CLIMATE CHANGE ADAPTATION MEASURES IN AGRICULTURE

Michaela ROLINCOVA

Institute of Economic Policy and Finance, Faculty of Economics and Management, Slovak University of Agriculture in Nitra, Slovakia

Miroslava RAJCANIOVA

Institute of Economic Policy and Finance, Faculty of Economics and Management, Slovak University of Agriculture in Nitra, Slovakia

Received: 16. April 2022   Reviewed: 29. May 2022   Accepted: 06. June 2022

Abstract

This paper aims to investigate the impact of changing climate on agricultural production and to provide an overview of possible adaptation measures to cope with changing climate. To estimate the impact of climate indicators on wheat yields the multivariate regression model was used and to describe the ways of adaptation to changed climate, information obtained through a guided interview with the representatives of an agricultural farm operating in Slovakia was analysed. All data represent the Levice District in Slovakia, covering the period between 1997 and2019. Our analysis revealed that climate change indeed has a significant impact on agricultural production. The highest positive impact on yield is attributed to the average maximum temperature, while the inverse effect was observed in the case of the average minimum temperature. On the other hand, the impact of wind did not prove to be significant.

Keywords: *climate change, time series analysis, adaptation measures*

JEL Classification: O13, Q54, Q57

Introduction and theoretical background

Our climate is constantly evolving and undergoing many changes. These changes result in the loss of diversity, the extinction of various plant and animal species, population migration, significant changes in the earth's surface and in ocean circulation (Wolff et al., 2020). Climate changes are caused by several factors, including natural processes as well as increasingly frequent human activities (Singh, 2021). Even if no human activities affected the climate, natural processes would continue to cause natural climate variability, weather changes and the occurrence of climatic extremes

(Seneviratne, 2012). However, it is not natural processes alone that cause the high rate of warming that has occurred since the 1950s (Stocker et al., 2013). Global warming caused by human activities mainly results from greenhouse gas emissions, from the use of fossil fuels, deforestation and land use changes (US Global Change Research Programme, 2018). In Slovakia, over the last 100 years, we have seen a gradual increase in the average annual air temperature by 1.1 degrees Celsius and a decrease in the annual total of atmospheric precipitation by an average of 5.6%. Regionally, these changes are not distributed evenly: while e.g. in the south of Slovakia, atmospheric precipitation decreased by about 10%, in the north and northeast only by 5%. In addition, humidity has also dropped significantly, by up to 5%, and the amount of snowfall has decreased in almost the entire territory of Slovakia (Slovak Hydrometeorological Institute, 2021).

Agriculture and climate change

Climate change is very closely related to agricultural production. One of the main factors by which agriculture affects climate change is the emission of greenhouse gases, such as methane and nitrous oxide. EU agriculture contributed between 8.3% and 10.1% of all greenhouse gas emissions between 2008 and 2019. The share of Slovak agriculture in greenhouse gas emissions was slightly lower and ranged between 5.3% in 2008 and 6.9% in 2019 (Eurostat, 2021). Another factor is that agriculture, as a production sector, requires the largest amount of water and also produces a large amount of wastewater from crop and animal production (Wreford, Moran and Adger, 2010). Its contribution to soil erosion and the imbalance of nitrogen and phosphorus in the soil is also a problem (Lu and Tian, 2017). Phosphorus and nitrogen that enter the soil through fertilization are removed from the soil during crop harvesting, residue removal, and runoff (Lu and Tian, 2017). An imbalance in the amount of phosphorus and nitrogen in the soil can cause the degradation of soil fertility and erosion in the case of their deficiency, while in the case of an excess, pollution of surface and of underground waters (including drinking water) and eutrophication can occur (Enviroportál, 2021).

However, the relationship between climate and agriculture is not only one-sided. Climate change also has a significant impact on the productivity and profitability of agricultural production through changing precipitation, temperatures, soil changes and water reserves (Yohannes, 2016). Higher concentrations of CO2 in the atmosphere, higher average annual air temperature, changes in the annual course and timing of precipitation and the frequency of extreme climatic events all affect water resources, soil, pests and diseases. This has a consequent impact on the quality, quantity and stability of agricultural production (Arora, 2019). An increase in average air temperature can have a positive effect on extending the growing season in areas where cold springs and autumns used to prevail. On the other hand, it can also negatively affect the cultivation of crops that are already threatened by the summer heat, since it will limit their production, increase the intensity of soil evaporation and bring severe droughts. Pests and thermophilic weeds may also increase (Hatfield and Prueger, 2015). The situation is the same with the supply of water. Higher atmospheric precipitation can have a positive effect on crop growth in one area, but it can also create drought zones and increase the risk of erosion elsewhere. In addition, soil absorbs CO2 from the atmosphere (carbon sequestration) and mitigates global warming, but increased temperatures can, in turn, promote biomass decomposition, increasing CO2, nitrous oxide and methane emissions (Hoegh-Guldberg et al., 2018).

As can be seen from the previous discussion, the effects of climate change on agriculture can be both positive and negative. The positive effects of climate change on Slovakia's agriculture include: increased plant photosynthesis and biomass growth, an increase in CO2 concentration also has an effect on increasing the production of some crops depending on the amount of water (Takáč, Šiška and Nováková, 2011); transfer of growing areas to the north of Slovakia (Ministry of Environment of the Slovak Republic, 2018); new possibilities for growing more thermophilic crops (European Environment Agency, 2021); extension of the main growing season (European Environment Agency, 2021).

However, Slovak agriculture is also exposed to the negative effects of climate change, which include: changes in the diversity, number and places of occurrence of harmful organisms (diseases, pests, weeds); changes in the distribution and amount of precipitation and humidity; changes in the thermal security of plant production; changes in phenological conditions and agroclimatic production potential; changes in wintering conditions and absence of snow cover; changes in physical and chemical properties of soil and soil diversity; increased wind erosion; changes in crop production or loss of production of some crops due to droughts (Ministry of Environment of the Slovak Republic, 2018).

Adaptation measures

In 2018, the Ministry of the Environment of the Slovak Republic published an updated the Strategy for the Adaptation of the Slovak Republic to Climate Change, the aim of which is to "improve Slovakia's readiness to face the adverse consequences of climate change, to bring the widest possible information about the current adaptation processes in Slovakia, and based on their analysis to establish an institutional framework and coordination mechanism to facilitate the effective implementation of adaptation measures at all levels and in all areas, as well as to increase overall awareness of this issue." In this report, the ministry gave examples of adaptation measures that can be used in agriculture. They include various adaptation measures for plant protection and varietal testing, irrigation, animal production, beekeeping and pollinator protection.

Plant protection and varietal testing measures include for example: adjustment of sowing procedure; eco-friendly cultivation technologies; use of resistant varieties and use of certified propagating material; promotion of biological protection and integrated production; support of crop diversity to ensure the sustainable production and introduction of integrated management of plant protection against pests; reduction of chemicals used in agriculture; support for breeding and production of seeds suitable for changed climatic conditions; support of Slovak breeding and subsequently the creation of domestic varieties adaptable to our climatic conditions (heat-loving and drought-resistant) to achieve more stable harvests; and other. Irrigation measures include: retarding the runoff, or regulating the level of underground water to influence the water regime of the soil aeration zone; use of irrigation with an emphasis on irrigation efficiency; application of micro-irrigation technologies; multi-purpose use of reconstructed or newly built irrigation systems, securing funds for the reconstruction of irrigation systems and hydromelioration facilities; reconstruction, or modernization of built irrigation systems to systems with micro-irrigation elements; precision agriculture in irrigation system. In case of animal production the adaptation measures include for example: increasing the adaptability of farm animals; development of methods of cooling animals and housing facilities; design of stables eliminating temperature extremes of the weather; proposals for feeding during extreme temperatures; development of procedures for the rescue and handling of animals during floods and fires; analysing the consumption of technological water and drinking water for individual species, breeds and categories of animals and other. In the last category of adaptation measures related to beekeeping and pollinator protection, there is a proposal to: use system measures in monitoring the movement of bee colonies and queens; mapping of dangerous bee diseases and monitoring of chemical plant protection; use of technical facilities to eliminate the adverse consequences of climate change on bee colonies; protection of plants and landscape elements in connection with the protection of bees and other pollinators; support for the nesting of wild insect pollinators and the diversity of food sources; integrated pest control methods, investigating the consequences of climate change on food sources for bees; or monitoring the impacts of changes in brood resources on the health status of bee colonies (Ministry of Environment of the Slovak Republic, 2018).

Material and methods

The impact of climate change on agriculture is indisputable. The discussion of the aforementioned literary sources shows that the impact of climate change can manifest itself through rising temperature, changes in the frequency and strength of rainfall, and increased frequency of extreme climatic events. Empirical evidence also shows that the impact of these changes on agricultural yields in the world is highly variable. However, specifically in Slovakia the expected short-term impact could be also positive, leading to increased yields. Even though, possible negative impacts urge for the implantation of adaptation practices that would diminish their negative consequences. Using a case study of a typical agricultural farm in the Levice District in Slovakia, we aimed to examine a farmer's perception of the climate change, its impact on agriculture and the possibilities of adaptation measures. The aim of the case study was to bring the i) general views on climate change, ii) positive and negative impact of climate changes on the business, and iii) ways to mitigate or to adapt to climate change.

To assess the impact of changing climate on agricultural production, time series analysis was used to confirm either the positive or the negative impacts of climate change on agricultural yields of wheat in the area of Levice District in the period between 1997 and 2019The analysis was started by using the unit root tests to check the stationarity properties of time series. Omission of this step might lead to the choice of an improper econometric model. One of the tests used for the verification of stationarity of time series data is the Augmented Dickey-Fuller test (ADF) with the following hypothesis set:

H_0: There is a unit root in the time-series, the data series is non-stationary.
H_1: There isn't a unit root in the time-series, the data series is stationary.

The Augmented Dickey-Fuller test equation is the following:

$$\Delta Y_t = \alpha + \beta t + \gamma Y_{t-1} + \sum_{j=1}^{p} (\delta_j \, \Delta Y_{t-j}) + e_t \qquad (1)$$

Where:
Y is the observed time series, t refers to the time index, α is an intercept constant called a drift, β is the coefficient of a time trend, y is the coefficient presenting process root, i.e. the focus of testing, p states for the lag order of the first-differences autoregressive process, and e_t is an independent identically distributes residual term.

Once we are sure that the analysed times series are stationary, we can opt for a multiple linear regression model that uses several explanatory variables in order to predict the outcome of a response variable. We use the logarithmic transformation of our variables so the coefficients in the model represent the elasticity of the dependent variable in respect of independent variables.

The general formula is:

$$lny_i = \beta_0 + \beta_1 lnx_{i1} + \beta_2 lnx_{i2} + \ldots + \beta_p lnx_{ip} + \varepsilon \quad (2)$$

Where:

lny_i is the natural logarithm of the dependent variable, lnx_i represents explanatory variables expressed in natural logarithms, namely the area in hectares, average temperature and rain, wind and humidity during the growing period for the years 1997-2019, β_o is the intercept, β_p refers to the slope coefficient for each explanatory variable, and ε is the model's error term.

Table 1 Descriptive statistics

	Mean	St. dev.	Max	Min
Yield	1.523	0.192	1.852	1.109
Area	10.311	0.127	10.481	9.961
Average min. temp	2.320	0.062	2.448	2.177
Average max. temp	3.065	0.053	3.146	2.989
Av. rain	1.553	0.239	2.010	1.227
Wind	1.143	0.047	1.232	1.053
Humidity	4.197	0.059	4.327	4.067

Source: own processing

Results and discussion

The first step in our analysis is the time series stationarity test. Possible non-stationarity of the variables could lead to misspecification of the model. Therefore, we decided to test the data using the Augmented Dickey-Fuller test. The results of the unit root test are shown in Table 2. We can conclude that all variables are stationary at the 5% significance level.

Table 2 Augmented Dickey-Fuller test (in logarithms)

Variables	Test statistics	5% Critical value	Interpretation
Yield	-4.520	-3.600	I(0)
Area	-5.217	-3.600	I(0)
Av. min. temp	-4.617	-3.600	I(0)
Av. max. temp	-5.517	-3.600	I(0)
Av. rain	-4.144	-3.600	I(0)
Wind	-3.975	-3.600	I(0)
Humidity	-5.360	-3.600	I(0)

Source: own processing

ACTA OECONOMICA UNIVERSITATIS SELYE 2022, VOL. 11., NO. 1.

Based on the results of the stationarity test, it is possible to perform a regression analysis for the analysis of the impact of climate change on wheat harvest. Regression analysis will serve us to estimate the relationship between the dependent variable, in our case wheat yields, and the independent variables. The results of the regression analysis show that 58.9% of the variation in wheat yield per hectare is explained by the independent variables. The significance of F at 0.015 indicates that the model is not statistically insignificant. As can be seen from the results of the regression model, the change in the average maximum temperature has the highest positive effect on the yield. A one percent increase in average maximum temperature would increase wheat yield per hectare by 5.884%. On the other hand, the coefficient of average minimum temperature is equal to -3.515, which means that if the average minimum temperature were to increase by one percent, the wheat yield per hectare would decrease by 3.515%. It is only the effect of wind change that is statistically insignificant, as its p-value of 0.758 is higher than 0.05, so we do not reject the null hypothesis (H_0).

Table 3 Regression results

	coeff.	st. error	t stat	p-value	lower 95%	upper 95%	lower 95%	upper 95%
Intercept	-30.330	8.423	-3.601	0.002	-48.186	-12.475	-48.186	-12.475
Area	0.942	0.325	2.899	0.010	0.253	1.631	0.253	1.631
Av. min. temp	-3.515	1.501	-2.342	0.032	-6.698	-0.333	-6.698	-0.333
Av. max. temp	5.884	2.211	2.662	0.017	1.197	10.571	1.197	10.571
Av. Rain	0.457	0.193	2.364	0.031	0.047	0.867	0.047	0.867
Wind	-0.284	0.907	-0.313	0.758	-2.206	1.638	-2.206	1.638
Humidity	2.828	1.134	2.494	0.024	0.424	5.233	0.424	5.233

Source: own processing

Based on our results, we can conclude that the current impact of climate change on wheat yields per hectare is mostly positive. The effect of the increased temperature was mainly positive, as was the effect of increased humidity. However, the negative impact of insufficient rains on yields per hectare should also be mentioned. The effect of wind, which causes wind erosion, came out to be insignificant from our concrete results. In the next part of our analysis, we focused on verifying these impacts on the specific case of an agricultural farm operating in the Levice district in Slovakia. With the help of this case study, we try to show the way a farmer copes with the impact of climate change on agricultural production. The company was founded in 1993, they manage 500 hectares of agricultural land located at an altitude of 188 meters above sea level. The company primarily focuses on the cultivation of various agricultural crops, such as wheat, rapeseed, corn, and milk thistle. In addition to primary agricultural production, cultivation, processing and sale of protected plants, the farm also focuses on providing services in agriculture and horticulture, production of feed mixtures, production of mill products, rental of movable property and storage.

From the information obtained via the interview, we gained an insight into how climate change is perceived by the agricultural enterprise itself. According to them, while the amount of precipitation has not changed significantly in recent years, the distribution has changed significantly. Rainfall no longer occurs at regular intervals, but occurs at shorter intervals and is more intense. The same applies to temperatures, when the winters are not so cold, there are no significant frosts in the winter, and winters are much milder and postponed. Windy weather is more pronounced and, as a result, wind erosion causes the upper, finest, most fertile part of the soil to be blown away. Sudden rains are much more frequent and, as a result, water erosion occurs and the best soil drains away. The soil does not freeze and moisture is generally absent. There is little moisture from the snow, which used to be a problem in the past if there was insufficient snow cover. Nowadays, however, plants are bred in a way so that they adapt and do not freeze. The soil can more or less cope with the lack of winter, since it is a living material, so it can partially adapt, even if it takes longer.

Due to these changes, it was necessary to change the cultivation technology as well as operations. Fertilizers and nutrients now need to be applied more regularly so that plants can absorb them. In warmer areas and longer periods, the plants must be treated at night because they would not receive nutrition or fertilizers during the day, which would cause a lot of evaporation and cause quite large economic and ecological losses.

When we look at the yields and quality of production on the selected farm in the Levice region, the impact of climate change is so far more positive than negative, which also corresponds to the result of our previous analysis using time series. It should be remembered that this can also be due to the timely adaptation of technology and overall processing, whether it is soil or crop treatment, which helped to improve it to a higher level than it was in the past. The farm has been affected by all of the following impacts of climate change:

- increased plant photosynthesis and higher amount of biomass due to higher CO_2 concentrations in the atmosphere
- moving the production cultivation areas towards the north
- cultivation of new, more thermophilic crops
- extension of the main growing season.

However, the farm does not only face the positive effects of climate change, but also has to deal with its negative effects. One of the adverse effects is a change in the species composition, number and places of occurrence of harmful organisms (diseases, pests, weeds). Since winters are no longer as intense, but warmer, weeds are also growing, and therefore it is necessary to choose herbicide sprays that are different from those used in the past. Pests and insects survive in the soil. Although the farm was not forced to stop growing any of the crops, the agro technical terms were changed. The producer usually plants early in the spring or later in the fall. Sometimes they sow the seeds in cold soil if rainfall is expected.

Application of adaptation measures

The farm has several options to adapt to climate change. One example of adaptation in production is shifting planting dates, diversifying into other crops, using crop rotation, changing the timing or the amount of chemical inputs, or using irrigation. The analysed farm opted for crop diversity, since the same crop cannot be grown on the same plot every year, except for corn. There was no change in the individual varieties, but the farm cannot grow wheat after wheat, as there are similar pesticides used, which may not work on weeds and insects. It is also a one-way depletion of nutrients. There is also diversification between crops such as wheat, where a farm does not grow all wheat with one length of vegetation, but a part that matures earlier and another later that year. This caters for at least an average harvest.

First of all, crop rotation is important, as it is necessary to grow some spring crops as well as some winter ones. It is necessary to adapt the timing and dosage of fertilizers to this, since rainfall does not come gradually. During hot spells, fertilizers dissolved in water can be applied foliarly, reducing the amount of the fertilizer needed to only half the normal amount, and essentially having an even better effect on the plant. When a solid, granular fertilizer is applied to the soil, it may not dissolve and reach the plant. In terms of reducing the need to use chemicals in agriculture, the farm was able to reduce the amount of fertilizer by applying it to the leaf rather than the soil. However, it is not possible to fertilize in this way throughout the season.

Because the farm is far from water sources that would be sufficient for irrigation, the farm is not considering changes to the irrigation system. Irrigation concerns more special crops, i.e. vegetables. It also happens that if several farmers use irrigation, since several of them are close to each other, when one irrigates, the others cannot, because there is not enough water. One way to influence irrigation is to increase the ability to hold more surface water. Instead of about 30 cm deep ploughing, the manufacturer can use the so-called subsoil, which reaches up to 40-50 cm and because the soil is swollen, it is like a sponge. Therefore, it can better absorb water that falls in the form of precipitation. And basically the roots of the plants still have access to moisture and this has a positive effect on the decomposition of post-harvest residues and those plants can then better survive the drought period caused by climate change. Instead of traditional tillage, the farm crushes post-harvest residues, works them in with a cultivator to create a mixture, so the soil is not turned over. In this way, evaporation of water during rotation is prevented. It depends on the weather, but on average 40 mm of water can evaporate this way. In such a case, if the seed is sown in such dry soil, it will not grow until the next rain and the deadlines will not be met. Another problem would be that it could freeze. Although it should be added that with the current varieties it is not likely any more. Instead, there is missed growth, which causes diminishing returns. This will subsequently require the excessive use of fertilizers, which is no longer economical or ecological.

Sowing procedures must also be adjusted (change in the species composition of sowing procedures, ecological cultivation technologies), including resistant varieties and the use of certified material. Biological protection and integrated production can also be successful.

The introduction of these adaptation measures is of course also reflected in the workforce. Thus each measure has a social impact in the sense of its impact on employment. Crop rotation, fertilization and tillage would not require any additional labour according to the company. On the other hand, intercropping, mixed cropping and mainly irrigation would require additional labour in certain parts of the season. For example, in the main season, it may be necessary to provide another set of tractors for sowing the second crop. There are several irrigation alternatives. One option is to use a tractor to drive the pump. This option is more labour-intensive, requiring more people to operate, control and move the irrigation applicator. Another option is a fully automated line, which, however, has the disadvantage of a higher initial investment, but on the other hand, it is fully automated and does not require constant supervision by employees, it is enough to ensure maintenance and control.

As mentioned above, crop rotation, fertilization and tillage would be the most beneficial when deciding which adaptation measures to use when considering costs. Crop rotation requires minimal implementation and maintenance costs and results in improved soil quality and reduced pest and disease incidence. The impact of the introduction of intercropping would have only a negligible temporary effect on yield increase. However, in the long run, this would lead to a reduction in costs (of pest and disease control), leading to an overall increase in profits. Crop rotation is one of the main principles of cultivation in agriculture. It prevents one-sided draining of nutrients from the soil, and each additional crop suppresses a different type of weed. Therefore, it is not necessary to apply such a large amount of herbicides, it leads to cost savings and the possible increase in yield would be up to 10% to 80%. Another adaptation measure, mixed cultivation, is more often applied in agricultural enterprises that also focus on animal production. Therefore, it would not bring significant advantages to a company that focuses exclusively on plant production.

Fertilizing, especially using foliar-applied fertilizers, can improve nutrient uptake and also halve the amount of fertilizers needed. Adaptation measures in tillage allow the farm to reduce soil evaporation and the amount of fertilizers used.

As for the least appropriate measure, we can mention irrigation here. The costs associated with this measure are extremely high, and given the insufficient water resources near the farm, investing in an irrigation system would be very risky. However, it is true that irrigation systems in Slovakia would clearly benefit companies that focus on growing special crops such as vegetables.

When we look at the problem of soil erosion, intercropping, mixed cropping, crop rotation and fertilization using manure as fertilizer all lead to a reduction in soil erosion. For example, in the case of intercropping, the additional ground cover provided by the second crop would help retain excess water and nutrients. The improvement of soil biodiversity in the case of the first three adaptation measures and minimal tillage would be achieved mainly through the decomposition of organic matter. Crop biodiversity would be improved by the implementation of intercropping, mixed cropping, and crop rotation.

Conclusion

Climate change has an increasingly significant impact on our daily lives. Extreme weather events, such as intense droughts, heat waves, rising sea levels and storms are becoming more frequent or more severe. Together with temperature changes and the frequency and intensity of precipitation, this leads to a more significant impact of climate change on agricultural production. There are many studies examining the impact of climate change on agriculture and although the current effects are not the same for agriculture worldwide, climate change is expected to lead to food insecurity in the future.

The main objective of this study was to analyse the impact of climate change on agriculture and evaluate the adaptation measures that need to be taken to adapt to changing climate conditions. In the first part of our analysis, we focused on confirming the impact of climate change on agriculture using a regression model that captured the impact of average maximum temperature, average minimum temperature, average precipitation, wind and humidity on wheat crops in the Levice District for the period 1997 - 2019. The results showed that our model was statistically significant, as well as the effect of the variables area, average minimum temperature, average maximum temperature, average precipitation and average humidity. While the increase in the average maximum temperature has the highest, positive impact, the most negative impact is attributed to the increase in the average minimum temperature. This indicates that, according to our results, the currently observed impact of climate change on wheat yields per hectare in the Levice District is positive. Despite this, agricultural enterprises must adapt to changing climatic conditions, and therefore, in the second part of our

ACTA OECONOMICA UNIVERSITATIS SELYE 2022, VOL. 11., NO. 1.

analysis, we focused on the evaluation of possible adaptation measures and their impact on the economy. Our case study confirmed that in recent years there have been changes in climatic conditions, changes in the intensity and frequency of precipitation, temperatures, and more frequent occurrence of windy weather. Climate change has so far had a positive impact mainly due to the rapid implementation of adaptation measures in the field of technology and crop treatment. However there are also some negative impacts including an increase in weeds, the occurrence of pests and insects as well as water and wind erosion. The company has already introduced measures such as shifting planting dates, diversifying crops, crop rotation, changing the timing and dosage of fertilizers used, but also adjusting the method of applying fertilizers or adjusting the method of tillage.

Acknowledgement

This publication is the result of the project implementation: „Scientific support of climate change adaptation in agriculture and mitigation of soil degradation ” (ITMS2014+ 313011W580) supported by the Integrated Infrastructure Operational Programme funded by the ERDF and the project VEGA 1/0225/22 "European Green Deal's Impacts on Agriculture, Food Production and Consumption Patterns".

Bibliography

1. Arora, K. N. (2019). Impact of climate change on agriculture production and its sustainable solutions. In Environmental Sustainability, Vol. 2. 95-96 p. DOI: <https://doi.org/10.1007/s42398-019-00078-w>.
2. Enviroportal. (2021). Bilancia dusíka a fosfore v poľnohospodárskej pôde. In Enviroportal. Retrieved from: <https://www.enviroportal.sk/indicator/detail?id=742>.
3. European Environmental Agency. (2021). Poľnohospodárstvo a zmena klímy. Retrieved from: <https://www.eea.europa.eu/sk/signaly-eea/signaly-2015/clanky/polnohospodarstvo-a-zmena-klimy>.
4. Greenhouse gas emissions from agriculture. (2021). In Eurostat. Retrieved from: <https://ec.europa.eu/eurostat/databrowser/view/tai08/default/table?lang=en>.
5. Hatfield, L. J., Prueger, H. J. (2015). Temperature extremes: Effect on plant growth and development. In Weather and Climate Extremes, Vol. 10, Part A. 4-10 p. ISSN 2212-0947. DOI: <https://doi.org/10.1016/j.wace.2015.08.001>.
6. Hoegh-Guldberg, O. et al. (2018). Impacts of 1,5°C Global warming on natural and human systems. In: Global Warming of 1,5°C. An IPCC Special report on the impacts of global warming of 1,5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Retrieved from: <https://www.ipcc.ch/site/assets/uploads/sites/2/2019/02/SR15_Chapter3_Low_Res.pdf>.
7. Lu, Ch., Tian, H. (2017). Global nitrogen and phosphorus fertilizer use for agriculture production in the past half century: shifted hot spots and nutrient imbalance. In Earth System Science Data, Vol. 9, Issue 1. 181-192 p. DOI: <https://doi.org/10.5194/essd-9-181-2017>.
8. Ministry of Environment of the Slovak republic. (2018). Stratégia adaptácie Slovenskej republiky na zmenu klímy. Retrieved from: <https://www.minzp.sk/files/odbor-politiky-zmeny-klimy/strategia-adaptacie-sr-zmenu-klimy-aktualizacia.pdf>.

9. Seneviratne, I. S. et al. (2012). Changes in climate extremes and their impacts on the natural physical environment. In: Managing the risks of extremes events and disasters to advance climate Change Adaptation. A special report of Working Groups I and II of IPCC. Cambridge: Cambridge University Press. 109-230 p. Retrieved from: <https://www.ipcc.ch/site/assets/uploads/2018/03/SREX-Chap3_FINAL-1.pdf>.
10. Singh, S. et al. (2021). Global climate change. Amsterdam: Elsevier. 442 p. ISBN 978-0128229286.
11. Slovak Hydrometeorological Institute (a). Prejavy klimatickej zmeny na globálnej úrovni. In Slovak Hydrometeorological Institute. Retrieved from: <https://www.shmu.sk/sk/?page=1379>.
12. Slovak Hydrometeorological Institute (b). Scenáre budúcej klímy. Retrieved from: <https://www.shmu.sk/sk/?page=1069>.
13. Stocker, F. T. et al. (2013). Climate change 2013: The physical science basis summary for policymakers. The report of Working Group I of the IPCC. 203 p. Retrieved from: <https://www.ipcc.ch/site/assets/uploads/2018/03/WG1AR5_SummaryVolume_FINAL.pdf >.
14. Takáč, J., Šiška, B., Nováková, M. (2011). Možné dôsledky zmeny klímy na potenciál úrod poľných plodín na južnom Slovensku. In Rosliny v podmínkách měnícího se klimatu. 612-622 p. ISSN 0139-6013. Retrieved from: <http://www.cbks.cz/rostliny2011/prispevky/TakacSiskaNovakova.pdf>.
15. US Global Change Research Program. (2018). Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II. Washington, DC: U.S. Global Change Research Program. 1515 p. Retrieved from: <https://nca2018.globalchange.gov/downloads/NCA4_2018_FullReport.pdf>.
16. Wolff, E. et al. (2020). Climate change evidence & causes. Washington, DC: The National Academies Press. DOI: <https://doi.org/10.17226/25733>.
17. Wreford, A., Moran, C. D., Adger, W. N. (2010). Climate change and agriculture. In Researchate. ISBN 978-92-64-08687-6. Retrieved from: <https://www.researchgate.net/publication/51996928_Climate_Change_and_Agriculture>.
18. Yohannes, H. (2016). A review on relationship between climate change and agriculture. In Journal of Earth Science and Climatic Change, Vol. 7, Issue 2. DOI: <http://doi.org/10.4172/2157-7617.1000335>.

Correspondence address:

prof. Ing. Miroslava Rajcaniova, PhD., Institute of Economic Policy and Finance, Faculty of Economics and Management, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, Nitra, Slovakia, email: *miroslava.rajcaniova@uniag.sk*
ORCID: https://orcid.org/0000-0003-4688-7690

Ing. Michaela Rolincová, Faculty of Economics and Management, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, Nitra, Slovakia, email: *xrolincova@uniag.sk*