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Review paper
Pregledni rad

IMPACT, ADAPTATION AND MITIGATION OF CLIMATE CHANGE IN CROATIAN AGRICULTURE

Utjecaj, prilagodba i ublažavanje klimatskih promjena u hrvatskoj poljoprivredi

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Abstract: Climate change is one of the greatest challenges facing humanity today. Anthropogenic activities add large amounts of greenhouse gasses (GHG) to those naturally occurring in the atmosphere, amplifying the greenhouse effect and causing climate change. One of the sectors most affected by climate change is agriculture, which is not only a victim of climate change, but also its cause. Therefore, in addition to climate change adaptation measures in agriculture, it is necessary to undertake climate change mitigation measures as well. Mitigation of climate change in agriculture can be achieved by reducing GHG emissions from the sector Agriculture and by increasing GHG removals through sinks within the Land Use, Land Use Change and Forestry (LULUCF) sector. Adaptation to climate change refers to responses to actual or expected climatic stimuli or their impacts in order to reduce vulnerability to negative impacts or the potential damage, or to take advantage of opportunities associated with positive climate change impacts. Agrometeorology plays a crucial role in assessing which actions will lead to improved agricultural productivity, either by minimizing risks from adverse weather conditions or by taking advantage of the positive aspects of climate change.

Key words: climate change, agriculture, adaptation, mitigation, greenhouse gas sources, greenhouse gas sinks

Sažetak: Klimatske promjene jedan su od najvećih izazova s kojima se čovječanstvo danas susreće. Uz stakleničke plinove koji se prirodno pojavljuju u atmosferi, antropogenim aktivnostima oslobađaju se dodatne velike količine stakleničkih plinova u atmosferu povećavajući učinak staklenika i uzrokujući promjenu klime. Jedan od najosjetljivijih sektora pogođenih klimatskim promjenama jest poljoprivreda, koja nije samo njihova žrtva nego i njihov uzrok. Stoga u poljoprivredi uz mjere prilagodbe na klimatske promjene treba poduzeti i mjere ublažavanja klimatskih promjena. To se može postići smanjenjem emisija stakleničkih plinova iz sektora Poljoprivreda i povećanjem uklanjanja stakleničkih plinova ponorima u sklopu sektora Korištenje zemljišta, prenamjena zemljišta i šumarstvo. Prilagodba klimatskim promjenama odnosi se na odgovore na stvarne ili očekivane klimatske podražaje ili njihove učinke kako bi se smanjila osjetljivost na nepovoljne utjecaje ili potencijalnu štetu ili kako bi se ostvarile prilike povezane s pozitivnim učincima klimatskih promjena. Agrometeorologija

ima ključnu ulogu u procjeni mjera koje će povećati poljoprivrednu produktivnost bilo minimiziranjem rizika od nepovoljnih vremenskih uvjeta ili iskorištavanjem pozitivnih učinaka klimatskih promjena.

Ključne riječi: klimatske promjene, poljoprivreda, prilagodba, ublažavanje, izvori emisija stakleničkih plinova, ponori stakleničkih plinova

1. CLIMATE CHANGE: IMPACTS AND CAUSES

The impacts of climate change are visible in all parts of the world. Climate change manifests in changes in hydrological cycles and air/soil/sea temperatures, in the increasing intensity and frequency of natural disasters such as storms, droughts, floods, heat waves, etc., in changes in sea levels, in the decline of biodiversity, in the increased occurrence of diseases and pests, in the deterioration of soil and water quality, etc. According to the Croatian National Inventory Report (NIR, 2023), air temperature trends over the last 60 years show a positive and statistically significant warming throughout the country. The strongest changes are observed on the central mainland. The overall positive trend in air temperature is mainly due to summer trends and an increase in mean winter air temperature on the central mainland. The observed warming is also reflected in all indices of temperature extremes, with positive trends in the warm indices and negative trends in the cold indices. In addition, there is a statistically significant decrease in annual precipitation amount in the mountain region, while the direction and extent of the trends in other regions are not spatially consistent. A significant decrease in summer precipitation amount was observed along the Adriatic coast and in the mountainous region, where a significant decrease was also observed in the spring season. On the other hand, the trend in fall precipitation amount has a positive sign throughout Croatia and is statistically significant in the central parts of the mainland. No statistically significant changes were observed in the winter months, although there is a weak negative trend in eastern Croatia and Dalmatia and a positive trend in the remaining areas.

One of the most affected sectors by climate change is agriculture. According to some predictions, agriculture is the sector that will suffer the most from the consequences of climate change in the future. In Croatia, the existing climate variability is already having a significant impact on agriculture. Extreme weather events led to average losses of 251 million euros in 2022 (Čop and Njavro, 2023). Most of the damage is caused by drought, but hailstorms, frost, floods, freezing rain, gale force winds, etc. also cause damage (MESD, 2020). The drought in the summer months between 2013 and 2016 caused damage amounting to 43% of the direct aid paid to agriculture in the same period (MESD, 2020). In recent decades, longer and more frequent droughts, storms, floods, hailstorms, fires and heat stress, especially in Dalmatia, are a clear signal, especially for fruit and olive growers and winegrowers, to start implementing climate change adaptation measures (MESD, 2020). The main expected impacts of climate change in the future, leading to high vulnerability of the agricultural sector, are lower yields of all crops, higher water requirements and changes in the duration of growing seasons of annual and perennial crops with an emphasis on arable crops such as cereals and oilseeds (e.g. maize, sugar beet, soy, etc.). Longer growing seasons will allow the cultivation of new varieties and hybrids, while more frequent flooding and stagnation of surface water will reduce or eliminate yields. Yields of maize in Croatia are expected to decrease by 14–25% by the end of the 21st century due to change of climate (Vučetić, 2011).

Agriculture is not only a victim of climate change, but also its cause. Human activities, primarily through greenhouse gas (GHG) emissions, have clearly caused global warming, with the global surface temperature in the period 2011–2020 being 1.1°C higher than in 1850–1900 (IPCC, 2023). According to the IPCC Guidelines for National Greenhouse Gas Inventories (2006), all sources and sinks of greenhouse gases are divided into 6 sectors: Energy, Industrial Processes and Product Use, Agriculture, Land Use, Land Use Change and Forestry (LULUCF), Waste and Other. Five

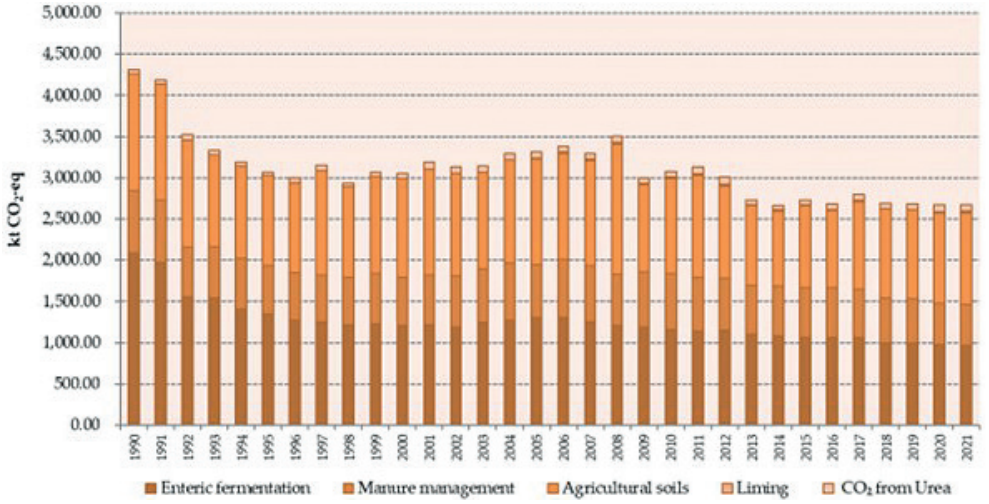

Figure 1. Agricultural emission GHG trend (source: NIR 2023, 2023).

Slika 1. Trend emisija stakleničkih plinova iz poljoprivrednog sektora (izvor: NIR 2023, 2023).

of these sectors are sources of GHG emissions and only the LULUCF sector is a sink. The largest contribution to Croatia's national GHG emissions in 2021 excluding LULUCF is made by the Energy sector (66.6%), followed by Industrial processes and product use (14.7%), Agriculture (11.0%) and Waste (7.7%) (NIR, 2023). This structure is consistent with minor changes over the entire period from 1990 to 2021. In addition, removals in the LULUCF sector contribute 31.3% to total national GHG emissions including LULUCF in 2021. According to Figure 1, the main sources of GHG emissions in the sector Agriculture are subsectors Livestock due to enteric fermentation (CH_4) and manure management (CH_4, N_2O), Agricultural soils (N_2O), Liming and Urea application (CO_2) (Fig. 1). Methane (CH_4) and nitrous oxide (N_2O) are the main greenhouse gases released as a result of agricultural activities. Of all ruminants, dairy cattle are the largest source of methane (CH_4), while emissions of nitrous oxide (N_2O) are relatively high due to agricultural soil and manure management.

2. CLIMATE CHANGE ADAPTATION MEASURES IN AGRICULTURE

The observed climate change has an impact on agricultural production, so adaptation measures are necessary to ensure food security. Adaptation measures in agriculture can prepare agricultural production for extreme weather events and other risks associated with climate change or take advantage of the positive aspects of climate change. The 5 pillars of the Action Programme for Climate Adaptation in Agriculture (2020) are the water system, soil system, crops and cultivation system, livestock farming and support and their objectives are:

Pillar 1: Water system (water management) is to be prepared for droughts and prevent future crises where possible by making agriculture and nature more resilient to the effects of climate change in order to limit the damage caused by the effects of climate change, such as nutrient deficiency, desiccation and the deterioration of water quality, while improving the availability of water through economical use, better retention and smarter distribution of water.

Pillar 2: The soil system (soil management) is seen as a crucial factor in making agriculture climate resilient. Improving soil structure and applying soil protection measures increase the water storage capacity of agricultural soils, while improving soil quality in the broadest sense (physical, chemical and biological) can help plants cope with extreme weather conditions, as healthy soils can absorb, store and release water and nutrients to plants. This is an essential prerequisite for good crop yields. It also helps if farmers plough less often, use lighter machinery and grow plants with an extensive root system.

Pillar 3: Crops and cultivation systems play

an important role in climate change adaptation. Farmers can select and use resilient crops to extreme weather conditions like drought or flooding, as well to diseases and pests, and to adopt cropping systems such as earlier harvesting, cover crops or intercropping that are largely self-regulating.

Pillar 4: Livestock farming refers to livestock animals which are also affected by climate change and affect both feed production and livestock husbandry practices. Adaptation related to feed production is addressed under Pillar 3, while the impact on livestock farming practices concerns animal welfare, transportation, husbandry systems, new animal diseases and the general improvement in livestock farming.

Pillar 5: Support refers to the support provided by different types of authorities. There are many different types of landscapes in Croatia and climate change poses different problems for each type of landscape. These problems are addressed at the local level in close cooperation between the different authorities and farmers. At the international level, policy programmes and knowledge are exchanged to learn from good examples of climate adaptation abroad.

The climate change adaptation measures in agriculture are referred to in the MESD (2020) as P-01 to P-08, which are divided into three categories depending on their importance (measures of very high importance: 01–05, high importance: 06–07 and medium importance: 08).

3. CLIMATE CHANGE MITIGATION MEASURES IN AGRICULTURE

Agriculture is a sector that is particularly vulnerable to climate change. The fundamental challenge is to reduce greenhouse gas emissions and maintain food production. Mitigating climate change in agriculture is possible in two ways, namely: 1) reducing GHG emissions from the sector Agriculture and 2) increasing GHG removals through sinks within the LULUCF sector. The reduction of GHG emissions from the sector Agriculture includes a direct reduction of GHG emissions from the largest sectoral sources: emissions from enteric fermentation, manure management, agricultural soils, liming and urea application.

According to MESD (2021), the vision of low-carbon development of the Croatian agricultural sector implies the full application of good agricultural practices, which should be applied by well-trained farmers, in restored villages, on large farms with high yields of various crops that are adaptable to climate variation and weather risks. Cultivation will be geared towards organic production and a green market, with the use of agro-environmental and agroforestry systems. Rural areas and economies will be almost energy neutral and resource efficient. Biomass for fuel production to be produced without jeopardizing food production, while proactively contributing to the reduction of greenhouse gas emissions without harming the environment.

Table 1. Climate change adaptation measures in the sector of agriculture.

Tablica 1. Mjere prilagodbe na klimatske promjene u sektoru poljoprivrede.

Measure ID	Measure name
P-01	Implementation of the climate change adaptation experimental-research programme in agriculture
P-02	Increasing the water absorption capacity of agricultural soil
P-03	Application of appropriate soil tillage methods (e.g. soil conservation tillage and other methods of reduced soil tillage)
P-04	Cultivation of species and varieties of agricultural crops for food and non-food supply chain and breeds of domestic animals that are more resilient to climate change
P-05	Integration of climate change risks into the development of irrigation systems
P-06	Application of anti-erosion measures
P-07	Reconstruction and construction (improvement) of drainage structures
P-08	Insurance of agricultural production from production losses caused by adverse weather conditions

(Source: MESD, 2020)

Low-carbon development policies to be based on cost-effectiveness, taking into account socio-economic and natural conditions. The positive impact of the implementation of measures on overall GHG emissions in the agricultural sector to be manifested as a direct reduction in emissions of methane and nitrogen compounds. According to MESD (2021), the mitigation measures are:

- changes in the cattle and pigs' diet and the composition of animal feed
- anaerobic digestion (silage and renewable lignocellulose raw materials, organic by-products of the food industry and slaughterhouses, biodegradable fractions of municipal solid waste and microbial biomass) and biogas production for electricity and heat production and fuel for internal combustion engines
- improve facilities or dwellings as well as the fertilizer management system
- improve fertilizer application
- construction of hydromelioration projects
- encourage the development of "precision agriculture" based on developed GIS and GPS technologies
- introduction of new cultivars, varieties and species.

As presented on Figure 2, the removal of GHGs by sinks is possible through biological and terrestrial carbon sequestration. Carbon circulates between the atmosphere, the biosphere and the pedosphere in relatively short time spans. Plants absorb atmospheric carbon through the process of photosynthesis and store it in their biomass, which enters the soil after the plant dies, where it undergoes decomposition and humification processes. Some of the carbon is released back into the atmosphere through the processes of soil respiration, while some of the carbon remains permanently bound in the soil as humus. Depending on biotic and abiotic factors as well as agricultural practices and soil management, agricultural soils can act as both a source and a sink of GHGs (Fig. 2.).

According to MESD (2021), in order to assess the potential reduction of total emissions expressed by an increase in soil organic carbon under the LULUCF sector through the implementation of an additional package of measures, it is necessary to conduct national surveys to define

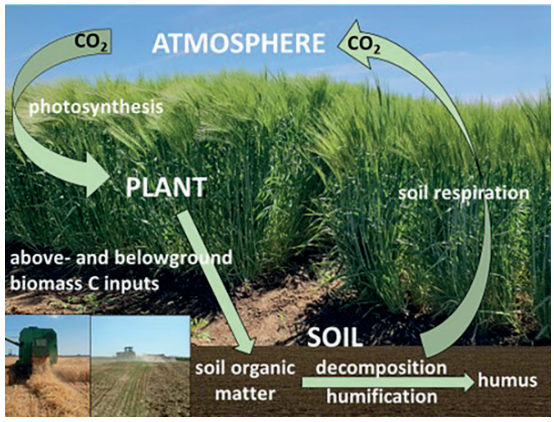

Figure 2. Carbon cycle in agroecosystem (source: Bilandžija, Galić and Zgorelec, 2023).

Slika 2. Kruženje ugljika u agroekosustavu (izvor: Bilandžija, Galić i Zgorelec, 2023.).

the actual potential for increasing carbon storage in agricultural soils of Croatia, in particular a relation of the reduced tillage system with regard to fertilizer recommendations, and further investigate the potential for application depending on the soil type. Measures that have the potential to increase carbon sequestration according to MESD (2021) are:

- improvement and change of tillage system (reduced tillage)
- expansion of crop rotation with a higher share of legumes
- intensification of crop rotation using intermediate crops
- improving the application of organic fertilizers
- green manure
- agroforestry
- promote ways of managing forests, pastures and agricultural land areas that are beneficial for climate and environment
- conduct scientific research to improve the management of all LULUCF land categories in order to reduce emissions and increase sinks.

It should be mentioned that an additional significant direct and indirect reduction in GHG emissions could be achieved by changing people's dietary habits, i.e. through measures that would encourage a higher consumption of plant origin food. The reduction of food residues and losses should be one of the priority measures. It is necessary to promote development of projects for the biogas

production, for the collection of pruned biomass from the permanent stands and the production of agropellets. In addition to technical measures to reduce GHG emissions or the introduction of alternative soil cultivation methods and animal husbandry methods, it is certainly necessary to examine the possibility of using the great synergy potential of agricultural production. Since Croatia has a great developmental strength in the preserved natural resources (water, soil, air), and landscape values and the fact that it is a strong tourism recipient, the promotion of the local connection of the entire food chain "from field to table" – i.e. the link between the local tourist offer, the processors and the local producers, can certainly expect a reduction in greenhouse gas emissions – both directly through the use of organic farming or farming techniques with lower nitrogen losses, and indirectly through the reduction of emissions from transportation, storage and processing far away from the agricultural products production sites.

4. DISCUSSION AND CONCLUSION

The national sectoral policies and measures of the Member States of the European Union are primarily determined by EU policies and regulations. In October 2014, the European Council adopted the EU's climate and energy target for 2030 (EC, 2020). On this basis, the EU adopted a series of climate and energy-related legal acts between 2015 and 2020. These set the following main targets for 2030:
1) Reduction of greenhouse gas emissions by at least 40% (compared to 1990)
2) Share of renewable energy by at least 32%
3) Improvement of energy efficiency by at least 32.5%. The EU's long-term climate target is to achieve climate neutrality by 2050. This target that was adopted by the European Council in December 2019 is part of the long-term EU strategy submitted to the UNFCCC and is legally binding due to the adaptation of Regulation (EU) 2021/1119 (EPC, 2021).

The positive impact of the implementation of measures on overall greenhouse gas emissions in the agricultural sector has been proven by numerous studies. The studies show that changes in the diet and composition of animal feed lead to better digestibility and consequently to lower emissions from enteric fermentation. For example, studies have shown that the addition of concentrates to natural grass hay leads to an improvement in digestibility (Čengić, Muratović, Handžić and Džomba, 2000), or that dry and fermented corn energy sources added to alfalfa hay increase the digestibility of the dry/organic matter of the hay (Vranić et al., 2018), indirectly reducing GHG emissions.

According to Petravić-Tominac, Nastav, Buljubašić and Šantek (2020), biogas production in Croatia is mainly based on manure and by-products from agriculture, the food industry and slaughterhouses, and the biogas obtained is mainly used for electricity and heat production. The potential for large-scale biogas production is not yet sufficiently exploited in Croatia, although various renewable raw materials are available. A more rational and targeted management of lignocellulosic residues, animal excrements, food processing by-products and biodegradable fractions of municipal waste could contribute to the development of the Croatian biogas sector. In addition, large unused agricultural areas have great potential for the cultivation of fast-growing biomass. The studies have shown that agricultural energy crops, the perennial grasses Miscanthus and switchgrass, have great potential for climate change mitigation in Croatia due to their high dry matter yields, good energetic properties and good carbon sequestration potential (Bilandžija, Bilandžija and Zgorelec, 2021; Bilandžija et al., 2022, Matin et al., 2023; Brandić, Voća, Leto and Bilandžija, 2024).

Improving and changing soil management practices such as tillage and fertilization also lead to a reduction in GHG sources and an increase in GHG sinks. Studies have shown that reduced tillage systems, where tillage depth and frequency are reduced and one or more operations are omitted, or no-tillage systems, where tillage is completely omitted, release fewer GHG emissions into the atmosphere due to reduced fossil fuel use. The study conducted in continental Croatia to compare the CO_2 emissions of conventional, reduced and no-tillage systems showed that the use of reduced and no-tillage systems saves 35.3 to 42.9% and

87.8 to 88.1% of fuel, respectively, thus reducing CO_2 emissions (Filipović et al., 2006).

Reduced tillage systems and the retention of plant residues as mulch on the soil surface increase carbon storage in the soil pool. It is estimated that the transition from conventional to conservation tillage can lead to an increase in C stocks, especially in the upper soil layers (0–30 cm) by 4.6 t ha^{-1} over ≥ 10 years (Đurđević et al., 2022). In addition, appropriate fertilization and tillage practices as well as the selection of plant species and their varieties/hybrids can reduce emissions from the soil, i.e. soil respiration rates in Croatia, and increase biological carbon sequestration, which has been reported in many papers (Galić et al., 2019; Bogunović et al., 2020; Galić, Bilandžija and Zgorelec, 2023; Bilandžija et al., 2021; Bilandžija et al., 2023a).

As climate conditions have a major impact on agricultural management practices, agrometeorological forecasts have always played an important role for farmers and have always been a concern of farmers. To achieve efficient adaptation of agricultural production to climate change and to ensure efficient implementation of climate change mitigation measures in agriculture, this role is becoming more important day by day, as agrometeorology plays a crucial role in assessing which measures will lead to improved agricultural productivity, either by minimizing the risks from adverse weather conditions or by taking advantage of the positive aspects of climate change.

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