in early- or late-stages of growth, while the seed development experienced more than 80% reduction under waterlogging. Li et al. (2011) also showed that hardening by multiple waterlogging events during the vegetative growth stage of wheat effectively enhance its tolerance to a waterlogging event during the sensitive generative growth stage. De San Celedonio et al. (2014) demonstrated that the period from the beginning of stem elongation to anthesis (7^{th} leaf-10^{th} leaf and 10^{th} to anthesis) in wheat, as well as in barley, were the most sensitive to waterlogging in terms of yield reduction. These phases are critical for grain yield formation (Li et al., 2011). Further, studies on field pea showed their sensitivity to both early- or late-waterlogging, attaining on average only 6% of controls for seed mass (Ploschuk et al., 2018). Concerning corn production, studies suggest that corn is more sensitive to flood in early growth stages when the growing point is still below or close to the soil surface (Kaur et al., 2020). In later vegetative or reproductive growth stages, corn was less susceptible to soil waterlogging. When compared to field crops, vegetable crops were found to be highly sensitive to water logging (Biswas and Kalra, 2018). In general, damage to vegetables by flooding is due to the reduction of oxygen in the root zone which inhibits aerobic processes (Patel et al., 2014). Hubbell et al. (1978) imposed waterlogging on field-grown tomatoes at the second flower cluster stage, which resulted in anaerobic soil conditions to a depth of 0.2 m (8 inches) for 24 h, and which led to wilting of 15% of tomato plants (versus 4% for nonwaterlogged plants) and to 40% yield reductions.

The farmers were also asked to give rough assessment on the effects of floods on their agricultural production rates (Figure 6).

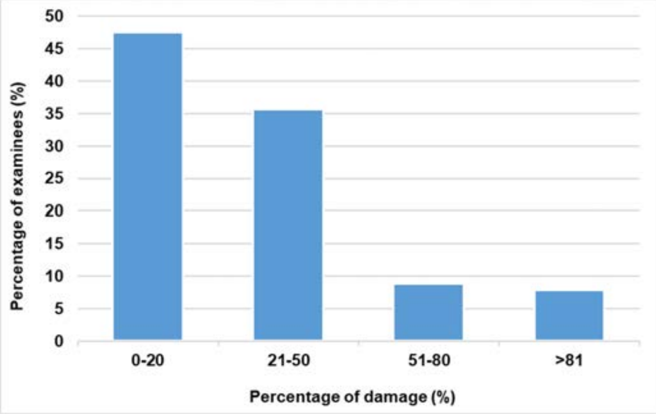

Figure 6. Assessment of the crop damage caused by floods by farmers

The majority of farmers (around 80%) reported to have lost up to 50% of their products - 48% of them reported up to 20% of crop damage and 36% of them lost between 20 and 50% of the expected product, while only 17% of farmers estimated damages to more than 50%. It should be mentioned that this data corresponds to the subjective assessment of farmers on crop losses while, in general, crop damage assessment is a very complex problem. Brémond et al. (2013) propose that the loss of the added value should correspond to the decrease in product minus the variation in production costs due to flooding. Therefore, a precise estimate of the variation in variable costs requires knowledge on the distribution of production costs over the year. Precise assessment of crop damage is important in the light of the potential return of farmer's investment. After extreme and unpredictable events, such as floods, it is important for farmers to get a return on investment. However, according to the collected data, only 8% of the farmers that participated in the survey received amends for flood damage. Most of the amends came from the state and other sources while a smaller number of examines received amends from the county and the Ministry of Agriculture from the Rural Development Program. The compensation system therefore needs to be improved as the damage caused by floods and other extreme events as a consequence of climate change will increase in the future.

Mitigation and adaptation measures used by farmers

The risk of crop damage by water retention could be reduced by a combination of different mitigation and adaptation measures. While mitigation includes activities that should be used before flooding occurs, with the aim to modify or to reduce the probability of a flood, adaptation corresponds to the measures taken to reduce the impact of flooding that already took place in the receptor areas (Rajanna et al., 2018). In Croatia, drainage systems are provided on agricultural plots by the state or county, however, drainage cannot be provided to all plots due to a fragmentation of plots into smaller particles. Based on our survey, almost half of the farmers do not use any form of pre-measures that would allow excess water to run off from fields. Only 3% of farmers used underground drainage systems on their plots while around 50% of them used drainage channels to redirect excess water (data not shown). Problems of excessive rain could be mitigated by drainage channels IV order whose basic task is to collect surface and drained groundwater and its drainage to the canals of higher (II and III) order (Croatian waters, 2010). These documents also define the option of underground drainage to locally increase soil permeability and bring leachate to artificially or naturally permeable soil, or to a collector or open watercourse. Our survey indicated that farmers in Croatia try to lessen problems only after excessive rain already caused water retention on their fields. In these cases, farmers used improvised form of drainage system done by cleaning and deepening of existing drainage channels, or by digging new drainage channels up to 25 cm deep.

One of the adaptation measures that could also be used for prevention of the water retention damage on fields is the selection and planting of crops tolerant to excess water (such as wheat, depending on phenophase) or by planting new genetically modified varieties of crops. Flood-tolerant plants possess traits to develop adaptive mechanisms, such as aerenchyma formation, development of adventitious roots, and stem hypertrophy and are therefore able to grow even at such harsh conditions (Kaur et al., 2020). Our survey, however, suggested that only 12% of farmers would consider sowing species/ varieties of plants more resistant to excessive rain. Half of the farmers, tried to help plants to recover by additional fertilization/foliar fertilization, cultivation, and by draining excess water by digging canals.

Finally, farmers were asked on their interest in using different types of aid-measures that would influence crop adaptation to floods and decrease consequences of water retention on crops. 75% of farmers acknowledged they would use aid-measures if they would be offered to them. Within the survey, we proposed 6 different mitigation and adaptation measures including (i) adapted tillage, (ii) fertilization, (iii) selection of resistant species / cultivars within the existing type of production, (iv) application of biostimulators in practice, and (v) change of crop group and transition to another type of agricultural production and transition to agroforestry. Farmers had to rank the measures from the easiest to implement to the most difficult ones (Figure 7).

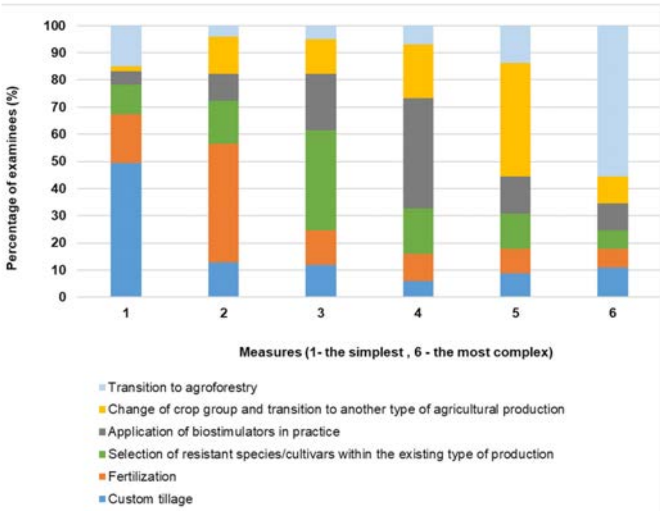

Figure 7. Measures related to the adaptation and mitigation of the consequences of floods from simple to complex

They consider the measure of adapted tillage as easiest to implement and put fertilization in second place. In third place, the measure of selection of resistant species / varieties / cultivars within the existing type of production was selected. The application of biostimulators farmers most often put in fourth place, as a quite complex measure for them. Since we wanted to research and offer this measure as a solution, we believe that it will be necessary to additionally educate farmers. The most difficult to implement were the measures of changing the group of crops, the transition to another type of agricultural production, and the transition to agroforestry.

CONCLUSIONS

Data obtained in this survey gave insight into the impact of excessive rain on the agricultural sector in Croatia, with emphasis on corn production in the Pannonian region representing the most important and largest agricultural region in Croatia. Even though agriculture is a fragile sector in Croatia, which will be greatly affected by climate change, no data on the effects of excessive rain followed by flooding currently exists. Based on our data, farmers in Croatia had mostly issues with short-term flooding events, taking place for up to maximum of 7 days. Although it is well known that excess water at any stage of the growth could severely hamper crop development, we were not able to collect the exact data on the effects of flooding in Croatia on different type of crops or effects on various stages of plant growth due to insufficient number of participants in our survey. However, our farmers estimated that flood most often occurred in the plant germination phase (before the appearance of the 5th leaf) which represents a risk for plant damage and consequent yield reduction. The majority of farmers reported crop damage lower than 50%. Since this is only a rough estimation by farmers, it needs further re-evaluation. Farmers participating in our survey raised the question of their scarce usage of different mitigation measures by which the damage can be reduced. Respondents use water canals on only 50% of plots, while the presence of under-ground drainage is very low (about 3%). Excessive rain, followed by floods, could greatly affect the economy and consequently jeopardize human food security in our near future. To mitigate this risk, it is important to start collecting long-term data on the prevalence and frequency of flooding events on agricultural fields across Croatia together with plant-induced damage. Such models could allow us to reduce the degree of uncertainty associated with climate change effects and to strengthen the resilience and recovery capacity of the agricultural sector to climate change.

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APPENDIX A

Table S1. Full list of question of the conducted survey, number of answers and answer possibility

Question to the participant	Number of collected answers	Possibility of multiple answers
Which plant species do you most often grow on plot?		
• field crops	71	
• vegetable crops	41	
• fruit species	52	+
• medicinal and aromatic herbs	16	
• vines	7	
• short rotation coppice	8	
Does your plot belong to category of permanent lawns? If yes, please select which one.	35	+
In which county the plot is located?	101	–
What does your agricultural production include?	101	+
What is the area of the plot (in m^2)?	101	–
How many times in the last 5 years there has been a flood on the plot as a result of excessive rain?	101	–
Which species have you noticed are most susceptible to flood as a result of excessive rain?		
– field crops	62	
– vegetable crops	35	
– fruit species	35	+
– medicinal and aromatic herbs	11	
– vines	6	
– short rotation coppice	4	
Which category of permanent lawns have you noticed are most susceptible to flood as a result of excessive rain?	19	-
On which variety/hybrid did you most often notice flood damage as a result of excessive rain?	101	-
At which stage of plant growth the flood occurred most often?	101	-
How long, on average, did the water stay on the production area?	101	-
Have you planned sowing species/varieties more resistant to high precipitation content?	101	-
If the answer to the previous question is "yes", please write how?	12	-
How much damage was most often caused to crops by the flood as a result of excessive rain?	101	-
Did you receive compensation for damages?	101	-
If you have received flood compensation support, by whom you received it?	11	-
Has the plot underground drainage?	101	-
Has the plot water channels?	101	-
Did you used any method of drainage of water that remained on the production surface?	101	-
If the answer to the previous question is "yes", please write how?	53	-
Did you help the plants, after the flood, in their recovery?	101	-
If the answer to the previous question is "yes", please write how?	50	-
Would you use aid for certain measures by which your activities would influence the adaptation and mitigation of the consequences of floods within your agricultural production?	101	-
Which activities within the measure related to adaptation and mitigation of flood consequences would be the easiest for you to implement? (1 - simplest, 6 - most complex)	101	-