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CONSEQUENCES OF CLIMATE CHANGE FOR FARMING AND RURAL AREAS

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Abstract:
Considerable climate changes have been observed in the last 50 years – warming in every spatial scale (global, continental, regional and local), changes in atmospheric precipitation and several weather extremes, shrinking of cryosphere and sea level rise. The warming since the mid-20th century has predominantly been due to greenhouse gas emissions from human activities, in particular the combustion of fossil fuels, farming and other changes in land use. The paper presents the aspects of impact of climate change for farming and food security and the impact of farming for climate change in Polish and global scale. Agriculture holds a meaningful potential of reduction of greenhouse gas emissions and of carbon sequestration. It will be necessary to manage optimally advantageous changes and effectively adapt to adverse changes.

Key words: climate change, farming, food security, agricultural adaptation.

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INTRODUCTION

The climate is changing globally. Over the last 65 million years, the climate has not changed as fast as it does today. Climatologists at the Stanford University have calculated that the climate is currently changing 10 times faster than any change that has occurred over the past 65 million years. The pace of climate change can be too fast for many species of plants and animals that will not be able to adapt to new environmental conditions (Diffenbaugh and Field, 2013). In the past, climate was the basic factor conditioning people's ability to settle, and its transformations forced major changes in the economy.

Forecasts show that the climate change will have two, positive and negative effects on the environment as well as on the economy and society. Considerable climate change has been observed in the last 50 years – warming in every spatial scale (global, continental, regional and local), changes in atmospheric precipitation and several weather extremes, shrinking of cryosphere and sea level rise (Kundzewicz and Kozyra, 2011). The warming since the mid-20th century has predominantly been due to greenhouse gas emissions from human activities, in particular the combustion of fossil fuels, agriculture and other changes in land use. For most emissions scenarios, global average temperature is projected to exceed 2°C above the pre-industrial level (the upper limit according to the Paris Agreement under the UNFCCC) by 2050. The unimpeded growth of greenhouse gas emissions is raising the Earth's temperature. The consequences include melting of glaciers, increased precipitation, more and more extreme weather events, and shift of seasons. The accelerating pace of climate change, combined with global population and income growth, threatens food security everywhere.

There is a need to reduce global greenhouse gas emissions substantially to avoid the most adverse impacts of climate change. Farming depends strongly on climatic conditions, but also drives climatic changes. Projections for the future augur even stronger climate change. The paper presents the aspects of the impact of climate change for agriculture and food security and the agricultural impact on climate change in Polish and global scale.

IMPORTANCE OF CHANGING CLIMATE VARIABILITY TO FARMING AND FOOD SECURITY

Regional temperature indicates significant and progressive warming for the entire globe, including Europe and Poland (Górski, 2007). The accelerated warming of the Earth continues to lead to modified ecosystem processes, changing climate variability and more intensive climate-related events across, including extreme temperatures (cold and hot spells) and variations in rainfall (floods and droughts). The increasing air temperature will have posi-

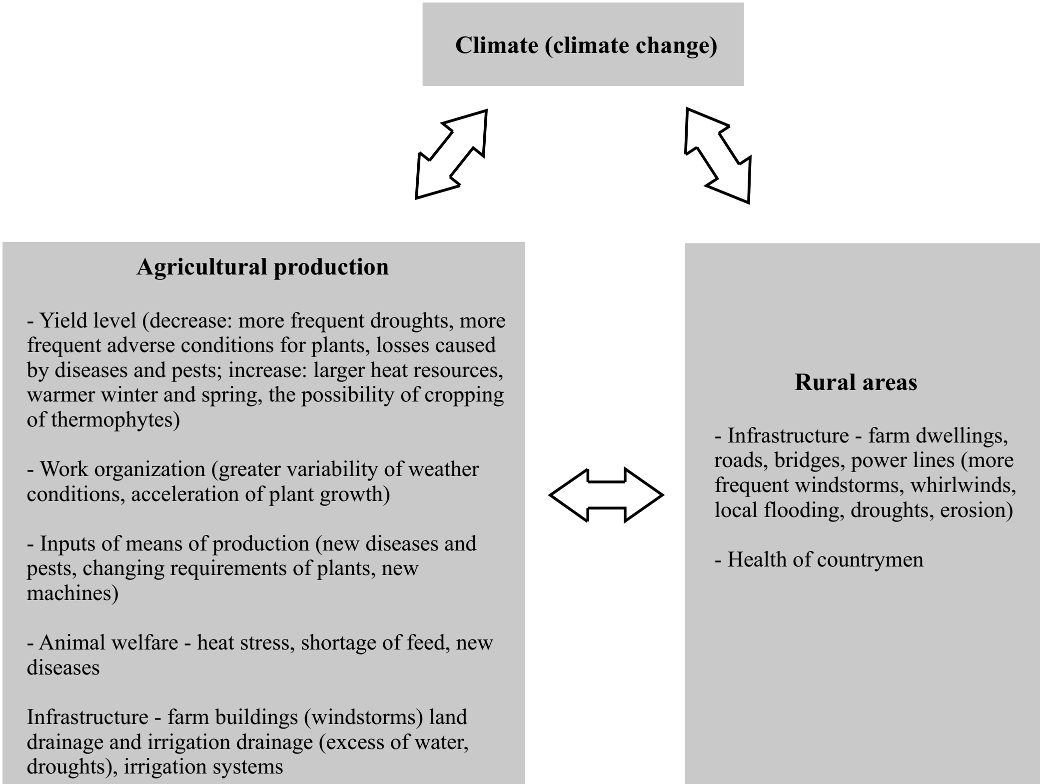

Fig. 1. Scheme of climatic threats with regards to agricultural production and development of rural areas. Source: based on: Z.W. Kundzewicz and J. Kozyra (2011).

tive effects, among others in extending the growing season and the possible growing of new plant species, shortening the heating season and extending the tourist season.

Looking ahead, climate change impacts are projected to intensify, and the underlying drivers of biodiversity loss are expected to persist. Climatic changes are associated with adverse changes in hydrological conditions. Direct negative effects of climate change are also: intensification of eutrophication of water bodies, increasing risk to human life and health as result of thermal stress and air pollution, greater demand for electricity in the summer season (Veenema *et al*., 2017). At the same time, the effect of climate change will increase frequency of extreme weather events and disasters (Trnka *et al*., 2011). More and more often strong winds and atmospheric discharges will be observed, which can significantly affect, among others agriculture, construction as well as energy and transport infrastructure (Fig. 1). The consequences of extreme weather events and natural disasters (e.g. the storm that passed through a large part of the Pomeranian voivodeship in August 2017) are long-term and make in the areas affected that traditional socio-economic professions for these areas connected with tourism, wood industry and forestry will be abandoned.

Climate change has already an impact on agriculture (Peltonen-Sainio *et al*., 2010) and is expected to continue to affect agriculture in the future (Olesen *et al*., 2011). A productivity of crops will increase in northern Europe owing to a lengthened growing season and an extension of the frost-free period. In southern Europe, climate change is likely to negatively affect a productivity of crops and their suitability in certain regions, primarily as a result of extreme heat events and an overall expected reduction in precipitation and water availability (Szwed *et al*., 2010). Year-to-year variability in yields is generally expected to increase throughout Europe, owing to extreme climatic events and other factors, including pests and diseases (Smith and Olsen, 2010).

Impacts of unfavourable meteorological conditions and extreme events vary considerably, depending on timing of occurrence and development stage of crops (Moriondo *et al.,* 2011; Eyshi Rezaei *et al*., 2015). Changes in occurrence of extreme events such as heat waves, droughts, heavy precipitation and floods will greatly affect crop yield leading to increased variability and economic consequences (Elsgaard *et al*., 2012).

Agriculture both contributes to climate change and its effects. In the face of growing global demand and competition for resources, production and consumption of food in the EU should be seen in a broader context that combines agriculture, energy and food security. By 2050, farming is expected to increase productivity of 70 to 100% if compared to the current level of production. Meeting these expectations requires significant changes in production technologies and crop structure as well as growing higher yielding and resistant to climate stress of cultivated plant varieties (Reidsma *et al*., 2010). However, farmers are still reluctant to use new technologies that can help reduce not only emissions but also production costs (up to 1/3).

The increase in air temperature observed in the 20th century caused the vegetation period to be extended by about 10 days. This affects not only the change of plant sowing dates, but also other agrotechnical works. The sowing dates of spring cereals will be significantly accelerated, and the winter will be delayed by approximately 3 weeks. Harvest will be earlier for 3–4 weeks. The longer growing season will create greater opportunities for cultivation of intercrops and stubble crops. It is estimated that 1°C rise in 100 years accelerates the maturation of basic cereals in Poland by one week, and maize by 2 weeks (Górski, 2007; Górski and Kozyra, 2011). The growing season is projected to increase further throughout most of Europe owing to the earlier onset of growth in spring and later senescence in autumn. As a result of the temperature rise, the pace of plant development accelerates, which is of particular importance in the case of thermophilic plants (maize, soybean, millet or sunflower). Larger heat resources also create the possibility of growing other thermophilic plants, such as sorghum or grapevine.

Increasing the duration of a thermal cultivation season has led to northward expansion of the areas suitable for several crops. Changes in crop phenology have been observed, such as the progress of flowering and cereal harvest dates. Specific stages of growth (e.g. flowering, grain filling) are particularly sensitive to weather conditions and critical to a final yield. The timing of the crop cycle (agrophenology) determines a productive success of a crop (Trnka *et al*., 2011; Elsgaard *et al*., 2012). A warming is expected to result in an earlier start of the growing season in spring and a longer duration in autumn. The date of the last frost in spring is projected to advance by about 5–10 days by 2030 and by 10–15 days by 2050 throughout most of Europe (Trnka *et al*., 2011). A longer growing season will, in many cases, allow for introduction of new crop species that were previously unfavourable owing to low temperatures or short growing seasons, but it may also increase the spread of weeds, insect pests and diseases. With the projected warming in Europe, further reductions in a number of days required for flowering and to reach maturity in cereals may be expected throughout Europe (Reidsma *et al*., 2010; Morindo *et al*., 2011).

Crop yields are affected by combined effects of changes in temperature, rainfall and atmospheric CO_2 concentration . In practice, the response depends on soil type, which can differ greatly in capacity for storing soil moisture and on possibilities for supplementary irrigation. Crop yield also depends on timing of crop growth and yield formation. Climate change will also affect water availability. Limited availability of water is already a problem in many parts of Europe and this situation is likely to deteriorate further. By 2070, Europe is expected to increase the surface area of water-poor areas from 1% at present to 35%. Water shortages are an example of a negative impact in the agricultural sector as a result of climate change. Desertification is a result, but also a reason for climate change and is caused by land management in a manner inconsistent with principles of sustainable development. Areas affected by this phenomenon lose the ability to store carbon dioxide and consequently, they can absorb less greenhouse gases. Periodically, the problem is also flooding, caused by intense rainfall as well as frost.

The effect of climate change may also limit the area of cultivation of cold and humid climate (e.g. potatoes), increasing a yield of thermophilic plants (maize, sunflower, soy) by up to 30%. Climate change can also affect animal production. Livestock production systems are of major economic, environmental and cultural importance to the EU. As they are reliant on crop and grass yields and quality, livestock production systems are highly exposed to the impacts of climate change at local (grazing and home-grown forage) and global (feed concentrate imports) levels. Livestock production systems in Europe are affected by climate change directly (through the effects of changing environmental conditions on animal health and welfare) and indirectly (through impacts on pathogens and feed (quantity, type and quality) and through the socio-economic changes entangled with climate change). In this context, international political settlements (relating to both agricultural and non-agricultural issues) will have an important influence on, and interact with, production responses.

With the expanding global population and increasing wealth, there is growing concern for food security, both globally and in the European context (Vermeulen *et al*., 2012). This concern is enhanced by many conflicting demands on scarce land and water resources, which are also needed for many other human uses, including biofuels, biodiversity and recreational activities (Soussana *et al*., 2012). Climate change is increasingly seen as a threat to global food security, because projections of climate change impacts show that rising temperatures have negative effects on crop yield and water availability (Challinor *et al*., 2014).

In the perspective of 2050 (certain reports even refer to 2020) there will be a breakdown of food production in regions of the largest demographic increase (Nelson *et al*., 2009). Population in the developing world, which are already vulnerable and food insecure, are likely to be the most seriously affected. Corteva Agriscience (Agricultural Department of DowDuPont) and The Economist Intelligence Unit (EIU) have published results of the World Food Security Index 2018 (GIBSI). In 2018 Singapore became the leader of the ranking for the first time. The GFSI report concludes that climate change in the world is already increasing uncertainty about the conditions of food production and distribution, creating new and unprecedented challenges. The phenomenon of hunger is increasing in those regions of the world where climate change is most noticeable and in societies strongly dependent on crops and agriculture. All dimensions of food security and nutrition, including food availability, access, utilization and stability, are potentially affected even in the short term by climate variability and climate extremes (Niles *et al*., 2017). For example, a direct impact occurs when drought undermines crop yields, which then results in reduced food production. On the other hand, crop failures can indirectly reduce food access if food prices rise significantly. Similarly, floods that reduce access to safe water and adequate sanitation can indirectly affect the utilization of food and nutrition, as a result of reduced quality and safety of food and disease outbreaks. The cumulative effect of these direct and indirect impacts leads to a downward spiral of increased food insecurity and malnutrition (The state of food…, 2018). Floods cause more climate-related disasters around the world than any other extreme climatic event.

Climate impacts vary between regions, countries and within a given country. Differences in overall aggregate impacts on national food production arise not only due to variations in type and geographical distribution of climate variability and extremes, but also due to diversity and complexity of agricultural systems. Divergences exist between crops, cropping patterns, farming technologies (e.g. rainfed vs irrigated, high and low input ratios, nomadic pastoral vs intensive livestock production) and agriculture management systems.

Increasing global demand on food definitely means a developmental chance. However the forecast that Poland would profit with climatic changes is surely unsubstantiated. Global warming does guarantee prolonging of the vegetative season in Poland. Changes of sea tides caused by melting of ice on the Earth poles can even cause cooling of the climate in our country. Besides, climate warming brings about increase of extreme phenomena which to a large extent can have impact on possible increase of agricultural production. Hydrological situation is a great unknown and although some forecasts indicate possible increase of rainfall, mostly in the winter season but not the vegetative period. At the same time, drought frequency has already increased since the mid-1990s. Before, droughts had occurred every five years' on average and now once in two years' time (Bendyk, 2009). The duration of a drought is often a critical factor in its overall impact on food security.

More than 25% of all economic losses and damages inflicted by medium- and large-scale climate-induced hazards in developing countries occur in the agriculture sector. Where extreme climate events lead to recurring climate-related disasters, the accumulated costs for the agriculture sector are even more significant.

REDUCING IMPACTS OF CLIMATE CHANGE IN RURAL AREAS THROUGH ADAPTATION

One of the main challenges for sustainable development in Poland is adaptation to the changing climate by improving the resilience of individual sectors of the economy. As further warming is inevitable, adaptation to change will be needed to an increasing extent. A step towards reducing global warming is the EU energy and climate package, which aims to reduce greenhouse gas emissions in the EU by at least 20% by 2020 (compared to 1990) and by 50% by 2050. By 2020, at least 20% of energy it should come from renewable sources, and energy efficiency should increase by at least 20%.

Among the possibilities of adapting to the changing climate, one should mention: breeding of new varieties of crops resistant to summer droughts and snowless winters, winter crops cultivation, breeding of new animal breeds with increased resistance to thermal stress and more frequent pressure changes, creation of water retention systems, not leaving unsaturated fields, planting meridian strips of mid-field trees.

Adaptation measures at farm level include adaptation of crops to changing conditions and fluctuations in temperature and rainfall (Moriondo *et al*., 2010; Szwed *et al*., 2010). Plants are affected not only by changes in temperature and precipitation, but also by changes in atmospheric CO_2 concentration, which affects crop yield and quality both directly and indirectly (Wang *et al*., 2011). One of the main adaptation options to cope with the shortening of crop growth phases is choosing crop cultivars that have higher thermal requirements, as this will reduce the negative yield effects of a shorter growth duration (Moriondo *et al*., 2011). In practice, this needs to be balanced against the need to avoid periods of high temperature stresses and drought.

It will also be necessary to use new technologies to increase plant adaptability or to apply practices such as restoring natural elements (hedges) to reduce soil erosion in case of increased rainfall. An important element of the adaptation is the diversification of crop rotation and agricultural activity and irrigation, which can offset the negative aspects of climate change – water shortage, especially in the case of spring crops. This type of activity brings double benefits: supporting the process of agricultural adaptation, as well as limiting the impact of agriculture on the climate (Smith and Olesen, 2010). The introduction of new arable crops may turn out to be a less profitable for agriculture, taking into account not only problems related to frost, but disappearance of traditional crops (e.g. potatoes) or better conditions for development of pests and diseases. An example is the growing contamination of maize and wheat in Europe with mycotoxins, which adapt well to dry and hot weather conditions (van der Fels-Klerx *et al*., 2016).

In the European Union, the Common Agricultural Policy should be an instrument supporting the adaptation, e.g. by encouraging farmers to diversify income on the farm – by cultivating not one, but a few commodity crops. The EU financially supports its farmers and encourages sustainable and eco-friendly practices, while also investing in the development of rural areas.

Dynamic changes in production cause that agriculture adapts to climate change on an ongoing basis, and the adaptation process takes place autonomously on farms, e.g. by changing dates of field works or introducing more effective production technologies (Reidsma *et al*., 2010). Agricultural science- and technology-based solutions are essential to meet climatic demands (Lipper *et al*., 2018). Climate change places new and more challenging demands on agricultural productivity. Crop and livestock productivity-enhancing research, including biotechnology, will be essential to help overcome stresses due to climate change. Research on dietary changes in food animals and changes in irrigation-management practices is needed to reduce methane emissions. Rural infrastructure is essential if farmers are to take advantage of improved crop varieties and management techniques.

International climate negotiations provide a window of opportunity for governments and civil-society organizations to advance proposals for practical actions on adaptation in agriculture.

SUMMARY

Agricultural production and food systems are major sources of GHG emissions and are particularly sensitive to climate. These systems need to be a priority for climate change adaptation and mitigation action.

Poland has great potential in reducing greenhouse gas concentrations through the use of, among others, forest potential, development of wooden construction as a CO_2 storage, use of forest and agricultural biomass for renewable energy production in dedicated installations, taking into account the potential for preservation and reconstruction of wetlands, carbon sequestration in soil. However, even with substantial reductions in greenhouse gas emissions, the climate will continue to change, and the impacts will be felt across the world. The probability of the acute consequences of climate change increases with the increase of the speed and amplitude of changes. Even if climatic projections are uncertain, in quantitative terms, they are foreseeable in qualitative terms.

Agriculture is extremely vulnerable to climate change. Higher temperatures eventually reduce yields of desirable crops while encouraging weed and pest proliferation. Changes in precipitation patterns increase likelihood of short-run crop failures and long-run production declines. Although there will be gains in some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to be negative, threatening global food security. Where agriculture production, food systems and livelihoods are vulnerable to climate variability and extremes, countries face the greatest risk of food insecurity and malnutrition.

Future climate change could lead to both decreases and increases in average yield, depending on the crop type and the climatic and management conditions in the region. Projected increases in extreme climatic events are expected to increase crop yield variability and to lead to yield reductions in the future throughout Europe. Climate change may also affect animal production by limiting the availability of cereals and their price, the impact on pasture availability, changes in the availability of plants for fodder and their quality. Given the significant impact of climate change on livestock farming that is expected, adaptation options should be developed far beyond adjusting current farm management. This could involve consideration of new farming systems or new interactions between farming systems, e.g. to better ensure feed supply for livestock under climate change. However, such changes would need to be intensified through changes in agricultural and rural policies.

In order to adapt agriculture to the changing climatic conditions, it will therefore be necessary to:
– adaptation of field treatments to plant vegetation conditions (date of sowing, application of fertilizers and plant protection products);
– proper selection of plants in crop rotation;
– exchange of cultivated plant varieties for better adapted to the changed climate;
– adaptation of feed plants to changed natural conditions – resistant to drought and heat;
– increasing irrigation of plants,
– increasing the area of energy crops;
– monitoring the spread of pests and diseases;
– implementation of internet systems (e.g. agricultural drought monitoring system, pest monitoring system).

Many adverse consequences of climate change can be avoided, weakened or delayed by implementation of an effective mitigation policy. Agriculture holds a meaningful potential of reduction of greenhouse gas emissions and of carbon sequestration. During analyses of correlations of development of agriculture and climatic changes, we have to be aware that the negative impact of such changes on agricultural production is in pair with negative impact of agriculture on climate. It will be necessary to optimally manage advantageous changes and effectively adapt to adverse changes.

Most of the projected impacts of climate change will be negative, but some positive impacts may occur, in particular for renewable energy production. Energy plays a fundamental role in supporting all aspects of modern life.

REFERENCES

Bendyk, E., 2009, The end of the food? (Koniec żywności?). Pomorski Przegląd Gospodarczy. Rolnictwo 3, 12 (in Polish).

Challinor, A.J., Watson, J., Lobell, D.B., Howden, S.M., Smith, D.R., Chhetri, N., 2014. A meta-analysis of crop yield under climate change and adaptation. Nature Climate Change 4(4), 287–291.

Diffenbaugh, N.S., Field, Ch.B., 2013. Changes in Ecologically Critical Terrestrial Climate Conditions. Science 341, 486–492.

Elsgaard, L., Børgesen, C.D., Olesen, J.E., Siebert, S., Ewert, F., Peltonen-Sainio, P., Rötter, R.P., Skjelvåg, A.O., 2012. Shifts in comparative advantages for maize, oat and wheat cropping under climate change in Europe. Food Additives & Contaminants: Part A 29(10), 1 514–1 526.

Eyshi Rezaei, E., Webber, H., Gaiser, T., Naab, J., Ewert, F., 2015. Heat stress in cereals: Mechanisms and modeling. European Journal of Agronomy 64, 98–113.

Górski T., 2007. Changes in Poland's agroclimatic conditions over the last century. Papers on Global Change, IGBP PAS 14, 55–67.

Górski T., Kozyra J., 2011. Agroclimatic normals of mean air temperature in Poland over the years 2011–2020 (Agroklimatyczna norma średniej temperatury powietrza w Polsce na lata 2011–2020). Polish Journal of Agronomy 5, 21–28 (in Polish with English summary).

Kundzewicz, Z.W., Kozyra, J., 2011. Reducing impacts of climatic threats to agriculture and rural areas (Ograniczanie wpływu zagrożeń klimatycznych w odniesieniu do rolnictwa i obszarów wiejskich). Polish Journal of Agronomy 7, 68–81 (in Polish with English summary).

Lipper, L., McCarthy, N., Zilberman, D., Asfaw, S. Branca, G., 2018. Climate Smart Agriculture: Building Resilience to Climate Change. Natural Resource Management and Policy. Berlin, Springer, 630 pp.

Moriondo, M., Bindi, M., Kundzewicz, Z.W., Szwed, M., Choryński, A., Matczak, P., Radziejewski, M., McEvoy, D., Wreford, A., 2010. Impact and adaptation opportunities for European agriculture in response to climatic change and variability. Mitigation and Adaptation Strategies for Global Change 15(7), 657–679.

Moriondo, M., Giannakopoulos, C., Bindi, M., 2011. Climate change impact assessment: The role of climate extremes in crop yield simulation. Climatic Change 104, 679–701.

Nelson, G.C., Rosegrant, M.W., Koo, J., Robertson, R., Sulser, T., Zhu, T., Ringler, C., Msangi, S., Palazzo, A., Batka, M., Magalhaes, M., Valmonte-Santos, R., Ewing, M., Lee, D., 2009. Climate Change. Impact on Agriculture and Costs of Adaptation. Food Policy Report. International Food Policy Research Institute, Washington D.C., 30 p.

Niles, M., Esquivel, J., Ahuja, R., Mango, N., 2017. Climate: Change and Food Systems: Assessing Impacts and Opportunities. Washington, DC, Meridian Institute, 55 pp.

Olesen, J. E., Trnka, M., Kersebaum, K.C., Skjelvåg, A.O., Seguin, B., Peltonen-Sainio, P., Rossi, F., Kozyra, J., Micale, F., 2011. Impacts and adaptation of European crop production systems to climate change. European Journal of Agronomy 34(2), 96–112.

Peltonen-Sainio, P., Jauhiainen, L., Trnka, M., Olesen, J.E., Calanca, P., Eckersten, H., Eitzinger, J., Gobin, A., Kersebaum, K.C., Kozyra, J., Kumar, S., Marta, A.D., Micale, F., Schaap, B., Seguin, B., Skjelvåg, A.O., Orlandini, S., 2010. Coincidence of variation in yield and climate in Europe. Agriculture, Ecosystems & Environment 139(4), 483–489.

Reidsma, P., Ewert, F.A., Lansink, A.O., Leemans, R., 2010. Adaptation to climate change and climate variability in European agriculture. The importance of farm level responses. European Journal of Agronomy 32(1), 91–102.

Smith, P., Olesen, J.E., 2010. Synergies between mitigation of, and adaptation to, climate change in agriculture. Journal of Agricultural Science 18, 543–552.

Soussana, J.F., Fereres, E., Long, S.P., Mohren, F.G., Pandya-Lorch, R., Peltonen-Sainio, P., Porter, J.R., Rosswall, T., von Braun, J., 2012. A European science plan to sustainably increase food security under climate change. Global Change Biology 18(11), 3269–3271.

Szwed, M., Karg, G., Pińskwar, I., Radziejewski, M., Graczyk, D., Kędziora, A., Kundzewicz, Z.W., 2010. Climate change and its effect on agriculture, water resources and human health sectors in Poland. Natural Hazards Earth System Science 10, 1725–1737.

The state of food security and nutrition in the world. Building climate resilience for food security and nutrition, 2018, Food and Agriculture Organization of the United Nations, Rome; http://www.fao.org/3/I9553EN/i9553en.pdf.

Trnka, M., Eitzinger, J., Semerádová, D., Hlavinka, P., Balek, J., Dubrovský, M., Kubu, G., Štěpánek, P., Thaler, S., Možný, M., Žalud, Z., 2011. Expected changes in agroclimatic conditions in Central Europe. Climatic Change 108, 261–289.

van der Fels-Klerx, H.J., Liu, C., Battilani, P., 2016. Modelling climate change impacts on mycotoxin contamination. Special Issue. Mycotoxins in a changing world. World Mycotoxin Journal 9, 717–726.

Veenema, T.G., Thornton, C.P., Lavin, R.P., Bender, A.K., Seal, S., Corley, A., 2017. Climate change-related water disasters' impact on population health. Journal of Nursing Scholarship 49(6), 625–634.

Vermeulen, S.J., Campbell, B.M., Ingram, J.S.I., 2012. Climate change and food systems. Annual Review of Environment and Resources 37(1), 195–222.

Wang, D., Heckathorn, S.A., Wang, X., Philpott, S.M., 2011. A meta-analysis of plant physiological and growth responses to temperature and elevated CO_2. Oecologia 169(1), 1–13.