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Economic and Environmental Impacts of Climate Change in Agriculture in Slovakia

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Abstract

The article focuses on the formulation and testing of adaptation and mitigation measures in the rural landscape, related to the expected development of the agricultural landscape of Slovakia. It will deal with the possible impacts of climate change on the economic and production function of land and the sustainability of farm management and its possible impact on natural and production value indicators. Through process and empirical modelling of the agroecosystem with emphasis on soil, its properties and also its production function, the results are interpreted in the form of spatially- explicit modelling framework covering the crop production sector of selected regions of Slovakia.

Keywords: integrated modelling framework, farm management practices, crop production, soil

INTRODUCTION

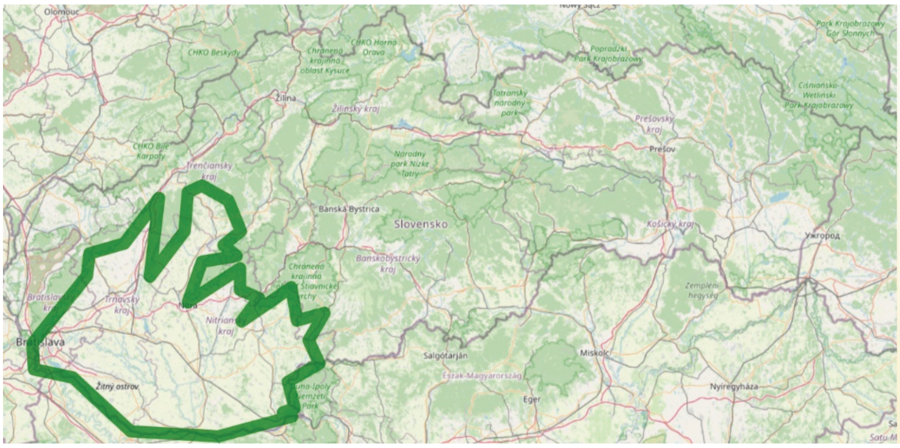
Society benefits from agricultural landscapes in many ways. The development of the agricultural landscape in Slovakia has proceeded through several land management regimes. Each of them is associated with the emergence of specific landscape structures and the emergence of diverse environmental and socio-economic issues. Individual landscape structures have different values, some being more, and others less, valuable. (Izakovičová Z., et.al., 2022). Agricultural sector in general must face many global challenges. Progressing climate change increasingly threatens the agricultural sector by compromising the resilience of ecosystems and endangering food security worldwide. Although yields of all crops have increased over the past decades, the growth has been achieved mainly due to improvements in plant genetics, the arrival of new crops, and land management practices. However, it is difficult to distinguish the direct influence of changing temperature and precipitation on the productivity of crops while simultaneously capturing other contributing factors, such as spatial allocation of agricultural lands, economic conditions of land use, and soil fertility (Erokhin, V. el al., 2021; Termorshuizen et al., 2009). Regarding the research on natural aspects, main focus is on how to build crop models for the dynamic simulation of crop growth and on the impact of climate change on crop growth (Hasegawa et al., 2022). By formulating efficient adaptation strategies, the negative effects of climate change on agriculture can be mitigated or even avoided. Within the food system, adaptation activities are aimed at reducing vulnerability and enhancing the flexibility of the system to climate change. By implementing the concepts as precision agriculture, ecological farming, whole farm eco-schemes, the whole production process can be monitored and controlled. Finally, data collection, transparency and interdisciplinary approaches will gain further importance in the future as well. Adaption to climate change and to its negative effects causes a significant transformation in the interaction between global society and the natural ecosystem. In addition to policy makers, cooperation between the private sector and the public needs to be established to overcome the harmful impacts of climate change. (Fróna, D. el at., 2021). Agricultural policy is a key element of the economic policy of each EU country. Agriculture is one of the most sensitive sectors of the economy, not only in Slovakia but also in the whole EU. Maintaining agricultural production in less developed regions is one of the objectives of the Common Agricultural Policy (CAP), which is the most integrated of all EU policies and represents a relatively large share of the EU budget. (Némethová, J. et al, 2015). In Slovakia, there are regional disparities with regards to crop diversity. It is typical the regions with the best soil quality that have the highest degree of crop diversity in the southwestern part of Slovakia, which is being influenced, for example, by the legal form of agricultural enterprises, the distance of the enterprise from city, the education of the managers, etc (to Lazíková et al., 2019). The analysis of Némethová, J. et al (2021) shows that the support for special crop production by the state, the diversification of crop cultivation, the achieving of the highest possible self-sufficiency in the production of post-harvest crops, and the securing of the quality and safety of food for the population through domestic production, are the necessary strategic goals of Slovak agriculture. Growing crops with higher added value has a positive impact on the structure of crop production and on the creation of new jobs in agriculture. Therefore, we propose the adaptation and mitigation measures for crop production in rural regions of Danubian Lowland in Slovakia. We applied spatially explicit integrated modelling framework enabling economic optimization of crop production in selected regions with respect to net returns maximization based on integration of economic and bio-physical data on selected crops in rural regions of Danubian Lowland.

Data and Methods

Selected area

We apply the integrated modelling of crop production system in selected west-south regions of Slovakia located in Danubian Lowland. It represents the most favourable agricultural area in country with highly concentrated agricultural production. As for the crop production, majority of key crops are cultivated in this area. Lowland forms an alluvial aquifer and is an important water resource for municipal and agricultural water supply. Therefore, it is also considered as most fertile land with the highest concentration of chernozems and mollic fluvisoils. Danubian Lowland includes 8 rural regions Dunajská Streda (DS), Galanta (GA), Komárno (KN), Levice (LV), Nitra (NR), Nové Zámky (NZ), Trnava (TT) and Topolčany (TO). Accentuated area on the picture 1 represents area of interest and its regions.

Picture 1: Danubian Lowland



Source: https://podunajska-nizina.oma.sk/

Data and their sources

For the analysis of the formulation and testing of adaptation and mitigation measures in the rural landscape we chose six most common crops cultivated in selected area, thus spring barley (BAR), grain maize (MAI), rapeseed (RAP), sugarbeet (SGB), sunflower (SNF) and winter wheat (WHE). Integrated optimization combines economic with bio-physical data on selected crops. Economic data were averaged for the period 2010-2020 based on statistical reports from Research institute of Agriculture and Food Economics (NPPC-VUEPP). Bio-physical data on crop response for specific soil parameters were simulated with EPIC Model (environmental policy integrated climate model) for selected crops. It provides average crop yields for reference period 2004-2014 (adopted according Svetlanská, 2017; Svetlanská et al., 2017) under six selected farm management practices and crop data are averaged on regional basis. Farm management practices (Mana) represent amount of applied nitrogen fertilizer and choice of irrigation. We employ low nitrogen input with irrigation (N0I), low nitrogen input rainfed (N0R), high nitrogen input with irrigation (NHI),), high nitrogen input rainfed (NHR),), medium nitrogen input with irrigation (NMI) and, medium nitrogen input rainfed (NMR). Nitrogen inputs for different management practices as well as irrigation amount and precipitation were extracted from Soil Science and Conservation Research Institute (NPPC-VUPOP).

Integrated modelling framework

Integrated modelling combines several types of models into bottom-up optimization model. The framework integrates agronomic information and bio-physical models into a regional bottom-up land use optimization model to account for heterogeneity in opportunity costs of agricultural production choices and environmental outcomes (Mitter et al., 2015). Bottom-up optimization model for rural regional level takes form:

$$\pi_{r,m} = \sum_{r}\left(YLDG_{r,c,m} * price\right) - \left(L_c + VC_c + FerC_{c,m} + IrrC_{c,m}\right)$$

$$max\pi = \sum_{r,m}\left(\pi_{r,m} * x_{r,m}\right)$$

$$s.t. = \sum_{r}\left(a_{r,m} * x_{r,m}\right) \leq b_p$$

, where π represents net returns, *YLDG* is yield of crop in dry matter, *L* represents labour cost, *VC* is variable cost, *FerC* denotes cost of fertilizer and *IrrC* stands for cost of irrigation. Indices *r, c* and *m* denote region, crops and farm management practices. The objective function is subject of land constrain (*b*) available for the region *r*. Variable *a* represents Leontief production function, the technology matrix to convert resources into crop products.

Results and discussion

Integrated optimization of crop production

Six selected crops were chosen for integrated optimization of crop production from economic and environmental viewpoint. The typical crop mixes were derived based on historical data and we used three reference mixes as the optimization choice; mix observed in 2010 (M_2010), mix observed in 2015 (M_2015) and mix in 2020 (M_2020). Crop mixes were used in optimization in order to prevent overspecialization of crop production. From reference mixes, M_2015 was proved as optimal for all regions as presents Table1. All arable land in respective regions reporting M_2015 as optimal ("Level" value in Table 1). Table also presents marginal cost of alternative mixes M_2010 and M_2020, showing how much would net return decrease if any hectare would be managed under alternative mix scenario.

Table 1: Choice of optimal crop mix (in ha)

Region	M_2010	M_2010	M_2015	M_2015	M_2020	M_2020
	Marginal	Level	Marginal	Level	Marginal	Level
DS	-6.13	0	0	314288	-411.77	0
GA	-5.94	0	0	233826	-402.11	0
KN	-6.76	0	0	429700	-410.76	0
LV	-6.64	0	0	234273	-383.88	0
NR	-6.71	0	0	336694	-383.69	0
NZ	-6.64	0	0	424633	-397.51	0
TO	-5.47	0	0	243027	-372.03	0
TT	-6.31	0	0	201878	-387.63	0

Source: own processing

The bio-physical simulations from EPIC provided information on the bio-physical responses using the rural agronomic and climate data (weather, topography, soil and nutrient/irrigation management). It provided the level and variability of crop yields as well as on environmental effects (e.g. nitrogen content in yield, water use efficiency,) of alternative and farm management practices. The output data of EPIC served as the input data for the regional bottom-up land use optimization model which integrates the simulated crop yields with economic data (prices and costs of crop production) to compute net returns for all production choices.

Table 2: Net returns maximizing farm management practices by region with arable land distribution among selected crops (ha)

Region	Mana	BAR	MAI	RAP	SGB	SNF	WHE
DS	NHI	52245.90	63708.70	41675.10	11218.10	28554.40	116886.00
GA	NHI	38870.10	47398.30	31005.60	8346.09	21244.10	86961.40
KN	NHI	71431.40	87103.50	56978.90	15337.60	39040.10	159809.00
LV	NHI	38944.50	47488.90	31064.90	8362.06	21284.70	87127.80
NR	NHI	55970.50	68250.50	44646.20	12017.80	30590.10	125219.00
NZ	NHI	70589.10	86076.40	56307.00	15156.70	38579.70	157924.00
TO	NHI	40399.80	49263.50	32225.80	8674.53	22080.10	90383.60
TT	NHI	33559.20	40922.20		7205.75	18341.40	75079.70
TT	NHR			26769.30			

Source: own processing

Table 2 represents the report on the crop production choice for each crop for each selected region. It identifies the distribution of arable land among six selected crops in each region (with respect to optimal crop mix M_2015). Clearly the net returns maximizing farm management practice is NHI. The nitrogen input with high nitrogen input refers to optimal crop yields observed in Slovakia (Svetlanská, 2017). The fact, that integrated optimization resulted into NHI, proves that irrigation has an importanat role in crop production. Slovakia is located in a temperate climate zone, while the full use of the potential of agricultural crops is hindered mainly by the lack of natural precipitation in the growing season, which causes a regular deficit of water in the soil (Jobbágy, 2019). Only RAP in region TT yields the greatest net returns under NHR farm management (meaning the rainfed scenario is sufficient). Intensive management practices lead to the highest net returns in selected regions and reflect the reality of crop production in Slovakia (but not only). Agriculture under the changing climate is widely dominated by conventional intensive farming systems, with highly specialized crop productions and a heavy reliance on pesticides and mineral fertilizers. When working with simulated bio-physical data, it is necessary to take into consideration the fact, that crop yield variability is heavily controlled by fertilizer use, irrigation and climate (Lechenet et al., 2014).

Adaptation of farm management practices

Naturally, higher shares of intensive farm management practices increase average crop yields, which is important factor especially when farmers have to face changing climate and its impact on crop production systems. Intensification of agriculture is main cause of ecosystem deterioration especially in terms of soil degradation. Adapting better management practices that prevent farmers from excessive use of fertilizers can ensure that the relationship between agriculture and ecology is a positive one to improve the structure of arable land, support biodiversity and fight against climate change.

Table 3: Net returns maximizing farm management practices by region with arable land distribution among selected crops with policy incentives application (ha)

Region	Mana	BAR	MAI	RAP	SGB	SNF	WHE
DS	N0I				11218.10		
DS	NHI		63708.70			28554.40	116886.00
DS	NMI	52245.90		41675.10			
GA	N0I				8346.09		
GA	NHI		47398.30			21244.10	86961.40
GA	NMI	38870.10		31005.60			
KN	N0I				15337.60		
KN	NHI		87103.50			39040.10	159809.00
KN	NMI	71431.40		56978.90			
LV	N0I				8362.06		
LV	NHI		47488.90			21284.70	87127.80
LV	NMI	38944.50		31064.90			
NR	N0I				12017.80		
NR	NHI		68250.50			30590.10	125219.00
NR	NMI	55970.50		44646.20			
NZ	N0I				15156.70		
NZ	NHI		86076.40			38579.70	157924.00
NZ	NMI	70589.10		56307.00			
TO	N0I				8674.53		
TO	NHI		49263.50			22080.10	90383.60
TO	NMI	40399.80		32225.80			
TT	N0I				7205.75		
TT	NHI		40922.20			18341.40	75079.70
TT	NMI	33559.20		26769.30			

Source: own processing

We employed policy premiums for low and medium farm management practices based on the Farmers manual for CAP 2023-2027 (Ministry of Agriculture and Rural Development of the Slovak Republic). For limiting the use of pesticides, herbicides and farming on land without the use of chemical fertilizers (N0I, N0R) we added policy premiums on top of the Basic Income Support for Sustainability (BISS) which is projected to be 101€/ha. Policy premium for N0I 200€/ha and for N0R 180€/ha. For limiting the nitrogen to medium loads (NMI, NMR) we added policy premium NMI 160€/ha and NMR 140€/ha on top of BISS.

Results of adapting policy premiums into integrated optimization are presented in Table 3. Despite policy premiums, intensive farm management practices (represented by NHI) still lead to maximal net returns in case of MAI, SNF and WHE. NMI is suitable for BAR and RAP and SGB can be managed under N0I scenario in order to maximize net returns, when policy premiums are applied. This also proves, that environmental impact caused by crop production can be reduced by adjusting management practices and increased incentives from policy makers in form of supporting sustainable management of land use (Frank et al, 2014; Mitter et al. 2015).

Impact of adapted scenarios on soil in terms of nutrients

Suitable production choices represented by farm management practices are important from the point of economic optimization on the one hand, but each of management practices influences the soil fertility. To see the impact Picture 2 provides comparison of the nutrient input of farm managements, which were proved to be optimal (NHI, NHR, NMI, N0I) with requirements of crop´s yield. In order to do so, we consider the nitrogen input (FTN) with nitrogen taken from soil together with the crop´s yield (YLN).

Picture 2: Comparison of nitrogen input (FTN) with nitrogen content in crop yield (YLN) in kg

Source: own processing

Crops, which are suitable for more intensive farm management practices (NHI, NHR) are BAR and WHE, as these are the crops which have higher YLN than FTN in case of less intensive farm management practices (N0I, NMI). Also, it is clear that MAI is not suitable to be managed by N0I as nitrogen in yield would be higher than nitrogen applied (upper left chart on Picture 2), but from viewpoint of soil, NMI would be suitable. RAP, SGB could be also managed by N0I and NMI and still have higher nitrogen input applied than yielded. For SNF the favourable management in terms of nitrogen application represents NMI. Comparison of nitrogen applied and taken with yields consider the soil as the primary production factor of agricultural production. Each farm management practice influences the soil fertility. Intensive farm management causes that the soil might be over fertilized with the aim to achieve the highest possible hectare crop yields. This leads to the soil organic carbon losses and pollution of groundwater caused by agricultural activity.

Conclusion

The main objective of article was formulation and testing of adaptation and mitigation measures for crop production in rural regions of Danubian Lowland in Slovakia. We applied spatially explicit integrated modelling framework which enabled economic optimization of crop production in selected regions with respect to net returns maximization, but we also considered environmental parameters. Results of modelling represent the distribution of selected crops on arable land in individual rural regions and most suitable farm management practice in terms of nitrogen application and irrigation use. We identified net maximizing farm management practices firstly without policy premium and consequently added policy premiums to model, to see the alternative cost of adapting environmentally acceptable farm management practices. By applying the low or moderate intensive managements, farmers can ensure or enhance the soil fertility and sustainability of crop production.

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