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Economic and environmental linear optimization model of crop production in selected regions of Slovakia

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For the agricultural industry in Slovakia, the dominating sector is crop production. The major part of arable land is devoted to the cultivation of cereals (57%), feed crops (20%) and industry crops (19%).The aim of this paper is to model the distribution of crop management practices in selected regions of Slovakia and identify the net return for four selected crops in these regions. We use integrated modelling framework which incorporates bio-physical and economic data to identify opportunity costs of agricultural production choices. We delineate homogenous response units (HRU) and aggregate them on regional level as the model is constrained by land endowment in particular region. The results suggest that highest yields and thus high returns are achieved in case of management practice with high nitrogen input and irrigation. The high input management causes environmental pressures on soils, therefore its enforcement in regions is not desirable. The solution might appear in policy premiums for low input management practices.

Key words: crops, management practices, inputs, net returns, linear programming

JEL CLASSIFICATION: C61, Q10, Q15

1 Introduction

Agriculture of Slovakia struggles with remains of the former regime. In the period before the transformation, the intensification of production led to excessive use of fertilizers and increased demands on livestock. The transition toward market economy after 1990 had led to the reduction of environmental pressure and further release occurred after 2000 due to the policy reforms and investments related to the accession to EU. The Slovak agriculture experienced complicated development after 1990, when the trade conditions changed and public subsidies were eliminated. Released environmental pressure is though attributed to the overall decline of agricultural sector. Gross agricultural production had decreased by almost 30% over the period 1993-2011. Furthermore, after the transition of economy there had been a change in the structure of agricultural sector. In the period between 2000 and 2011 there was a decline in livestock production. The cattle breeding declined by 28.3% the stocks of pigs declined by 61%, sheep by 1.3% and poultry by 16.2% (Kročková, 2013).The livestock production became less profitable, because of cheap imported meat (Bielik, 2014).Because of the overall decline in livestock production, the crop production has become a major agricultural sector.

More than 39% of total area of Slovakia was covered by utilized agricultural area (UAL) in 2014. UAL has a downward trend, which is environmentally negative phenomenon especially when it comes to set-aside areas of UAL and subsequent re-classification of it into built-up areas, what is the case of Slovakia. Loss of the UAL land in recent years is approximately 1000 ha of agricultural land per year according to Soil Service. On the other hand, intensive farming is usually accompanied by stronger mechanisation, higher fertiliser and pesticide use and irrigation. This does not only lead to higher GHG

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emissions but also has adverse impacts on soil, water and air quality, depletion of fresh water resources, and loss of biodiversity (Elbersen et al., 2013; Foley et al. 2011). According to Bujňáková (2010) there is a significant potential of Slovakian agriculture in terms of use of marginal lands and pastures and interest of farmers in ecological farming and production of high valued products.

Crop yield variability is heavily controlled by fertilizer use, irrigation and climate (Mueller et al., 2012) and intensification of production raises a question of more sustainable crop management practices. To minimize the environmental impacts of production intensification, increased irrigation and nutrient application to close crop yield gaps should be complemented by efforts to decrease overuse of crop inputs wherever possible. Agricultural production can benefit even from small changes in management practices as adjustments in sowing dates and fertilization intensity (Lehmann et al. 2011). The use of bioeconomic models linking crop bio-physical models with economic decision models has been suggested in various studies as a way toward integrated assessments (Challinor et al., 2009, Finger et al., 2011, Olesen et al., 2011). Most of the early crop optimization models were developed for application at the plotor field scale, with single crops and a limited range of management options over one or a few seasons. They were developed to integrate and document current understanding of crop physiology and its ability to quantify the effects of environment and basic management on crop productivity. More recently, emphasis has been placed on improving model flexibility to support the simulation of different crops, cropping systems and production situations (Ewert et al., 2014). Jánová (2011) developed the dynamic programming model for the long run crop plan optimization covering the typical conditions of Czech farms, which serve as a platform for enlargements and changes according to needs and conditions of particular farm. In her work, she discussed the possibility of covering different constraints by generating the state space. Galán-Martín (2015) developed a multi-stage linear programming model identifying the optimal cropping plan decisions under the new CAP payments, illustrated through its application to the Spanish agricultural regions. They suggested the optimal cropping plan (crops to be grown and their acreage each year during the reform horizon) that maximizes the farmer's net return in each region.

The main objective of this paper is to use an integrated modelling framework which incorporates bio-physical and economic data to identify opportunity costs of agricultural production choices. Based on the aim we state the question, what management practices maximize the economic results of selected crops in four regions of Slovakia.

The obvious benefits of integrated modelling is, that it allows to simulate yields under different management practices and integrate economic data in order to identify opportunity cost of management practices. There are four crops under consideration: wheat, grain maize, green maize and rapeseed. The management practices are focused on nitrogen input and irrigation. We use the average economic and biophysical data for the period 2004-2014. The selected regions are two regions from maize production – NovéZámky (NZ) and Bratislava (BA) and two regions from mountain production area – Bánska Bystrica (BB) and Prešov (PO). Selection of these regions was determined based on the natural condition as NZ, BA belong to the most fertile areas and BB and PO can be classified as less favoured areas considering the natural conditions.

2 Methods and data

The input data for a small regional bottom-up integrated model are divided into economic and biophysical dataset. The economic dataset consists of direct costs (DirCost) and price for crops and regions. Costs and prices are differentiated based on production areas (tab. 1). NZ and BA have assigned costs and prices for maize production area, while BB and PO for mountain production area. The direct costs per hectare are the expenditures for fertilizers - purchased and produced, chemical protection, agrochemicals and seed – purchased and produced and are provided by Research Institute of Agricultural and Food Economics (NPPC-RIAFE, 2015). Direct costs were calculated for four selected crops green maize (GMA), grain maize (MAI), wheat (WHE) and rapeseed (RAP). These crops represent all major categories cultivated in Slovakia (cereals, feed crops, oil crops).

Tab. 1 Direct costs and price for selected crops

Crop	YLDG	DirCost	Price
GMA_NZ	10.59	375.92	122.43
MAI_NZ	8.02	432.87	147.72
WHE_NZ	3.78	360.64	155.13
RAP_NZ	1.53	532.39	319.95
GMA_BA	11.32	375.92	122.43
MAI_BA	8.37	432.87	147.72
WHE_BA	4.23	360.64	155.13
RAP_BA	1.77	532.39	319.95
GMA_BB	8.49	410.33	122.43
MAI_BB	6.68	430.93	148.22
WHE_BB	3.59	337.06	122.72
RAP_BB	1.91	540.13	318.61
GMA_PO	7.75	410.33	122.43
MAI_PO	6.23	430.93	148.22
WHE_PO	3.19	337.06	122.72
RAP_PO	1.81	540.13	318.61

Note: YLDG – represents yield of crop in dry grain, thus dry matter, i.e. completely without water. In the table there are average yields under selected four management practices.
Source: Direct costs and price, RIAFE; YLDG - EPIC SK, Soil Science and Conservation Research Institute

The biophysical data set is based on EPIC (environmental policy integrated climate model) simulation for selected crops. It provides information on crop yields under four selected management practices (tab. 2) as the average for time period 2004-2014. The crop yield data are provided on 1 km^2 HRU in regions. These crop yield data were later merged on level of regions, thus each 1 km^2 was assigned to region. Consequently, the HRUs crop data were averaged on regional level.
Management practices (MP):

NZI – low nutrient input, full irrigation
NZR – low nutrient input, no irrigation
NHI – high nutrient input, full irrigation
NHR – high nutrient input, no irrigation

FTN from table 2, represents nitrogen allowance in kg per hectare for selected crop. The nitrogen input in case of NZI and NZR are up to lowest levels of crop yields in Slovakia and NHI and NHR are up to optimal crop yields observed in Slovakia. Optimal yields in this case are stated according to Soil Science and Conservation Research Institute (SSCRI) as the highest yields observed in Slovakia according to potential of respective bonitation soil-ecological units. On the other hand IRGA represents irrigation water in millimetres.

Tab. 2 Crop management practices

Crop	MP	FTN (kg/ha)	IRGA (mm/ha)
GMA	NZI	40	143.38
	NZR	40	0
	NHI	120	143.38
	NHR	120	0
MAI	NZI	80	185.7
	NZR	80	0
	NHI	120	185.7
	NHR	120	0
WHE	NZI	40	171.85
	NZR	40	0
	NHI	150	171.85
	NHR	150	0
RAP	NZI	80	155.28
	NZR	80	0
	NHI	200	155.28
	NHR	200	0

Source: EPIC SK, Soil Science and Conservation Research Institute

The linear program for bottom-up optimization model is simplified version of Austrian agricultural and forestry sector model PASMA (Schmid and Sinabell, 2007) adjusted for small regional model of Slovakia in form:

$$\pi_{r,c,m} = \sum_{c=1}^{C}\left(YLDG_{r,c,m} * price\right) - \left(DirCost_{r,c} + FerCost_{r,c} + IrCost_{r,c}\right), \forall m \tag{1}$$

$$maximize \sum_{r=1}^{R}\sum_{m=1}^{M}(\pi_{r,c,m}x_{r,c,m}) \tag{2}$$

$$s.t. \sum_{r=1}^{R}\sum_{m=1}^{M}\left(a_{r,c,m}x_{r,c,m}\right) \leq b \tag{3}$$

$$x_{r,c,m} \geq 0, r = 1, \dots, R, c = 1, \dots C, m = 1, \dots, M$$

where:

π - net return

r – region

c – crop

m – management practice

x – non-negative variable representing MP

a – number of hectares

b- land constraint

DirCost – direct cost of crop in region

FerCost – fertilizer cost

IrCost – irrigation cost (1€/mm irrigation water)

R – number of regions

C – number of crops

M – number of MP

3 Results and discussion

3.1 Characterization of crop production and yields

The average yields of crops covering the major part of utilized agricultural area (UAL) in regions of Slovakia and their development during the 2004-2014 period are captured in Box and Whisker plots (Fig.1-3). There are 8 general regions of Slovakia: Bratislava, Trnava, Trenčín, Nitra, Žilina, BánskaBystrica, Prešov and Košice. Box and Whisker plot showing the development of yields for cereals is captured in Fig. 1. Regions of Trnava and Nitra produced the highest yields among all regions. In the year 2014 there were highest yields of cereals over the observed period ranging from 4.12 t/ha in region of Prešov to 6.89 t/ha in Nitra region. 50% of regions have the yields between 5 t/ha and 6 t/ha. The lowest average yields of cereals in all regions was clearly in year 2007 when the average yield varied between 2.9 t/ha and 3.9 t/ha. This was mainly caused by extremly hot temperatures as well as the freezing in spring months. The highest variability in yields among the regions can be observed in 2005. This variability was influenced by floods in regions of southern and eastern part of Slovakia.

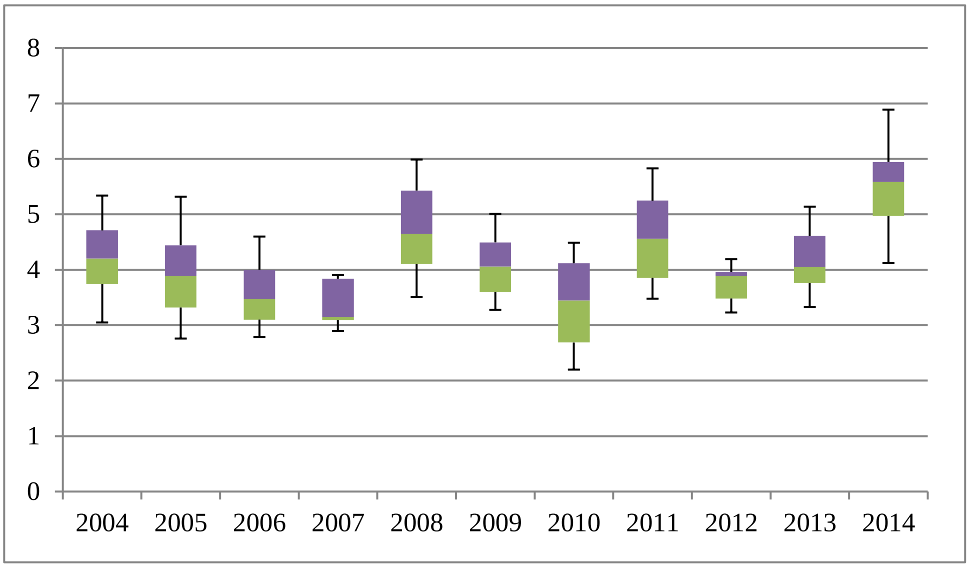

Fig. 1: The development of yields of cereals in regions of Slovakia (t/ha)

Source: own, based on DATAcube 2015

Fig. 2 represents the Box and Whisker plot for yields development in the category of oil-crops. Over the whole period the yields in regions were ranging between 1.4 t/ha and 3.6 t/ha. Again, the highest observed yields of oil-crops in most of the regions occured in 2014, when 50% of regions produced the oil-crops yields between 2.7 t/ha and 3.3 t/ha. The region with the lowest oil-crop yields over the observed period is the region in central part of Slovakia, Bánska Bystrica, where the yields were ranging between 1.52 t/ha in 2010 and 2.61 t/ha in 2014.

The different development can be seen in case of fodder crops (Fig. 3). Box and Whisker plot shows that the average yields were ranging between 2.8 t/ha and 8.2 t/ha.The highest average yields occured in 2004. 50% or regions had the yields between 4.8 t/ha and 6.5 t/ha. The difference in case of fodder crops is that they are harvested more times a year. The variability among the regions is much higher over the observed period, what imply the different natural conditions among the regions but also the different use. In the mountains regions (Banská Bystrica, Žilina, Prešov) the yields are usually lower and the green fodder is usually used as the animal feed. For its bioenergy potential and high yields the green fodder is a desirable energy crop.

The most fertile regions for cultivation of cereals, oil-crops and fodder lasting more years are Nitra, Trnava and Bratislava. The crop production is highly sensitive in terms of weather, soil type, slope and altitude. The lowland in south of Slovakia and south-west part is able to produce higher yields because of warm temperatures, fertile chernozems and higher precipitation.

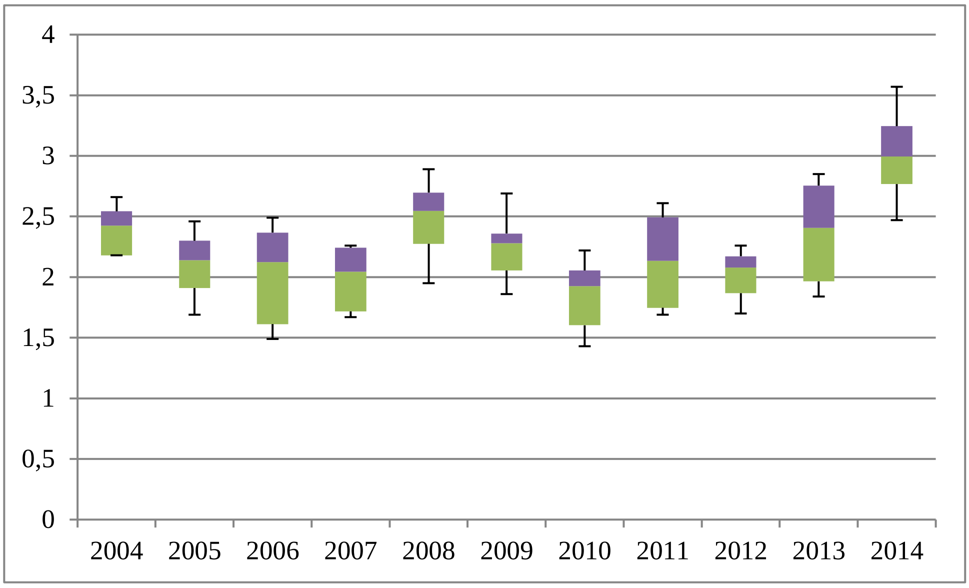

Fig. 2: The dvelopment of yields of oil-crops in regions of Slovakia(t/ha)

Source: own, based on DATAcube 2015

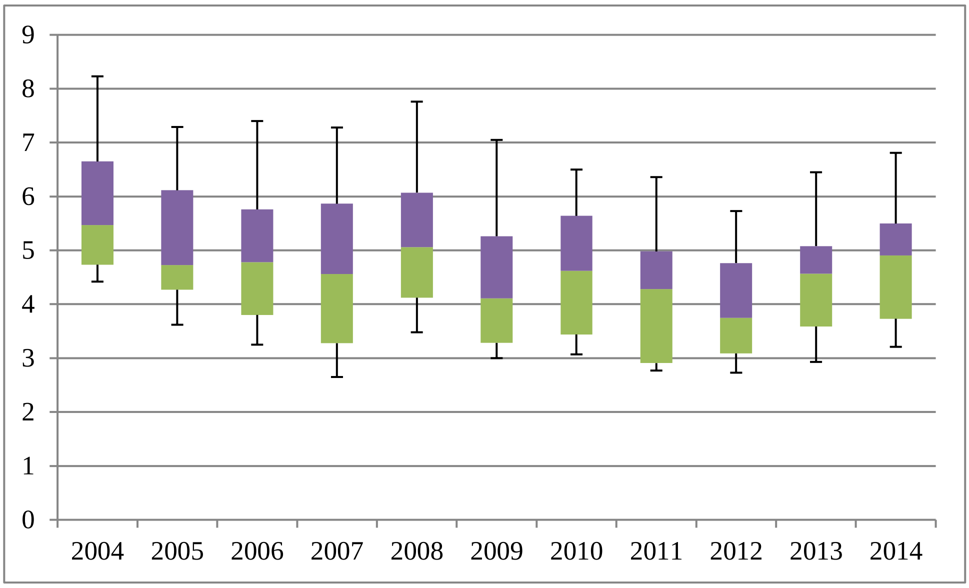

Fig. 3: The development of yields of perennial crops in regions of Slovakia (t/ha)

Source: own, based on DATAcube 2015

The most widely spread soil type in Slovakia is cambisols. Because of the high representation of mountains areas the fertile lowlands are primary locations of almost all agricultural production. On the other hand extensive crop production causes environmental pressures and the losses of soil organic carbon. According to Soil Science and Conservation Research Institute , the lowest concentration of soil organic carbon is in the arable land in south and south-west part of Slovakia (23.25 t/ha) despite of having the most fertile types of soil. This is clearly the negative effect of extensive crop production.

3.2 Economic and managerial optimization of crop production in selected regions

The distribution of arable land devoted to crop production, among the selected regions which is shown in table 3, prove that the region with highest proportion of arable land for crop cultivation is region NZ located in the southern part of Slovakia. This area is characterized by favourable natural conditions in terms of soil fertility and weather conditions. BA is in the south-west part and has similar condition, but as for the proportion of arable land, it is considerably lower than in case of NZ. It is necessary to point out that this region has significant share of land devoted to built-up area. These regions are classified as maize production area (MPA), which is characterized by appropriate condition for cultivation of cereals and oil crops, especially maize, wheat from selected crops.

Tab. 3 Distribution of arable land for crop production in selected regions

Region	Arable land (ha)	Marginal land	Production area
NZ	424 632.93	102 748.94	MPA
BA	69 481.79	12 516.96	MPA
BB	62 574.88	66 597.26	MNPA
PO	107 813.75	53 295.01	MNPA

Source: own processing based on EPIC SK, Soil Science and Conservation Research Institute

Regions BB and PO have lower proportion of arable land for crop production, what is caused by less favoured natural conditions. They are classified as mountain production area (MNPA), which is characterized by relatively low temperatures and damp climate with predominance of permanent grassland on agricultural land with very rugged terrain. Marginal land in table 3 represents the permanent grassland which might be potentially used for agricultural production. Regions in MNPA has clearly higher share of marginal land, especially BB.

Tab. 4 Net returns of selected crops per ha, under different management practices

Region.MP	Net return	Region.MP	Net return
NZ.NZI	39.71	BB.NZI	168.51
NZ.NZR	597.00	BB.NZR	430.38
NZ.NHI	1326.79	BB.NHI	589.89
NZ.NHR	1315.63	BB.NHR	425.34
BA.NZI	637.10	PO.NZI	-129.15
BA.NZR	989.27	PO.NZR	257.47
BA.NHI	1526.38	PO.NHI	361.76
BA.NHR	1403.02	PO.NHR	410.60

Source: own processing

Table 4 shows net returns of four regions under different management practices per hectare. The low input management with irrigation is the least profitable as under this management practise selected crops achieve the lowest yields. In PO the NZI even lead to loss of 129.15€ per hectare, as the fertilizers and irrigation cost together with direct cost exceed the returns. It is worth to mention that there is a significant difference in net revenues under NZI management in NZ (39.71€/ha) and BA (637.10€/ha). This is caused by highest yields of all four crops in BA region compare with NZ (by ↑± 2 t/ha). All regions report highest net returns per hectare under the management with high nutrient (nitrogen fertilizers) input. Regions NZ, BA, BB report highest net returns for NHI management and PO for NHR management. Net returns in table 4 also show the obvious difference between MPA and MNPA in terms of yields and direct cost for selected crops (shown in table 1). The difference is noticeable under the managements with high nutrient input. The most profitable region is clearly BA. The high input management practices cause environmental pressures and soil degradation.

Proved by Lechenet et al., 2014, 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. This was also proved for case of Slovakia by our results, when the most intensive management practices led to the highest net returns in all regions.

Tab. 5 Water use efficiency (WUEF) of selected crops per ha

Region.MP	WUEF	Region.MP	WUEF
NZ.NZI	40.00	BB.NZI	48.90
NZ.NZR	46.56	BB.NZR	52.05
NZ.NHI	65.32	BB.NHI	63.49
NZ.NHR	66.81	BB.NHR	60.70
BA.NZI	51.35	PO.NZI	41.92
BA.NZR	56.58	PO.NZR	44.50
BA.NHI	72.37	PO.NHI	57.06
BA.NHR	72.20	PO.NHR	56.45

Source: own processing

Table 5 represents the water use efficiency per hectare in selected regions for four selected crops. WUEF measures how many kilograms of crops can be produced per 1 millimetre of irrigation water. Region NZ has the lowest WUEF for NZI management what is in line with lowest net return (tab. 4). Noticeable fact is that in MPA the high input management practice without irrigation does not have significant effect on WUEF.

Tab. 6Net returns of crop production choices in selected regions and optimal management practices

	Net return (in thousands €)	ha
NZ	563 398.00	
BA	106 056.00	
BB	36 913.00	
PO	44 268.00	
NHI		556 689.60
NHR		107 813.70

Source: own processing

Table 6 shows the net returns and optimal management practices distribution in selected regions. In region NZ, BA and BB the highest returns from cultivation of selected crops can be achieved under the high input management with irrigation. In PO region the optimal management practice, which should be applied is high input management without irrigation.

Tab. 7 Shadow prices of crop production choices in selected regions (€)

Region.MP	MARGINAL	Region.MP	MARGINAL
NZ.NZI	-1287.08	BB.NZI	-421.38
NZ.NZR	-729.79	BB.NZR	-159.51
NZ.NHI		BB.NHI	
NZ.NHR	-11.16	BB.NHR	-164.55
BA.NZI	-889.28	PO.NZI	-539.74

BA.NZR	-537.11	PO.NZR	-153.13
BA.NHI		PO.NHI	-48.84
BA.NHR	-123.35	PO.NHR	

Source: own processing

Shadow price (MARGINAL) of crop production represents how would the net return changed if the crops where cultivated under different management practice. If the crops where cultivated under NZI management in region NZ on one hectare of arable land, net return for region would decreased by 1287.08€. The smallest decreases are observed between NHI and NHR managements.

Clearly switch to lower input management practice would mean a decrease in net returns. These results are in accordance with current research findings. For example, according to Mitter et al. (2015) who applied a portfolio optimization model for Austria, crop production portfolios include higher shares of intensive crop management practices, increasing average crop yields by 2- 15% and gross margins by 3-18% under changing climate. According to them solution might be the threefold increase in agri-environmental premiums which would reduce nitrogen inputs by 23–33%. On the other hand it would also lead to decrease of crop yields and net returns by 18–37%, on average.

4 Conclusion

The fertile lowlands are primary locations of almost all agricultural production in Slovakia. The major part of arable land over the period 2004-2014 was devoted to the cultivation of cereals (57%), followed by feed crops (20%) and industry crops (19%).

Our analysis was therefore focused on two regions from production areas with different natural conditions for crop cultivation – the most fertile MPA (NZ and BA) and the least fertile MNPA (BB and PO). We employed only four crops for simplification: wheat, grain maize, green maize and rapeseed. The aim of analysis was to develop bottom-up integrated optimization model integrating economic and biophysical data. The economic data comprised direct cost and prices of selected crops for regions and biophysical data provided information on yields under the different management practices. The management practices were focused on nitrogen input and irrigation. We used the average economic and biophysical data for the period 2004-2014.

Results showed that the regions produce the highest net returns when the crop production is managed with use of high nitrogen input and irrigation. This management practice proved to be most suitable for all regions except of PO, where the most suitable crop production choice is high nitrogen input without irrigation. The low input management with irrigation seemed to be the least profitable choice as under this management practice selected crops achieve the lowest yields and the low yield with combination with direct costs cause low net returns or even loss in case of PO.

High nitrogen input and irrigation represent conventional way of managing the crop production, which might cause environmental pressures in terms of depletion of water resources and soil degradations. The initiative in form of policy premiums might motivate the farmers to shift toward low input, sustainable and ecological management practices, while ensuring the high returns from crop productions. Therefore, for the direction of future research it would be beneficial to work on policy scenarios in order to determine the possible initiatives toward lower input management practices. It would be also vital to involve medium input management practice under this policy scenarios.

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