Environmental Impact of Climate Change on Crop Production

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Abstract Obvious changes in our climate system are having a strong negative impact on crop yields. Besides the fact that the temperature of the air is changing, our agricultural fields are often exposed to severe weather conditions and higher levels of CO_2 in the atmosphere. Extreme temperature and precipitation can considerably reduce crop yield. Also, in areas with high temperatures during the summer dealing with drought has become a challenge, and only in some places increased irrigation can be a solution. Various pests, weeds, and fungi thrive under warm and humid climates and enhanced CO_2 levels. This requires more investment in pesticides and creates a potential threat to public health. Also, an increase of CO_2 in the atmosphere is a threat to public health, because it also decreases the nutritional quality of most food crops. A higher concentration of carbon dioxide in the atmosphere can cause a lower content of essential minerals and proteins in wheat, rice and soybeans, and other plant species. Within this chapter, our aim is to present every aspect of the adverse effect of climate change on crop development with special emphasis on potential influence on human health. Evaluation of the influence of the climate change observed through recent studies presented that the most often result are yields decrease and yields variability increase, abundance, and distribution of pests, and nutritional value of crop grains. Furthermore, these effects have a massive influence on safe food production in both quantitative and quality approaches.

1 Introduction

The impact of climate change on safe food production can be defined in two separate routes. In the first route, the direct impact can be observed through quantity and

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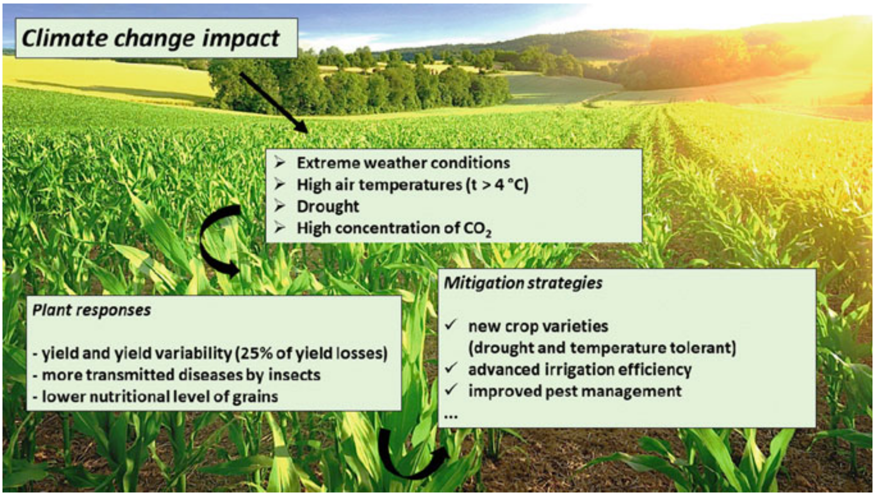
variability of yields and the indirect impact can be estimated via more occurring pests and diseases on plants. In the second route, the impact of climate change can be defined through changes in atmospheric CO_2 concentrations, which is altering the nutritional quality (Picture 1).

All of these impacts have the potential to change the quantity, quality, and safety of food for every individual worldwide (Mbow et al. 2019).

Recent studies are confirming that there is a strong connection between climate change, in terms of higher air temperature, and crop yields (Hatfield and Prueger 2015; Liu et al. 2019; Parkes et al. 2018; Jiang et al. 2018; Smith et al. 2013; Wang et al. 2016; Ray et al. 2015; Chen et al. 2004; Iizumi and Ramankutty 2016; Olesen et al. 2011; Olesen and Bindi 2002; Alcamo et al. 2007; Olesen et al. 2011; Arata et al. 2020; Luo 2011; Chen et al. 2020). The results of these studies are implying that higher temperatures can reduce crop yields and increase yields variability. In some cases, for example in northern Europe, higher air temperatures can have a positive effect (Holmer 2008).

Climate change is influencing crop production by modifying the dynamics of diseases and pests, this is reflected in alterations in the distribution and population size of pests. A major influence on the abundance and distribution of pests and their threat to global crop production has been analysed (Pareek et al. 2017; Pareek et al. 2017; Prasad and Mukhopadhyay 2013; Saren et al. 2015; Roy et al. 2019; Sharma 2010). One of the side effects is an alteration in the effectiveness of pest management control, hence frequent treatment with pesticides will be needed and some of the commonly used pesticides have a negative effect on human health (Agostini et al. 2020; Sabarwal et al. 2018; Kumar et al. 2014; Roy et al. 2009; Kabir et al. 2018; Niehoff et al. 2016; Paul et al. 2016; Parrón et al. 2014; Fareed et al. 2013).



Picture 1 The impact of climate change on crop production

High concentrations of atmospheric CO_2 are prone to have a direct impact on physiology, development, and nutritional composition in plants because plants are photosynthetic organisms. The positive effect of increased photosynthesis is enhanced growth, however, the negative effect is the decrease of the crop nutritional value in the term of mineral content in the grains (Mcgrath and Lobell 2013; Leisner 2020; Loladze 2014; Medek et al. 2017; Bisbis et al. 2018; Hogy and Fangmeier 2009; La Puente et al. 2000; Myers et al. 2014; Dietterich et al. 2015; Högy et al. 2010), also decreased of protein content has been observed (Medek et al. 2017; Leisner 2020; Taub et al. 2008; Abebe et al. 2016; Hogy and Fangmeier 2009; Fernando et al. 2012).

The agricultural practice contributes to climate change, every stage of food production releases significant quantities of greenhouse gases into the environment. It is estimated that agriculture releases 10% of the European Union's total greenhouse-gas emissions in 2012. One of the main objects of the new policy Agenda 2020 for the EU is to lower the negative environmental impact of EU farming (Vlontzos and Pardalos 2017).

The purpose of this chapter is to present these aspects of the negative effect of climate change on crop production and the potential influence on public health.

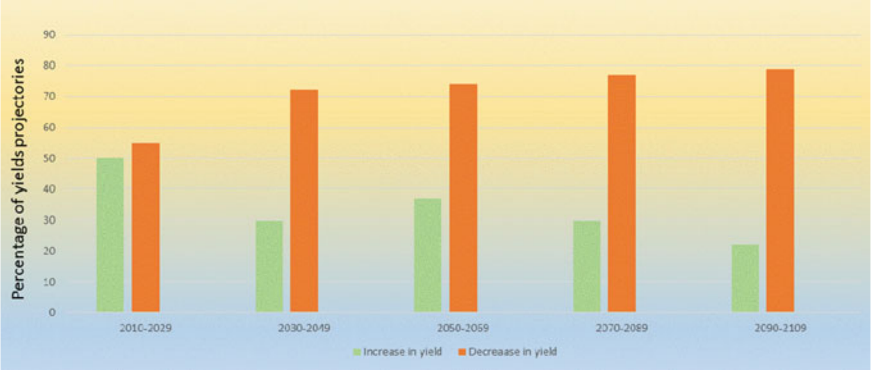
2 High Temperatures Altering Crop Yields

For each crop and every part of the growth development, a different range of temperatures can be determined. The outcome of enhanced temperature will depend on the optimal crop temperature for germination and reproduction.

The impact of global warming is certainly evident in crop production, yield responses to higher temperatures differ among different species depending on their optimum temperature for growth and development (Hatfield and Prueger 2015).

Scientific researches are indicated, with high confidence that global temperature will increase for more than 4 °C during the twenty-first century (IPCC 2014). The changes in the global temperature concurrently with water scarcity and severe weather conditions have a negative impact on every aspect of food safety. Also, the projected impacts are showing 25% of yield losses (Picture 2) compared to the end of the twentieth century (IPCC 2014).

Evaluation of the impact of global warming by 2 °C on wheat production presented that average yield on a global scale will be changed from − 2.4% to 10.5%, related to wheat production from the period of 1980–2010 (Liu et al. 2019). Following this information, we can observe a positive impact of climate change on annual yield, but this projection also suggested that extremely low yields will be frequent in regions with a warm climate and low precipitation, including India, which produces more than 14% of the wheat in the world (FAO 2014). A similar study was conducted in West Africa for maize, sorghum, and millet with the same predictions and conclusions (Parkes et al. 2018).



Picture 2 Review of forecasted changes in crop yields (wheat, maize, rice, and soy) due to climate change over the twenty-first century (IPCC 2014)

Assessment of climate change impact on the production of corn and soybean in Canada implied that higher temperatures would significantly reduce the yield of corn by 27% with just 4% reduce in soybean yield (Jiang et al. 2018). Additional studies with projected climate situations in Canada (Smith et al. 2013) and USA (Wang et al. 2016) observed that corn yields enhanced when cultivars with higher GGD (growing degree day) were planted.

The study of the influence of climate variation on wheat, maize, rice, and soybean crops yield on a global scale defined that nearly 32–39% of the changes in yield can be defined by climate variations (Ray et al. 2015).

A similar study was developed for major crops in the U.S. and the results showed that effects are differed by crop, for example, higher temperatures are reducing sorghum yields and yields variability and corn yields, but also increasing corn yield variability (Chen et al. 2004).

Global analysis of yield variability results showed that more than 21% of yield variation can be defined by climate change, these results also implied that yield worldwide has become unstable (Iizumi and Ramankutty 2016).

Higher air temperatures can also have a positive effect, in northern Europe yields are limited by low temperatures (Holmer 2008). A small increase in yield is apparent in the last 20 years in Finland, however, in Greece, the yields are decreasing (Olesen et al. 2011). Increases in the crop yield in Europe are expected in the northern region, but the significant decreases are expected in the Mediterranean and the south-western Balkans, especially for maize, soybean, and sunflower (Olesen and Bindi 2002; Alcamo et al. 2007).

It is obvious that crop production in Europe is affected by climate change, extreme temperatures in the central and southern Europe followed by drought has an adverse impact on crop yield and yield variability (Olesen et al. 2011).

Agriculture, food security, and policies are considerably affected by changes in crop yields and yield variability. Changes in climate and agricultural practices are mainly accountable for the increase in yield variability (Arata et al. 2020).

Acknowledging these studies it appears that there is an essential need to identify temperature optimum to estimate the effect of higher temperatures on crop production. Experimental studies, in the open field as well as under controlled conditions, can provide necessary information for more precise identification of higher temperature effects on crop production in every region (Luo 2011). For example, the productions of rice in China can be reduced by 13,5% due to climate change impact and higher air temperatures, but with changes in agricultural practices and policies these negative impacts could be partially avoided (Chen et al. 2020).

3 Impacts on Pest Management

The higher existence of pests and diseases is more pronounced while the temperature is increasing in the cooler zones, this effect is enabling insects to achieve more reproductive cycles (Bale et al. 2002). Climate change will enhance the development of diseases, weed and other pests accommodated to a warmer climate (Baker et al. 2000).

Climate change has a major influence on the abundance and pests distribution, therefore it poses a large threat to global agricultural production. Higher temperatures can likely raise levels of growth and potentially add one generation per year. This could influence the crop yield and change the effectiveness of pest management control, hence frequent application of insecticides will be needed (Pareek et al. 2017).

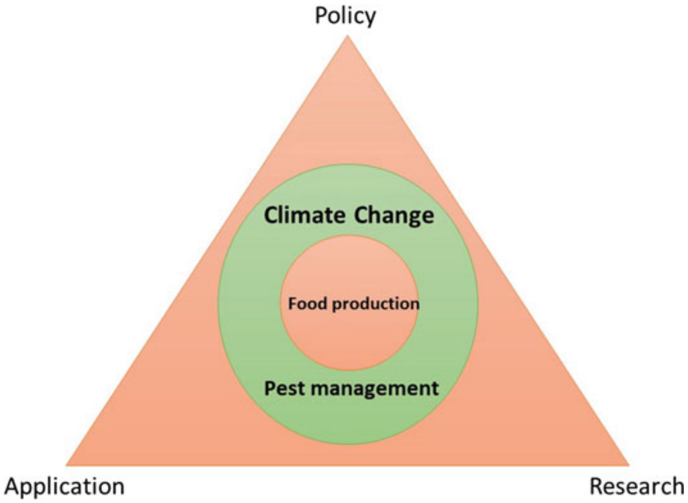
Some of the major impact of climate change on pests are also: different geographical distribution; more population of insects during winter; adjustment to other host plants; less resistance by host plants; different abundance of natural enemies; higher risk of invasive species of pests; the occurrence of more transmitted diseases by insects (Pareek et al. 2017).

Studies of the influence of climate change on tea insects indicate that their life cycle is shorter than expected (Prasad and Mukhopadhyay 2013; Saren et al. 2015), this has a positive effect on the population and causes more damage to crops.

With temperature rise, insects can reproduce more rapidly with the longer breeding season, this phenomenon leads to alteration in nutritional quality in plants, for example, more insects feed on plants so C:N ratio gets modified (Roy et al. 2019).

These impacts will have a significant effect on crop protection and safe food production. As a biological response to higher temperatures, all aforementioned effects will spread through all regions and influence all crops. It is necessary, through multidisciplinary cooperation (Picture 3), to achieve the monitoring of insect population and their adaptation, and to include effects of climate change in the development of improved pest management (Sharma 2010).

Despite the existence of numerous effects of climate change on growth, distribution, and development of pests there is a lack of cross-collaboration between climate and pest management scientists and this leads to limited knowledge exchange between scientists (Young et al. 2019).



Picture 3 Need for multidisciplinary cooperation (Young et al. 2019)

The use of pesticides for control of pests and disease and crop protection is inevitable in agriculture, however, pesticides are posing a threat to the environment and public health. For instance, it has been observed that the use of pesticides is causing in protected areas a severe decrease in the number of insects (Hallmann et al. 2017). Additionally, some of the frequently used pesticides have an accumulative negative effect on human health (Agostini et al. 2020).

It is estimated that pesticide poisoning accounts for 300,000 deaths in a year on a global scale (Sabarwal et al. 2018). Various health disorders are linked with exposure to pesticides, such as childhood leukemia (Kumar et al. 2014), prostate cancer (Roy et al. 2009; Kabir et al. 2018), breast cancer (Niehoff et al. 2016), Parkinson's disease (Paul et al. 2016), Alzheimer's disease and multiple sclerosis (Parrón et al. 2014), Respiratory disorders (Fareed et al. 2013).

4 Impact of High CO_2 Concentration on Grain Quality

Plants are photosynthetic organisms, therefore elevated concentrations of atmospheric CO_2 are prone to have a direct impact on physiology, development, and nutritional composition in plants (Ziska 2008).

Higher concentrations of CO_2 have a stimulating consequence on plant growth because of increased photosynthesis (Müller et al. 2014). However, another effect is the reduction of the crops nutritional value in the term of mineral content in the seeds (Mcgrath and Lobell 2013; Leisner 2020).

Research on this effect, elevated atmospheric CO_2, on wheat and rice indicated a decrease in total mineral content by 8% (Loladze 2014), and protein, Fe and Zn decreased by 3–17% (Medek et al. 2017; Leisner 2020).

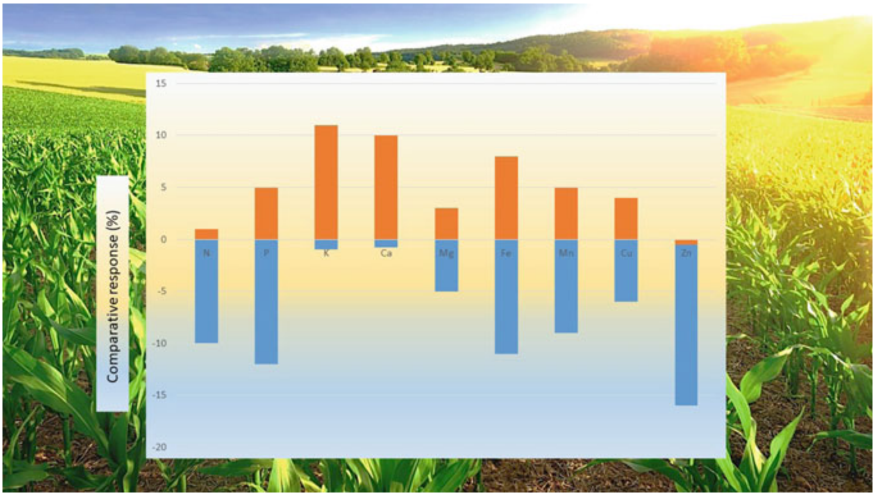
A similar study observed a decrease in protein content in wheat, rice, and barley by 10–15%, in potato by 14%, and soybean by 1.4% (Taub et al. 2008). Another study with a similar experimental design showed a decrease in protein content in maize (11%) (Abebe et al. 2016).

Several studies including leafy vegetables on increased CO_2 influence indicate higher content of sugars and vitamin C in edible parts of plants, while nutrients content decreased (Bisbis et al. 2018).

The study of the effects of elevated CO_2 concentrations on the chemical content of potato tube showed increased content of glucose and fructose by 22% and 21% respectively, and decreased levels of proteins, potassium, and calcium (Hogy and Fangmeier 2009). Furthermore, a similar study observed lower protein content in wheat (13.4–15.3%) (Fernando et al. 2012).

Elements that are essential for our nutrition, such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), copper (Cu), magnesium (Mg), manganese (Mn), iron (Fe), zinc (Zn), and selenium (Se) (Smith et al. 2018) are found in grains. The impact of raised CO_2 concentration on grain nutrient content differs within crops. For example, under the influence of higher concentrations of CO_2 canola and wheat (Picture 4) have a lower content of N, however, this is not the case for field pea (Jin et al. 2019).

Previous studies of this impact on wheat reported a reduction in the content of Fe and Zn in the grains (La Puente et al. 2000). More recent studies observed a reduction



Picture 4 Effect of elevated concentration of atmospheric CO_2 on nutrient content in crop grain (Jin et al. 2019)

in nutrients content such as Ca, N, Fe, and Zn in the grains of soybean, sorghum, potatoes, wheat, and barley (Myers et al. 2014; Dietterich et al. 2015).

Spring wheat tested under a high concentration of CO_2 revealed a reduction in Ca, Mg, and Mn by 9.7%, 4.2%, and 4.9% respectively (Högy et al. 2010). The same experiment showed an increase in K by 3.9%, P by 1.1%, and Fe by 1.2%.

According to Högy et al. decrease in macroelements is uniform for all wheat cultivar. Also, under experiment conditions with elevated CO_2 concentration microelements content is decreasing from 3.7 to 18.3% (Senghor et al. 2017).

The higher concentration of atmospheric CO_2 can cause more dietary deficiencies and create a global problem for public health. For example, the content of zinc in significant food crops can be lower, which is prompting dietary deficiency of zinc, on a global scale 2 billion people suffer this deficiency (Myers et al. 2014).

Nutrient deficiencies are more often in less-developed countries particularly concerning micronutrients (Schmidhuber et al. 2018), and the occurrence of anemia will increase since more people will suffer from protein and zinc deficiency (Smith and Myers 2018).

One of the many Sustainable Development Goals by the United Nations General Assembly (2015) is to enhance nutrition and limit all models of malnutrition by 2030 (Wu et al. 2020).

A study on a dietary nutrient deficiency of the population in China prognosticated decreases for both male and female intake of protein, zinc, and iron, as an outcome, the nutrient insufficiency would progress by 1.35–4.42% (Wu et al. 2020).

Other similar studies determined that the average change for the Chinese population in protein intake would be −4.91% (Medek et al. 2017), the iron intake will decrease by 3.8% (Smith et al. 2017), and zinc deficit will enhance by 0.6% (Myers et al. 2015).

The global prognosis is that the average profits of economic growth are higher than the adverse climate change impacts on macronutrient quantities, proteins included, though this prediction doesn't apply to micronutrients (Nelson et al. 2018).

The reduction of CO_2 emissions is a major challenge, hence it is needed to prevent degradation in crop nutrient quality (Wu et al. 2019).

5 Mitigation Strategies in Combating Climate Change Effects

Extreme temperatures followed by drought are showing a negative impact on crop yield and yield variability. Further, this negative impact is leading to increased irrigation, cultivation costs, and negative variations in soil and water quality (Dai et al. 2020; Gomez-Zavaglia et al. 2020). To achieve sustainable agriculture, and to reduce this adverse impact on crop yield, the best option is to breed crop varieties that are drought and temperature tolerant. With this approach, we can improve irrigation efficiency and achieve sustainable use of water for irrigation (Sofi et al. 2019).

Climate change has a significant impact on the effectiveness of pest management control, and on food safety, due to the frequent application of insecticides is needed. FAO advises the use of two simultaneous strategies with actions taken on both, global and local scale, this includes improvement of the system for control and detection, breeding of diseases and pest-resistant crop varieties, and implementing the integrated pest management systems (Sharma 2010). Additionally, a sustainable option is to adjust agricultural systems to enhance the activity of specific cultivation natural enemies and to explore the possibility to use biopesticides or natural essential oils as pesticides (Gomez-Zavaglia et al. 2020).

The essential part of mitigation strategies is the development of integrated monitoring in both sectors, environment, and food, to achieve the early identification of possible problems. Such systems can produce valuable data that can be easily shared on a national and international level and used to improve risk assessment. Adequate control tests are necessary at each step within food chain production to ensure food safety (Zwietering et al. 2010).

The government should provide policies and investment strategies to support education, demonstration training, and to raise awareness about climate change adjustment strategies, especially for smallholder farmers (Thinda et al. 2020).

Mitigation strategies have great success in developed countries, and adaptation options to fight against climate change are very similar on a global level. However, in developing countries, strategies that provide irrigation efficiency or improve crop management are limited.

6 Conclusion

Climate variability has a major influence on crop production, as temperature and CO_2 are increasing quality and the quantity of crop production is decreasing. Evaluation of the impact of the global warming observed through recent studies presented that the most often result are yields decrease and yields variability increase.

Crop production is also very vulnerable to variation in the distribution and abundance of pests. One generation of insects per year as a result of higher temperatures are influencing crop yield and requiring a frequent application of insecticides. The more frequent use of insecticides has a strong negative effect on the environment and public health, hence different health complications are linked with exposure to pesticides. Understanding that the use of pesticides is inevitable in crop production it is essential to achieve multidisciplinary cooperation to implement the effects of climate change in the development of improved pest management.

The aforementioned studies observed that higher levels of CO_2 in the atmosphere are affecting the nutritional value of crop grains. This impact has an important influence on safe food production, more dietary deficiencies are a potentially public health issue on a global scale.

Analysed three influences are among the most significant. Furthermore, there are impacts that we have not addressed, for example, soil microbe interaction under climate change and extreme weather conditions that can reduce access to food and price increases of a particular product. Additionally, it is crucial to analyse the sociological aspect and national security in the event of food deficiencies.

References

Abebe A, Pathak H, Singh SD, Bhatia A, Harit RC, Kumar V (2016) Growth, yield and quality of maize with elevated atmospheric carbon dioxide and temperature in north–west India. Agr Ecosyst Environ 218:66–72

Agostini LP, Dettogni RS, Dos Reis RS, Stur E, Dos Santos EV, Ventorim DP, Louro ID (2020) Effects of glyphosate exposure on human health: insights from epidemiological and in vitro studies. Sci Total Environ 705:135808

Alcamo J, Moreno JM, Nováky B, Bindi M, Corobov R, Devoy RJN, Giannakopoulos C, Martin E, Olesen JE, Shvidenko A (2007) Europe. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK, pp 541–580

Arata L, Sckokai P, Fabrizi E (2020) A worldwide analysis of trend in crop yields and yield variability: evidence from FAO data. Econ Model. https://doi.org/10.1016/j.econmod.2020.05.006

Baker RHA, Sansford CE, Jarvis CH, Cannon RJC, MacLeod A, Walters KFA (2000) The role of climatic mapping in predicting the potential distribution of non-indigenous pests under current and future climates. Agric, Ecosyst Environ 82:57–71

Bale JS, Masters GJ, Hodkinson ID, Awmack C, Bezemer TM, Brown VK, Butterfield J, Buse A, Coulson JC, Farrar J, Good JEG, Harrington R, Harley S, Jones TH, Lindroth RL, Press MC, Symrnioudis I, Watt AD, Whittaker JB (2002) Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. Glob Change Biol 8:1–16

Bisbis MB, Gruda N, Blanke M (2018) Potential impacts of climate change on vegetable production and product quality—a review. J Clean Prod 170:1602–1620. https://doi.org/10.1016/j.jclepro.2017.09.224

Chen CC, McCarl BA, Schimmelpfennig DE (2004) Yield variability as influenced by climate: a statistical investigation. Clim Change 66(1–2):239–261

Chen C, van Groenigen KJ, Yang H, Hungate BA, Yang B, Tian Y, Chen J, Dong W, Huang S, Deng A, Jiang Y, Zhang W (2020) Global warming and shifts in cropping systems together reduce China's rice production. Glob Food Secur 24:100359

Dai C, Qin XS, Lu WT, Huang Y (2020) Assessing adaptation measures on agricultural water productivity under climate change: a case study of Huai River Basin,China. Sci Total Environ 721, art. no. 137777. https://doi.org/10.1016/j.sci-totenv.2020.137777

Dietterich LH, Zanobetti A, Kloog I, Hybers P, Leakey ADB, Bloom AJ, Carlisle E, Fernando N, Fitzgerald G, Hasegawa T, Holbrook NM, Nelson RL, Norton R, Ottman MJ, Raboy V, Sakai H, Sartor KA, Schwartz J, Seneweera S, Usui Y, Yoshinaga S, Myers SS (2015) Impacts of elevated atmospheric CO_2 on nutrient content of important food crops. Sci Data 2:150036

FAO (2014) Asian wheat producing countries-Uzbekistan-Central Zone, http://www.fao.org/ag/agp/agpc/doc/field/Wheat/asia/Uzbekistan/agroeco_central.htm

Fareed M, Pathak MK, Bihari V, Kamal R, Srivastava AK, Kesavachandran CN (2013) Adverse respiratory health and hematological alterations among agricultural workers occupationally exposed to organophosphate pesticides: a cross-sectional study in North India PLoS One 8(7):e69755

Fernando N, Panozzo J, Tausz M, Norton RM, Fitzgerald GJ, Seneweera S (2012) Rising atmospheric CO_2 concentration affects mineral nutrient and protein concentration of wheat grain. Food Chem 133:1307–1311

Gomez-Zavaglia A, Mejuto JC, Simal-Gandara J (2020) Mitigation of emerging implications of climate change on food production systems. Food Res Int, 109256

Hallmann CA, Sorg M, Jongejans E, Siepel H, Hofland N, Schwan H (2017) More than 75 percent decline over 27 years in total flying insect biomass in protected areas. PLoS One 12:e0185809

Hatfield JL, Prueger JH (2015) Temperature extremes: effect on plant growth and development. Weather Clim Extrem 10, Part A:4–10

Hogy P, Fangmeier A (2009) Atmospheric CO_2 enrichment affects potatoes: 2 tuber quality traits. Eur J Agron 30:8594

Högy P, Keck M, Niehaus K, Franzaring J, Fangmeier A (2010) Effects of atmospheric CO_2 enrichment on biomass, yield and low molecular weight metabolites in wheat grain. J Cereal Sci 52(2):215–220

Holmer B (2008) Fluctuations of winter wheat yields in relation to length of winter in Sweden 1866 to 2006. Climate Res 36:241–252

Iizumi T, Ramankutty N (2016) Changes in yield variability of major crops for 1981–2010 explained by climate change. Environ Res Lett 11(3):034003

IPCC (2014) Fifth assessment report. http://www.ipcc.ch/report/ar5/wg1/#.Um-xf_mcfTp

Jiang Q, Qi Z, Xue L (2018) Assessing climate change impacts on greenhouse gas emissions, N losses in drainage and crop production in a subsurface drained field. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2019.135969

Jin J, Armstrong R, Tang C (2019) Impact of elevated CO_2 on grain nutrient concentration varies with crops and soils–a long-term FACE study. Sci Total Environ 651:2641–2647

Kabir A, Zendehdel R, Tayefeh-Rahimian R (2018) Dioxin exposure in the manufacture of pesticide production as a risk factor for death from prostate cancer: a meta-analysis. Iran J Public Health 47(2):148

Kumar A, Vashist M, Rathee R (2014) Maternal factors and risk of childhood leukemia. Asian Pac J Cancer Prev 15(2):781–784

Leisner CP (2020) Review: climate change impacts on food security focus on perennial cropping systems and nutritional value. Plant Sci. https://doi.org/10.1016/j.plantsci.2020.110412

Liu B, Martre P, Ewert F, Porter JR, Challinor AJ, Müller C, Ruane AC, Waha K, Thorburn PJ, Aggarwal PK, Ahmed M (2019). Global wheat production with 1.5 and 2.0 °C above pre-industrial warming. Glob Chang Biol 25(4):1428–1444. https://doi.org/10.1111/gcb.14542

Loladze I (2014) Hidden shift of the ionome of plants exposed to elevated CO_2 depletes minerals at the base of human nutrition. Elife 3:e02245. https://doi.org/10.7554/eLife.02245

Luo Q (2011) Temperature thresholds and crop production: a review. Clim Change 109:583–598. https://doi.org/10.1007/s10584-011-0028-6

Mbow C, Rosenzweig C, Barioni LG, Benton TG, Herrero M, Krishnapillai M, Liwenga E, Pradhan P, Rivera-Ferre MG, Sapkota T, Tubiello FN, Xu Y (2019) Food Security. In: Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [Shukla PR, Skea J, Calvo Buendia E, Masson-Delmotte V, Pörtner H-O, Roberts DC, Zhai P, Slade R, Connors S, van Diemen R, Ferrat M, Haughey E, Luz S, Neogi S, Pathak M, Petzold J, Portugal Pereira J, Vyas P, Huntley E, Kissick K, Belkacemi M, Malley J (eds)]. In press

Mcgrath JM, Lobell DB (2013) Reduction of transpiration and altered nutrient allocation contribute to nutrient decline of crops grown in elevated CO_2 concentrations: nutrient decline mechanisms in CO_2. Plant, Cell Environ 36:697–705. https://doi.org/10.1111/pce.12007

Medek DE, Schwartz J, Myers SS (2017) Estimated effects of future atmospheric CO_2 concentrations on protein intake and the risk of protein deficiency by country and region Environ Health Perspect 125. https://doi.org/10.1289/EHP41

Müller C, Elliott J, Levermann A (2014) Fertilizing hidden hunger. Nat Clim Chang 4:540–541. https://doi.org/10.1038/nclimate2290

Myers SS, Wessells KR, Kloog I, Zanobetti A, Schwartz J (2015) Effect of increased concentrations of atmospheric carbon dioxide on the global threat of zinc deficiency: a modelling study. Lancet Glob Health 3:e639–e645. https://doi.org/10.1016/S2214-109X(15)00093-5

Myers SS, Zanobetti A, Kloog I, Huybers P, Leakey ADB, Bloom A, Carlisle E, Dietterich LH, Fitzgerald G, Hasegawa T, Holbrook NM, Nelson RL, Ottman MJ, Raboy V, Sakai H, Sartor KA, Schwartz J, Seneweera S, Tausz M, Usui Y (2014) Rising concentration of atmospheric CO_2 threatens human nutrition. Nature 510(7503):139–142

Nelson G, Bogard J, Lividini K, Arsenault J, Riley M, Sulser TB, Mason-D'Croz D, Power D, Gustafson D, Herrero M, Wiebe K, Cooper K, Remans R, Rosegrant M (2018) Income growth and climate change effects on global nutrition security to mid-century. Nat Sustain 1:773. https://doi.org/10.1038/s41893-018-0192-z

Niehoff NM, Nichols HB, White AJ, Parks CG, D'Aloisio AA, Sandler DP (2016) Childhood and adolescent pesticide exposure and breast cancer risk. Epidemiology (Cambridge, Mass.) 27(3):326

Olesen JE, Bindi M (2002) Consequences of climate change for European agricultural productivity, land use and policy. Eur J Agron 16:239–262

Olesen JE, Trnka M, Kersebaum KC, Skjelvag AO, Seguin B, Peltonen-Saino P, Rossi F, Kozyra J, Micale F (2011) Impacts and adaptation of European crop production systems to climate change. Eur J Agron 34:96–112

Pareek A, Meena BM, Sharma S, Tetarwal ML, Kalyan RK, Meena BL (2017) Impact of climate change on insect pests and their management strategies

Parkes B, Defrance D, Sultan B, Ciais P, Wang X (2018) Projected changes in crop yield mean and variability over West Africa in a world 1.5 K warmer than the pre-industrial. Earth Syst Dyn Discuss 9(1):119–134

Parrón T, Requena M, Hernández AF, Alarcón R (2014) Environmental exposure to pesticides and cancer risk in multiple human organ systems. Toxicol Lett 230(2):157–165

Paul KC, Sinsheimer JS, Rhodes SL, Cockburn M, Bronstein J, Ritz B (2016) Organophosphate pesticide exposures, nitric oxide synthase gene variants, and gene–pesticide interactions in a case–control study of Parkinson's disease, California (USA). Environ Health Perspect 124(5):570–577

Prasad AK, Mukhopadhyay A (2013) Changing Life-Cycle Pattern of a Minor Looper Pest of Tea, *Ectropis* Sp. (*Lepidoptera: Geometridae*) in Summer and Winter Seasons of Darjeeling Terai North Bengal University. J Anim Sci 7:31–34

Puente la de LS, Pérez PP, Martínez-Carrasco R, Morcuende RM, del Molino IMM (2000) Action of elevated CO2 and high temperatures on the mineral chemical composition of two varieties of wheat. Agrochimica 44:221–230

Ray D, Gerber JS, MacDonald GK, West PC (2015) Climate variation explains a third of global crop yield variability. Nat Commun 6:5989

Roy S, Barooah AK, Ahmed KZ (2019) Impact of climate change on tea pest status in northeast India and effective plans for mitigation. Acta Ecol Sin. https://doi.org/10.1016/j.chnaes.2019.08.003

Roy S, Gu M, Ramasamy K, Singh RP, Agarwal C, Siriwardana S, Agarwal R (2009) p21/Cip1 and p27/Kip1 are essential molecular targets of inositol hexaphosphate for its antitumor efficacy against prostate cancer. Can Res 69(3):1166–1173

Sabarwal A, Agarwal R, Singh RP (2017) Fisetin inhibits cellular proliferation and induces mitochondria-dependent apoptosis in human gastric cancer cells. Mol Carcinog 56(2):499–514

Sabarwal A, Kumar K, Singh RP (2018) Hazardous effects of chemical pesticides on human health–cancer and other associated disorders. Environ Toxicol Pharmacol 63:103–114

Saren J, Das S, Mukhopadhyay A (2015) Temperature- dependent development of red spider mite, *Oligonychus coffeae* (Acari: Tetranychidae) using degree-day model. J Appl Biosci 41(2):163–167

Schmidhuber J, Sur P, Fay K, Huntley B, Salama J, Lee A, Cornaby L, Horino M, Murray C, Afshin A (2018) The Global Nutrient Database: availability of macronutrients and micronutrients in 195 countries from 1980 to 2013. Lancet Planet Health 2:e353–e368. https://doi.org/10.1016/S2542-5196(18)30170-0

Senghor A, Dioh RMN, Müller C, Youm I (2017) Cereal crops for biogas production: a review of possible impact of elevated CO_2. Renew Sustain Energy Rev 71:548–554

Sharma HC (2010) Effect of climate change on IPM in grain legumes. In: Fifth international food legumes research conference (IFLRC V), and the seventh european conference on grain legumes (AEP VII), 26ñ30 April2010, Anatalaya, Turkey

Smith MR, Myers SS (2018) Impact of anthropogenic CO_2 emissions on global human nutrition. Nat Clim Change 8(9):834–839

Smith EG, Janzen HH, Ellert BH (2018) Effect of fertilizer and cropping system on grain nutrient concentrations in spring wheat. Can J Plant Sci 98:125–131

Smith MR, Golden CD, Myers SS (2017) Potential rise in iron deficiency due to future anthropogenic carbon dioxide emissions. GeoHealth 1:248–257. https://doi.org/10.1002/2016GH000018

Smith WN, Grant BB, Desjardins RL, Kroebel R, Li C, Qian B, Worth DE, McConkey BG, Drury CF (2013) Assessing the effects of climate change on crop production and GHG emissions in Canada. Agric, Ecosyst Environ 179:139–150. https://doi.org/10.1016/j.agee.2013.08.015

Sofi PA, Ara A, Gull M, Rehman K (2019) Canopy temperature depression as an effective physiological trait for drought screening. In: Drought-detection and solutions. IntechOpen

Taub DR, Miller B, Allen H (2008) Effects of elevated CO_2 on the protein concentration of food crops: a meta-analysis. Glob Change Biol 14(3):565–575

Thinda KT, Ogundeji AA, Belle JA, Ojo TO (2020) Understanding the adoption of climate change adaptation strategies among smallholder farmers: evidence from land reform beneficiaries in South Africa. Land Use Policy 99:104858

United Nations General Assembly (2015) Resolution adopted by the General Assembly on 11 September 2015. A/RES/69/315 15 September 2015. New York

Vlontzos G, Pardalos PM (2017) Assess and prognosticate green house gas emissions from agricultural production of EU countries, by implementing, DEA Window analysis and artificial neural networks. Renew Sustain Energy Rev 76:155–162

Wang ZZ, Qi ZM, Xue LL, Bukovsky M (2016) RZWQM2 simulated management practices to mitigate climate change impacts on nitrogen losses and corn production. Environ Model Softw 84:99–111. https://doi.org/10.1016/j.envsoft.2016.06.016

Wu W, Hasegawa T, Ohashi H, Hanasaki N, Liu J, Matsui T, Fujimori S, Masui T, Takahashi K (2019) Global advanced bioenergy potential under environmental protection policies and societal transformation measures. GCB Bioenergy 11(9):1041–1055. https://doi.org/10.1111/gcbb.12614

Wu W, Takahashi K, Zhou L, Jin S (2020) Income inequality and the distributional effects of elevated carbon dioxide on dietary nutrient deficiency. J Clean Prod, 121606

Young SL, Goldowsky-Dill NW, Muhammad J, Epstein MM (2019) Connecting experts in the agricultural and meteorological sciences to advance knowledge of pest management in a changing climate. Sci Total Environ 673:694–698

Ziska LH (2008) Rising atmospheric carbon dioxide and plant biology: the overlooked paradigm. In: Kleinman DL, Cloud-Hansen KA et al (eds) Controversies in science and technology, from climate to chromosomes. New Rochele, Liebert, Inc., pp 379–400

Zwietering MH, Stewart CM, Whiting RC (2010) Validation of control measures in a food chain using the FSO concept. Food Control 21(12):1716–1722