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Impact of climate change on agriculture in Poland

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Abstract. Agriculture, on the one hand, emits greenhouse gases which contribute to climate change, and on the other hand, it is the sector which is most affected by the progressing climate change. The aim of the study was to assess the impact of climate change on agriculture and to identify measures adapting agriculture in Poland to changing climatic conditions. The sources of information were legal acts, reports and documents of international institutions, as well as literature on the subject. The study analysed the impact of climate change effects on the conditions of conducting and the volume of agricultural production in global, European and national terms. The analysis showed that progressive climate change and its impact on changing agricultural production conditions threaten the productivity of agriculture, and thus limit the provision of food security. The dynamics of these changes, the extensive scope of threats and the strength of their negative impact prompt adaptation measures. Adaptation measures, the implementation of which enables adaptation to the current and expected climate and its impacts, have been identified.

Keywords: climate change, adaptation, agriculture

GENERAL INFORMATION ON CLIMATE CHANGE, CURRENT AND PROJECTED IMPACTS OF CLIMATE CHANGE RELEVANT TO AGRICULTURE

UN Secretary-General Antonio Guterres, opening the COP25 Climate Summit (Madrid 2–13 December 2019), said that humanity has come to a crossroads and has two roads ahead (Guterres, 2019). The first leads to a tipping point, which equates to losing control of climate change, meaning no return to a secure existence. The second way is the path of hope, consisting of unleashing the political will, applying the necessary technical measures and resources to avoid climate catastrophe. These words are substantiated by some recently published articles and scientific reports.

An article published in Nature formulates the thesis that it cannot be ruled out that we have already lost control of climate change processes (Lenton et al., 2019). This is supposedly due to the achievement of *tipping points* in ecosystem functioning. These include frequent droughts in the Amazon rainforest, reduction in Arctic ice extent, changes in Atlantic circulation since the 1950s, fires and pests in boreal zone forests, large-scale extinction of coral reefs, disappearance of Greenland ice, thawing of permafrost and acceleration of ice loss in West and East Antarctica. In addition to being symptoms of a warming climate, some of these changes may contribute to further increases in temperatures, while others may cause significant increases in greenhouse gas emissions. Research also suggests that climate change is occurring faster than predicted, which could lead to climate disasters (Bendell, 2018). In the author's view, it is too late to stop these changes. What remains is to seek to minimise the impacts of climate disasters through deep adaptation.

Increased emissions of greenhouse gases into the atmosphere as a result of human activity are primarily considered to be the direct driver of recent climate change. In 2021, the quantities of greenhouse gases emitted into the atmosphere reached 37.9 Gt CO_2. The global increase in CO_2 emissions compared to 2020 was 5.3%. The largest emitters were China, the United States, European Union countries, India, Russia and Japan. All major emitters saw an increase in CO_2 emissions between 2020 and 2021 (Crippa et al., 2022). In the EU27, total CO_2 emissions increased by 6.5% (0.17 Gt) in 2021 compared to 2020. At the same time, CO_2 concentrations in the atmosphere reached 415 ppm in 2021, 50% above pre-industrial levels (Friedlingstein et al., 2021). The excessive accumulation of carbon dioxide in the Earth's atmosphere causes an increase in the average air temperature and accelerates global warming. The global annual temperature in 2022 was 1.15 °C higher than the 1850–1900 average (IPCC, 2023; WMO, 2023).

In order to currently achieve a stabilisation of global temperature increase at 1.5 °C, according to the Paris Agreement, greenhouse gas emission reductions should be 7.6% per year. However, with current national emission reduction plans lower than required, the temperature by the end of the century could rise by 3.0–3.2 °C relative to the pre-industrial period (Lenton et al., 2019; UNEP, 2022). Addressing this risk and keeping the temperature rise to 1.5 °C by 2100 requires achieving zero net greenhouse gas emissions before 2067 and reducing emissions to 27.4 Gt CO_2 eq before 2030 (IPCC, 2018). The European Union is considering achieving net zero emissions at least before 2050 (European Parliament, 2019; European Commission, 2019).

Most climate change scenarios predict that as early as 2050, the minimum increase in global average temperature could be 2 °C over pre-industrial levels (IPCC, 2022; IPCC, 2023). This could result in changes in long-term trends in temperatures, precipitation patterns, atmospheric humidity, wind strength, as well as an increase in the frequency and intensity of extreme climate events such as heat waves, storms, droughts and intense precipitation.

In the existing situation, with still insufficient reduction of greenhouse gas emissions (mitigation), adaptation of agriculture to climate change is of particular importance. The aim of the study was to assess the impact of climate change on agriculture and to identify measures adapting agriculture in Poland to changing climatic conditions. The sources of information were legal acts, reports and documents of international institutions as well as literature on the subject. The impact of climate change effects on the conditions of conducting and the volume of agricultural production was analysed in global, European and national terms. The analysis showed that progressive climate change and its impact on changing agricultural production conditions threaten agricultural productivity and limit the food security. Documents on adaptation in agriculture were presented, which indicate the need for proactive measures in this regard. Adaptation measures whose implementation enables adaptation to the current and expected climate and its impacts, are identified.

THE IMPACT OF CLIMATE CHANGE ON AGRICULTURE TO DATE – GLOBAL, EUROPEAN AND NATIONAL PERSPECTIVES

Modification of climatic factors such as the length of the growing season, thermal conditions or precipitation distribution affects agriculture on global, European and national level. The effects of climate change affect the conditions for agricultural production (Karaczun, Kozyra, 2020):

– Global warming is leading to changes in the extent of climate zones, including the expansion of dry zones and the contraction of polar zones. The effect of this process is not clear-cut. On the one hand, it will make farming more difficult in many areas (especially in the equatorial and subtropical zones), while on the other hand it will improve production conditions in areas closer to the poles. This applies to northern Europe, Canada and Russia.
– In the central regions of North America, south-eastern Australia, South America and some regions in northern Europe and Asia, the intensity of photosynthesis increases, which favours agricultural production. In contrast, a decrease in photosynthetic intensity has been observed in the northern regions of Eurasia, Central Asia, North America and the Congo River Basin. The current effects of climate change are also resulting in lower animal growth rates and productivity of pastoral systems in Africa.
– The increase in the average land temperature increases the frequency and intensity of heat waves and thus increases the frequency and intensity of droughts. Mediterranean countries, western and north-eastern Asia, most South American countries and almost all of Africa are particularly exposed to these hazards. An increase in the frequency of violent and torrential rainfall has also been found in these regions. This threatens crop production.
– Particularly dangerous for agriculture are the effects of rising temperatures and changes in rainfall in areas that are already affected by water scarcity and the occurrence of high temperatures. In sub-Saharan Africa, parts of Australia and East and Central Asia, climate change has contributed to the desertification of these regions.

High temperature also affects animal production. Animals exposed to heat stress reduce feed intake which translates into slower growth, lower body weight and worse health (Babinszky et al., 2011). The consequence is also a decrease in cow milk yield and milk quality (Cho et al., 2011). Breeds with higher production capacity are more sensitive to heat stress. Thus, a higher frequency of heat waves can significantly negatively affect livestock produc-

tion volumes. Another effect of climate change is an increase in the incidence of animal diseases, even new ones that did not previously occur in the area. Modification of climatic factors also affects the productivity of pastures and thus indirectly affects livestock production. This is particularly relevant in areas where pastoralism is developed, e.g. in African and Asian countries.

Climate change is also differentially affecting agriculture in Europe (European Commission, 2018; EEA, 2019; IPCC, 2022):

– Extend of the growing season, leading to an extension northwards of the areas where certain crops can be grown. Areas favouring grassland, wheat and barley cultivation can be expected to include the boreal zone (Finland, Sweden, Lithuania, Estonia, Latvia). In some parts of southern Europe (e.g. Spain), warmer conditions will in some cases allow crops to be shifted from summer to winter.
– Changes in the phenology of crops could lead to a shorter filling period for cereals and oilseeds and ultimately reduce yields.
– Increased incidence of plant pests and animal diseases due to rising temperatures.
– Increased occurrence of extreme events (heat waves, droughts and floods) increasing the risk of crop loss and damage to livestock production, particularly in central and southern Europe.
– Increased demand for crop irrigation, especially in Southern Europe, where there is already considerable competition between different users of water resources.

In Poland too, climate change is having an impact on agricultural production conditions:

– The most dangerous is the increase in the frequency and intensity of extreme weather phenomena: hurricane winds, torrential rain. These pose a threat to both crops and the infrastructure necessary for agricultural production.
– One effect of the increase in mean daily air temperature is the lengthening of the growing season. Currently, the growing season is 8 days longer than in 1971–2000 (Nieróbca et al., 2013). As the length of the growing season increases, the potential for crop diversification increases.
– Thermal conditions have the effect of accelerating plant development and thus faster harvests. The possibilities for growing heat-loving crops such as maize increase. However, it should be noted that adequate moisture conditions must be ensured, which is not easy due to the change in precipitation distribution.
– Rising temperatures also accelerate the development of diseases and pests.
– A change in the precipitation cycle involving an increase in winter precipitation totals and a decrease in summer precipitation totals may affect water resource deficits. The distribution of precipitation will favour winter crops. Spring crops, on the other hand, may be hampered by high summer temperatures and a water deficit. Crop irrigation is expected to be necessary (Wawer, 2020).
– A major threat to agricultural production is the change in rainfall patterns. Heavy rainfall during the summer cannot be fully utilised by plants (Konca-Kędzierska, 2019). In contrast, heavy rainfall occurring when soils are not covered by vegetation increases soil erosion and nutrient leaching (Krasowska, 2016).
– The increase in temperature observed in recent years has also increased the frequency of heat waves, which are increasingly regional in nature (Wibig, 2018). Heat waves pose threats to the efficiency of crop production. They also significantly reduce animal performance (Traczykowski, 2019).

Climate change also affects the volume of agricultural production (Ray et al., 2019). A study of 20 000 administrative units worldwide for ten major crops (barley, cassava, maize, oil palm, rapeseed, rice, sorghum, soybean, sugarcane and wheat) found that yield decreases or increases ranged from -13.4% (oil palm) to 3.5% (soybean). Yield decreases occurred mainly in Europe, Southern Africa and Australia, while increases occurred in Latin America. The impact of climate change on yields in Asia, Northern and Central America was mixed (yield decreases and increases). The impact of climate on crop declines reduced the amount of calories consumed by people by an average of about 1.0% (-3.5×10^{13} kcal year^{-1}). Caloric availability has decreased in about half of food insecure countries.

Yields for the dominant (non-tropical) crops in Western and Southern Europe declined by between 6.3 and 21.0% due to climate change (Ray et al., 2019). Annual yield losses in Western and Southern Europe were quite high, although there were exceptions, as in Andalusia in Southern Spain, where wheat yields increased. In Eastern and Northern Europe, yield losses were common in maize (-24.5%), barley (-9.1%) and wheat (-2.1%). Yield losses in France reduced the calorie production of the crops studied by about 24% and in the food consumed by about 7% of calories. Large reductions in calories consumed due to climate change also occurred in Germany (~ -11%), Spain (~ -4%), Italy (~ -7%). In Eastern and Northern Europe, large decreases in calories consumed were found in Hungary (~ -10%), Romania (~ -7%) and Ireland (~ -3%).

Declines in yields of staple crops (wheat, barley, maize and oilseed rape) were also found in parts of the steppes of European Russia and in the cereal belt of Western Siberia (Roshydromet, 2014). Barley, maize and sorghum also yielded lower in Ukraine (Müller et al., 2016).

A study of yield trends, aggregated for European country levels, shows that since 1989, yields in Europe have declined statistically significantly for wheat (-2.5%) and barley (-3.8%), while increasing slightly for maize (0.2%) and sugar beet (0.3%) (Moore, Lobell, 2015). The authors indicate that yield reductions in Europe were due to increased temperatures and reduced rainfall. Significant yield declines in most crops occurred mainly in the Mediterranean region. The results suggest that climatic trends

explained about 10% of the stagnation found in wheat and barley yields in Europe since 1990.

The variability of weather conditions in Poland is expressed in greater yield variability from year to year. Adverse weather patterns resulted in a decrease in average maize yields for grain by 39% in 2006 and 2015 and 13% in 2018 (Karaczun, Kozyra, 2020).

Simulations have further shown that by 2050, the agricultural sector will be affected by both regional climate change and the changes in production competitiveness caused by it (Pérez et al., 2018). Analyzing the impact of climate change on the prices of agricultural products according to two scenarios (taking into account the fertilising effect of carbon dioxide on plants and a scenario not taking into account this effect), the authors conclude that climate change leads to reductions in most prices of agricultural produce in the EU in both scenario variants. In a scenario that does not take into account the fertilising effect of carbon dioxide on plants, prices at the producer level in the EU will fluctuate between -3% for cereals (-7% for wheat) and +5% for other crops (e.g. bean and sugar beet). Producer price changes for animal products will range between -6% for sheep and goat meat and +4% for pig meat. In the scenario with the fertilising effect of carbon dioxide on plants, agricultural producer prices in the EU decrease for all commodities. Producer prices will fall from -20% for cereals (-25% for wheat) to almost -50% for vegetables and permanent crops. For livestock products, producer prices will fall between -7.5% for cow's milk and -19% for beef, due to lower feed prices. Under both scenarios examined, the EU trade balance will improve for most agricultural products, with the exception of beef, sheep and goats. No major changes in EU food consumption are expected. Changes in production, trade and producer prices will result in a 5% increase in EU-28 aggregate agricultural income in the scenario without fertiliser CO_2. In the scenario with fertiliser action CO_2 aggregate agricultural income will fall by 16%. Also in Poland, agricultural income will increase in the scenario without the fertiliser effect of CO_2 and will decrease in the scenario with the fertiliser effect of CO_2.

The presented impact of climate change on the conditions and volume of agricultural production also indicates the difficulties in ensuring food security. A detailed analysis of the impact of climate change on Poland's food security is presented by Karaczun and Kozyra (2020).

DOCUMENTS AND REGULATIONS ON ADAPTATION IN AGRICULTURE

Climate change is a global problem. Therefore, all countries should be committed to reducing greenhouse gas emissions and taking active measures to adapt to climate change.

The first milestone in the history of adaptation was the drafting of the text of the United Nations Framework Convention on Climate Change (UNFCCC) and its signing at the Earth Summit in Rio de Janeiro in 1992. The international negotiations mainly focused on developing mechanisms to reduce greenhouse gases. Most countries were satisfied that the target for stabilising greenhouse gas concentrations was non-binding (van der Gaast, 2015). Eventually, the UNFCCC entered into force in 1994.

In December 1997, an international treaty was negotiated, the so-called Kyoto Protocol, which entered into force in February 2005. The countries that decided to ratify the Protocol committed to reducing their own greenhouse gas emissions by 2012 by the negotiated values listed in the annex to the treaty. They were also obliged to support poorer countries in the fight against global warming.

Although climate change adaptation was accepted in the UNFCCC regulations, for many years it was not part of the international discussion on how countries should deal with climate change. It was only in 2001 that the IPCC (Intergovernmental Panel on Climate Change) published a report indicating that activity aimed at mitigating climate change was insufficient. Since then, consideration has begun to be given to how to implement adaptation (UNFCCC, 2019).

A further IPCC report published in 2007 had a significant impact on the interest in adaptation (IPCC, 2007). The authors of the report indicated that it is essential for the international community to engage in adaptation activities to achieve resilience to future climate change, which is inevitable.

In 2010, a package of solutions known as the Cancun Adaptation Framework was adopted, which indicated the need to give adaptation the same priority as mitigation (Decision, 2011).

Another important document on climate change adaptation was the Paris Agreement (Porozumienie Paryskie, 2015). The Agreement formulated the following objectives:

- to limit the increase in global average temperature to well below 2 °C above pre-industrial levels;
- to increase the capacity to adapt to the negative impacts of climate change and to promote climate resilience and low greenhouse gas emission development in a way that does not jeopardise food production;
- to ensure that financial flows are consistent with a path towards low greenhouse gas emissions and climate-resilient development.

The literature emphasises that setting a limit on average temperature rise has been made possible by extending aspirations to adaptation and supporting sustainable development (Rajamani, Guérin, 2017).

Successive meetings of the Conference of the Parties to the Framework Convention (COP) show that global greenhouse gas emissions continue to increase. As mentioned, China and the USA are the largest emitters. The European Union's share of global emissions is only 10%, indicating

a limited impact on global emissions (Szpak, 2020). Despite this, the EU is establishing itself as a leader in halting climate change.

The United Nations Framework Convention on Climate Change (UNFCCC), in Article 4.1b, states that parties are obliged to develop and implement national and, where appropriate, regional programmes that lead to the mitigation of climate change and facilitate adaptation to climate change. In addition, the Kyoto Protocol (Article 10) commits parties to promote and facilitate adaptation and the implementation of adaptation technologies to address the impacts of climate change (United Nations, 2007).

The EU's current most important climate policy strategy is the European Green Deal (EDG). It aims to "transform the EU into a fair and prosperous society living in a modern, resource-efficient and competitive economy that achieves zero net greenhouse gas emissions by 2050 and where economic growth is decoupled from the use of natural resources" (European Commission, 2019).

A special report on the links between land use and climate change was published in 2019 (IPCC, 2019). One of the report's conclusions was that limiting the temperature rise to 1.5 °C requires a reduction in emissions related to land use, land use change, and increased afforestation and reduced deforestation (European Commission, 2019a).

In the context of climate change, the European Green Deal reaffirmed the need to achieve climate neutrality by 2050 by reducing greenhouse gas emissions and increasing removals. In 2021, the European Climate Law (Regulation, 2021) was published. The Council and the European Parliament reached an initial agreement setting a joint reduction of net GHG emissions (emissions after deduction of removals) by at least 55% by 2030 compared to 1990 levels, and achieving climate neutrality by 2050. The implemented GHG reduction pathway in the EU assumes that all Member States implement a common climate policy. The main tool for achieving the GHG reduction target is the implemented EU ETS (European Union Emissions Trading System), which primarily covers energy-intensive sectors of the economy and energy production. Installations covered by the EU ETS must account for their emissions with allowances. The number of these allowances is reduced each year in order to achieve the appropriate level of greenhouse gas reductions. Also in July 2021 the European Commission presented a legislative proposal to amend the Effort Sharing Regulation (European Commission, 2021). According to the proposal, GHG emissions from non-ETS sectors in Europe should be reduced by 40% in 2030 compared to 2005. For Poland, the reduction in GHG emissions in 2030 should be 17.7%.

The adoption of the Strategy "Bringing nature back to our lives" (European Commission, 2020) within the framework of the European Green Deal can be of significant importance for the agricultural sector. This is a long-term plan to protect nature and reverse ecosystem degradation processes. The second "farm-to-table" strategy is to contribute to a fair and environmentally friendly food system (European Commission, 2020a). The objectives outlined should be considered ambitious, but at the same time necessary. Despite the potential difficulties and challenges for agriculture, it is essential to create solutions that will result in an improved environment and contribute to climate stabilisation. Member States have committed to developing long-term strategies on how they plan to meet their commitments. In August 2022, the European Commission accepted the CAP Strategic Plan for 2023–2027, developed in Poland. The Plan promotes actions to protect the environment and mitigate climate change and to contribute to the Union's environmental and climate objectives, including the Union's commitments under the Paris Agreement.

ANALYSIS OF THE SITUATION REGARDING ADAPTATION TO THE EFFECTS OF CLIMATE CHANGE IN POLAND

The IPCC defines adaptation as the process of adjusting to the current or expected climate and its impacts (IPCC, 2014). Linked to the term adaptation is the term climate vulnerability. It is understood as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes" (IPCC, 2007a). Vulnerability is a function of the nature, magnitude, rate of climate change and variability to which a system is exposed and the ability of that system to adapt. Agriculture is among the systems that are most vulnerable to climate change, so agricultural adaptation to these changes is critical to maintaining food security and is a prerequisite for effective farm operations (Karaczun, Kozyra, 2020).

Weather variability increases the risk of farming. Farmers are now aware of these climate changes they are experiencing. However, there is a need to inform them widely about the expected climate changes and their impacts, and the appropriate ways to adapt to these changes.

With climate change, plant requirements for cultivation and fertilisation, the incidence and severity of crop diseases and pests are changing, and the environmental impact of agriculture is changing. The varying economic and climatic conditions require appropriate adaptation measures. These measures must take into account the increase in thermal conditions and thus the lengthening of the growing season of plants. This requires:

- adapting the timing of on-farm work, such as sowing and planting dates and cultivation operations, to the new conditions;
- selecting crops and varieties that are better adapted to the expected length of the growing season and water availability and more resistant to the new temperature and humidity conditions;
- increasing the area under thermophilic plants;

– improving the effectiveness of pest and disease control through better monitoring of their appearance, diversification of crop rotations or integrated methods of disease and pest control.

Also, diversifying crops and adapting the production structure to long periods of heat waves and drought will reduce potential losses due to adverse climatic conditions.

Livestock production is also affected by climate change through reduced availability of feed grains, pasture availability, range shifts and the spread of diseases and parasites. Based on the assessment of the impact of climate change on livestock production to date, adaptation measures are needed for livestock maintenance and feeding. These measures should include:

– building an infrastructure for monitoring the impact of climate on livestock production;
– supporting technical solutions for animal buildings and structures that provide protection against heat stress;
– supporting technologies and solutions that rationalise the use of process water and secure the drinking water requirements of animals;
– technological advice that takes into account aspects of adapting livestock production to greater climatic risks;
– supporting research work and breeding programmes to select animals for greater resistance to high-temperature stress.

An important production factor in agriculture is water. The changing climate is leading to an imbalance between rainfall and the needs of plants during the growing season and this will affect yields and the quality of agricultural products. Already, agriculture is struggling with the effects of extreme events such as droughts and violent storms, resulting in water shortages or excesses. Climate change scenarios for the development of the hydrological balance indicate a high risk of rainfall deficits. It is to be expected that agriculture will be irrigation-dependent (Kozyra et al., 2020). Crop irrigation carried out without estimating water needs results in losses of water, energy and nutrients, which are leached. Decision support systems to optimise water use are therefore recommended (Wawer, 2020). A way to reduce water use in agriculture is to introduce varieties with higher tolerance to temperature changes and reduced water requirements. It is also recommended to collect as much water as possible in the agricultural landscape by increasing small-scale water retention (mid-field ponds, swamps and marshes). The practice promotes increased groundwater recharge and improves the microclimate of the area. An increase in groundwater resources can be achieved by damming up water in the beds of small rivers and watercourses.

Appropriate soil management is important in a changing climate. Maintaining soil quality and functionality and mitigating the risks associated with soil use is reflected in higher yields. Measures to increase the water-holding capacity of the soil are recommended. A practice that contributes to improving soil structure, thereby improving nutrient utilisation and reducing nutrient losses through leaching, is the provision of an organic matter supply. Increasing the stock of organic matter in soils also contributes to increasing the resistance of soils to dryness. Humus improves soil air-water relations, increases soil sorption capacity, reduces susceptibility to compaction and degradation by water and wind erosion, and improves soil structure and is a source of nutrients. Humus compounds have a high water holding capacity, so crops grown on soils with high humus content are less vulnerable to agricultural drought stress.

There are many methods to increase soil carbon sequestration. A way to increase content of soil organic matter is to use an appropriate crop rotation by including legumes and grass crops and their mixtures. It is also advisable to include early-maturing crops in the rotation on the most susceptible land in order to harvest before the wet season and facilitate the introduction of cover crops. Cover crops prevent erosion and help build and maintain humus in the soil. Ploughed catch crops are also a source of organic matter in the soil. The choice of plant species used as catch crops depends on climatic and soil conditions. The use of catch crops is effective in areas where there is an excess of precipitation in winter. In contrast, they should be avoided in areas where cover cropping can lead to soil drying. Intercropping is a practice that promotes the formation of organic matter and improves soil structure. Intercropping is particularly important on sloping land. Intense rainfall or surface runoff on sloping land causes soil particles to be washed away, leading to nutrient depletion and a deterioration in soil properties (less water infiltration and soil aeration). On the other hand, leaching of nutrients causes pollution of surface- and groundwater.

The basic element of agrotechnology that shapes soil properties is soil tillage. Conventional tillage accelerates the mineralisation of organic matter, leading to its loss. In addition, soil after ploughing is more susceptible to wind and water erosion, which also has a negative impact on organic matter. Therefore, it is increasingly recommended to use conservation tillage techniques that have a beneficial effect on the soil environment (Smagacz, 2018). Such systems include reduced tillage, which involves reducing tillage depth and intensity and leaving crop residues on the soil surface. Another type of conservation tillage is no-tillage. Conservation tillage significantly increases volume and velocity of water infiltration, thereby reducing surface run-off and evaporation. Leaving crop residues also reduces evapotranspiration, by reducing the amplitudes of soil temperature changes (insulating properties), reducing vapour diffusion, absorption of water vapour by the mulch and shielding the surface soil layer from the wind. As a consequence, the relative soil moisture and the amount of water available to plants are increased.

The problem of climate change and its impact on agriculture should not be underestimated. Climate change is al-

ready noticeable and will worsen in the coming years. The dynamics of climate change, the extent of the threats and the severity of their negative impacts all call for adaptation measures. In this situation, farms should be provided with adaptation advice adapted to local farming conditions.

CONCLUSIONS AND RECOMMENDATIONS

For many years, climate change mitigation was seen as a much more important activity than climate change adaptation. Today, with mitigation less effective than expected, adaptation is becoming particularly important. Agriculture is an area of the economy that is particularly sensitive to climate change. Therefore, carrying out effective adaptation measures in it is an imperative. The future productivity of agriculture, and consequently the level of food security, will depend on the ability of farms to adapt.

The analysis carried out showed that climate change affects agriculture by modifying atmospheric and soil conditions and the frequency and intensity of extreme events (droughts, heat waves, violent and torrential rains). These factors influence the coverage of plant and animal requirements due to changes in length of vegetation period, as well as in terms of fertilisation and pest or disease incidences. The increasing incidence of agricultural droughts and worsening water deficits contribute to high yield variability. This causes uncertainty in achieving planned production results and threatens food security. It is therefore necessary to search for and implement methods which, on the one hand, reduce the risk of crop losses due to climatic factors and mitigate the consequences of extreme climatic events, and, on the other hand, make it possible to reduce greenhouse gas emissions and improve the environment and contribute to climate stabilisation.

Particular adaptation strategies depend on environmental and socio-economic conditions. In Poland, at farm level, adaptation to climate change requires technical measures such as: maintaining drainage systems in working order, improving irrigation efficiency, collecting rainwater, using precision agriculture, modifying the cropping calendar, using cover crops, introducing crops adapted to climate change, diversifying crops, improving soil structure and using reduced farming or no-till farming. Measures are also needed in the area of livestock feeding and maintenance, such as: equipping livestock housing with air cooling systems and implementing solutions to protect animals from heat stress, using water rationalisation technologies, optimising grazing conditions for animals, adapting feeding and rations to the needs of animals resulting from climate change, and monitoring and preventing threats to livestock health caused by new diseases related to climate change.

From the above summary, it can be concluded that in order to ensure food security, it is necessary to take actions to adapt agriculture to the effects of climate change. Incurring significant financial outlays for the indicated activities requires financial support for agricultural farms. It is, therefore, necessary to create a program that will constitute a road map leading to better adaptation to changes.

The global climate system is characterized by significant inertia. Most of the impacts of climate change will last for many years, even if CO_2 emissions come to a halt. Therefore, a further deterioration of the conditions for conducting agricultural activity should be expected. It is therefore important to carry out further actions to counteract climate change (reducing GHG emissions), as well as actions to strengthen adaptive capacity and resistance to climate threats.

The level of public education and awareness about climate change mitigation, the effects of climate change and adaptation possibilities should be increased. The effectiveness of climate action also requires the dissemination of knowledge among farmers and advisors. Further research should be conducted to determine in detail the directions of changes in agricultural production conditions and to be used by advisors providing services in the agricultural sector.

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