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Resilience of dairy farms measured through production plan adjustments

Odpornost kmetij s prirejo mleka z različnimi prilagoditvami proizvodnega načrta

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ABSTRACT

In this study, the resilience of farm production plan through different management adjustments was analyzed. For this purpose, a farm model based on mathematical programming was applied. Through organized workshops typical farms focusing on dairy production were defined through qualitative and quantitative classification. Data were obtained from various databases and expert assessments from the agricultural sector. Analysis of resilience was carried out for three of these typical dairy farms. Using the farm model, the production plan of each farm was reconstructed in the first step and then tested for possible deviations from the baseline. Gross margin was used as the main economic indicator. The results show that the typical farms have very different levels of efficiency and potential for improvement. Furthermore, it was found that all farms can achieve significantly higher gross margin only with improved feed quality, which indirectly leads to a lower need for purchased feed and consequently to lower variable costs and higher gross margin. The level of the latter is also significantly affected by the milk yield achieved, especially on larger farms. However, on smaller farms they can improve profitability more significantly by keeping dairy cows on pasture to a greater extent, which results in a reduction in harvesting costs.

Keywords: animal breeding, milk production, economic analysis, impact assessment, mathematical programming

IZVLEČEK

V študiji smo analizirali odpornost proizvodnih načrtov kmetij z različnimi prilagoditvami upravljanja. V ta namen smo uporabili model kmetijskih gospodarstev, ki je temeljil na matematičnem programiranju. Z organiziranimi delavnicami smo s kvalitativno in kvantitativno klasifikacijo definirali tipična kmetijska gospodarstva usmerjana v prirejo mleka. Podatke smo pridobili iz različnih podatkovnih zbirk in strokovnih ocen. Analizo prožnosti smo opravili na treh tipičnih kmetijah. V prvem koraku smo z modelom rekonstruirali proizvodni načrt vsake kmetije in nadalje analizirali morebitna odstopanja od izhodišča. Kot glavni ekonomski kazalnik smo uporabili bruto dodano vrednost (BDV). Ugotovili smo, da imajo analizirane kmetije zelo različne stopnje učinkovitosti, kot tudi možnosti za izboljšanje. Nadalje smo ugotovili, da lahko vse kmetije dosežejo pomembno višje pokritje zgolj z izboljšano kakovostjo pridelane krme, kar posredno privede do manjših potreb po kupljeni krmi in posledično nižjih spremenljivih stroškov ter višje bruto dodane vrednosti. Na višino slednje pomembno vpliva tudi dosežena mlečnost, zlasti je ta vpliv izrazit na večjih kmetijah. Na manjših kmetijah pa lahko ekonomičnost izboljšajo predvsem z vključevanjem večjega obsega paše krav molznic, kar vpliva predvsem na znižanje stroškov spravila.

Ključne besede: živinoreja, prireja mleka, ekonomska analiza, analiza poslovanja, matematično programiranje

INTRODUCTION

Measuring the performance of a farm business, as well as monitoring how resilient an individual agricultural holding (AH) might be to various changes is becoming a very important focus in farm management. Both in finding solutions to improve operations as well as finding appropriate measures to adapt farms to a more demanding economic situation. However, such analysis can be very challenging if there is not enough data available. Moreover, even in cases where some data are available at the level of a single AH, technological and economic data are often lacking. These are some facts why recent research in agricultural economics also focuses more often on the analysis of typical agricultural holdings (TAH).

The definition of TAH has advantages if it is based on the economic performance data of each AH (Köbrich et al., 2003). Due to the great diversity in the political, social, economic, and technological environment, the economic analysis of a single sector in agriculture can be analyzed based on farms defined in specific groups. TAH can be defined on the basis of a group of AH with common characteristics, according to criteria established qualitatively and quantitatively (Robles et al., 2005).

Classification and typification of farming systems is a fundamental step in building models to represent agricultural decision-making situations (Köbrich et al., 2003). The definition of TAH is the process of classifying, describing, comparing and interpreting or laying out a set of characteristics or elements based on selected criteria that allow the reduction and simplification of a set of characteristics to a few basic types. TAHs are model farms defined to facilitate understanding of complex agricultural systems. With TAHs, we simplify the diversity within agricultural systems by classifying AHs into homogeneous groups (Alvarez et al., 2018). The differentially defined TAHs can be further used for two purposes. The first purpose allows economic analyzes at the level of individual TAHs and, with further appropriate extensions, can reflect the situation at the level of a single sector or agriculture as a whole. The second purpose allows production plan reconstructions and scenario analyzes to be carried out at the TAH level and the results to be transferred and benchmarked at the AH level.

Most of the research dealing with TAHs has been published in the last two decades. In some studies, researchers have defined TAHs and used them for impact analysis. Others have only defined them but used or developed a new approach to defining TAHs. For example, Köbrich et al. (2003) defined TAHs in Chile and Pakistan using factor analysis and cluster analysis. Robles et al. (2005) identified five TAHs in the El Páramo region of northern Spain using cluster analysis. Rednak et al. (2009) used data from the Agency of the Republic of Slovenia for Agricultural Markets and Rural Development, the statistical census and the FADN on TAHs and used cluster analysis to define TAHs. In Uruguay, Righi et al. (2011) quantitatively defined seven TAHs based on data on available labor, level of mechanization, and proportion of land under irrigation to achieve sustainable development. Kuivanen et al. (2016) classified 70 AHs in the northern part of Ghana into six TAHs. The classification was based on data obtained from a survey. The data were analyzed using two multivariate statistical methods, cluster analysis and principal component analysis. TAHs were defined based on the variables of households, work, activity, type of livestock and income. Lopez-Ridaura et al. (2018) classified 269 farms in India into five TAHs. Multivariate statistical methods were used to classify them into TAHs. Impact analyzes were tested for TAHs and compiled according to the occurrence of extreme weather events and agricultural intensification.

To support planning, farm models have been developed for almost two decades, progressively complementing the previously dominant sectoral models based on partial and general equilibria (Van Tongeren et al., 2001; Langrell et al., 2013). Farm-level modeling requires comprehensive farm-level data sources. The main advantage of using TAHs is that various economic indicators can be analyzed through modeling (Breen et al., 2019). Farm systems models are used to link economic theory and data, solve practical problems, and create policies. Hazell and Norton (1986) outlined the potential benefits of modeling, i.e. conceptually they are quite abstract, but if used wisely they can be used for various analyzes and to support management decisions at different levels by estimating various economic and/or environmental indicators for a sector or farm type and also provide guidance for policy makers. Indeed, impact assessment to different policy scenarios should be part of an evidence-based approach of agricultural policy and help decision-makers in planning policies, including the EU Common Agricultural Policy (Lee and Kirkpatrick, 2006). This is also in line with the apparent shift towards more outcome-based agricultural policies and a clear commitment to policies based on evidence and established intervention logic (Lovec et al., 2020).

In the past, researchers have developed many models with different purposes to address challenges in agriculture. Breen et al. (2019) developed a model to optimize milk production. Finneran et al. (2010) simulated feed costs. Stamenkovska et al. (2013) analyzed the economic situation of vegetable farms. Ferreira et al. (2007) developed a model for the selection of shellfish species in aquaculture, the economic optimization of their cultivation and the choice of cultivation site in relation to the effects of eutrophication on the surrounding water. Examples of modeling in agriculture in Slovenia include fertilizer planning (Žgajnar and Kavčič, 2011), feed ration optimization (Žgajnar et al., 2007), emergy analysis (Kocjančič et al., 2018), and economic analysis of the equestrian center (Žgajnar, 2015). To analyze the impact of agricultural policies, the European Commission uses the IMF CAP model, which is also based on a mathematical programming approach (Langrell et al., 2013). Žgajnar et al. (2020) present an example of a future CAP scenario analysis that uses the same farm model tool as our study.

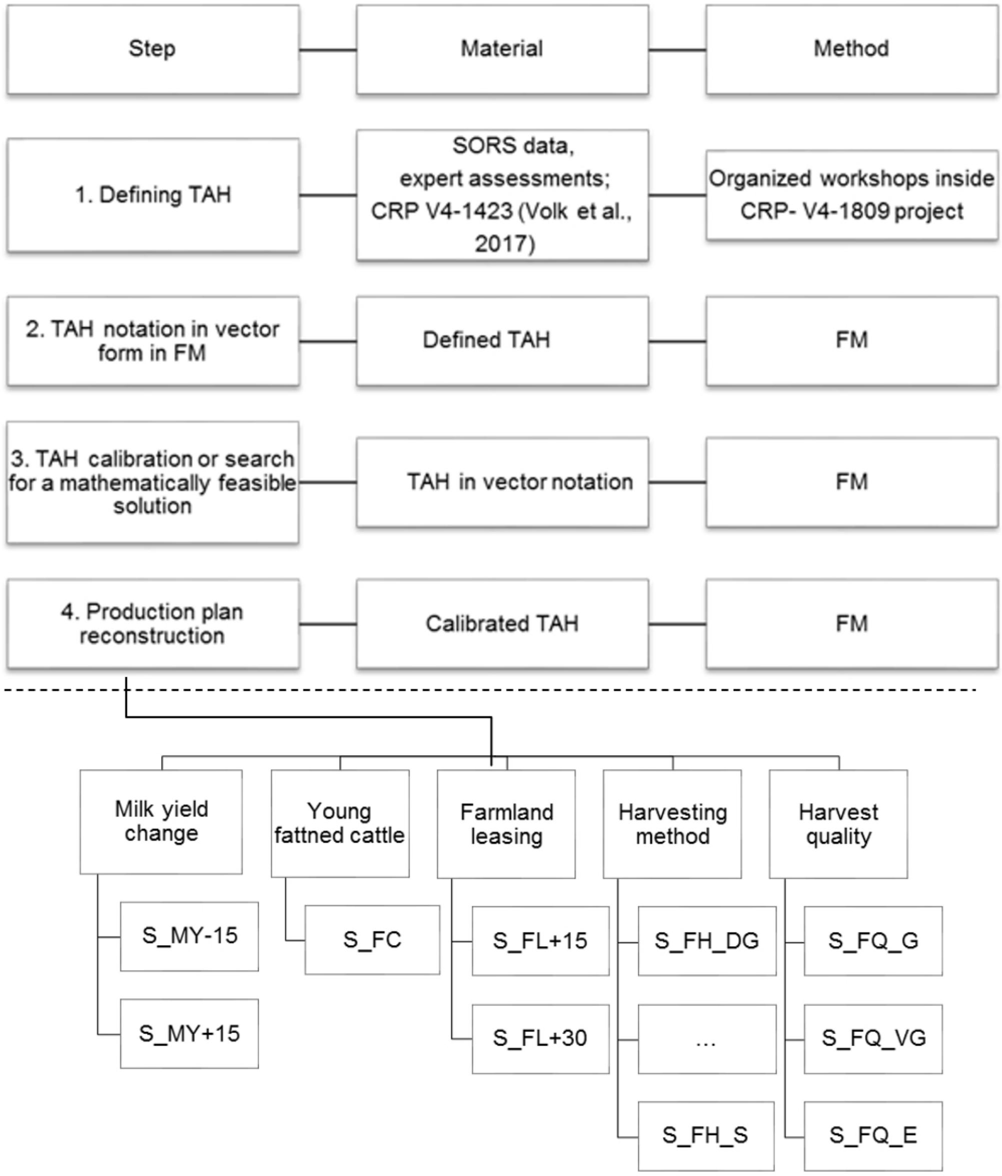
In this study, we analyzed selected TAHs focusing on milk production. Moreover, we present materials and methods for our study, followed by the results, with the aim of proving the following hypotheses: i) the farm model, based on linear programming, enables reconstruction of the production plan of selected TAHs, which is the starting point for further economic analysis; ii) the approach enables analysis at TAH level; and iii) TAHs have different cost efficiency and potential for improvement, which is reflected in different scenarios.

MATERIALS AND METHODS

Dairy production oriented typical agricultural holdings

Our study focuses on the analysis of the economically most important Slovenian livestock activity, i.e. milk production. Dairy production represents the largest share (30%) in the structure of total income of Slovenian agriculture (Žgajnar et al., 2021). The number of AH, where dairy cows are kept, was 6,541, with a total number of 100,098 dairy cows in 2019 (Agricultural Institute of Slovenia, 2020). Based on the study by Volk et al. (2017), we defined the structures of those TAHs that cover a part of Slovenian agricultural production, taking into account the actual size structure of AHs in Slovenia and their economic importance. In order to define the main technological parameters of production on TAHs, we performed qualitative and quantitative classification in organized workshops with expert estimations of technological and economic parameters. Our approach was conducted interactively in several steps (Figure 1). In the first step, TAHs were defined based on standard assessments and accessible databases (Volk et al., 2017). In the second step, typical agricultural holdings were defined according to the number of dairy cows kept on TAHs. Within each class, TAHs were subdivided by the region in which they are located, as well as by breed and average milk yield per cow. Other production resources that are in some way required and typical for each AH were defined. Based on these parameters for each TAH, the third step was to reconstruct the production plans for each analyzed agricultural holding.

Since this was a preliminary analysis, three TAHs were selected, one in the dairy cow class 5 to 9 (TAH1), one in the dairy cow class 10 to 14 (TAH2), and one in the dairy



SORS - Statistical Office of the Republic of Slovenia; FADN - network of accounting data from agricultural holdings; CRP - target research project; TAH - typical agricultural holding; FM – farm model; S_MY - scenario related to milk yield change; S_FC - scenario related to young fattened cattle; S_FL - scenario related to farmland leasing; S_FH - scenario related to forage harvesting method; S_FQ - scenario related to grassland crop quality

Figure 1. Summary of the course of the analysis with the farm model and the implementation of the scenario analysis

cow class 20 to 29 (TAH3)[1]. TAH1 is located in a hilly area belonging to the Less-Favored Area (LFA), while TAH2 and TAH3 are located in the lowlands, with better tillage conditions. The main production activity of all three TAHs is dairy cow breeding. An additional livestock production activity is heifer breeding for herd replacement and surplus for sale. There are six main production activities on each of the three TAHs. Fodder wheat, barley, maize silage, and potatoes are grown on TAH1. Identical farming activities to those on TAH1 also exist on TAH2, which differs from TAH1 in the harvesting method, i.e. they harvest some of the maize as grain. On TAH3, no wheat or potatoes are grown, barley is sold, and part of the maize is fed as grain and part as silage. The basic production parameters are shown in Table 1.

[1] Together, these three types of farms contribute slightly less than 3% of the output of total agriculture and account for more than 9% of farms in the dairy sector. However, more than 50% of dairy farms are classified in these dairy cows size classes, but they are represented by slightly different types that are not included in this analysis. Farms with fewer dairy cows than analyzed represent more than 35% of all dairy farms.

Table 1. Basic characteristics of livestock production in TAHs*

			TAH1	TAH2	TAH3
Livestock activities	Number of dairy cows		9	12	25
	Number of heifers		3	4	8
	Milk production per cow	(l)	9,500	8,000	7,000
	Heifer weight	(kg)	550	550	550
	Cow weight	(kg)	700	700	700
Available resources	Owned land				
	Field	(ha)	2	5	8
	Meadow	(ha)	5	5	10
	Rented land				
	Fields and meadows	(ha)	1	1	1
	Own labor	(AWU)	1	1.1	1.8

TAH1 – first typical agricultural holding; TAH2 – second typical agricultural holding; TAH 3 – third typical agricultural holding; AWU – annual work unit; * – The data were generated in a workshop with experts and consultants as part of the CRP V4-1809 project

Farm model

In Slovenia, a farm model (FM) based on the mathematical programming approach was developed to analyze the situation at the operational level (Volk et al., 2017). It is a modular approach. The complex system of model calculations (reference and unpublished) created by the Agricultural Institute of Slovenia (AIS) is fully integrated in FM. On this basis, production and economic indicators are calculated to measure production activity.

For this study, the farm model (FM) was applied. FM is a dynamic, modular tool developed in the form of spreadsheets in MS Excel and exploits the potential of VBA macros. FM allows the adaptation of the Model calculations prepared by AIS (2021) and uses them as the main source of information for farming production activities that can be included in the (optimal) production plan. The FM consists of several sub-modules, which are presented in more detail by Volk et al. (2017) and Žgajnar et al. (2020). The main contribution of FM for this study is the aim to analyze the production plan at the TAH level in more detail from farm management perspective.

Whenever activities at a TAH level are converted into a production plan, certain constraints have to be considered. These can be divided into several groups. The main group is "technological constraints", which capture the number of animals per category and the available tillage area. An important group of constraints is related to the balance of nutrients from the feed ration point of view, based on the possibilities of own production per TAH. Another important group is devoted to the constraints of crop rotation, and the share of different technologies of grass harvesting, etc.

The final production plan of the TAH, also called baseline, is the result of a calibration process carried out with FM and based on the optimization possibilities of mathematical programming. It should be noted that the basic guideline in the reconstruction of each production plan was that the model takes into account the given main production constraints while maximizing the expected gross margin (GM). In this way, FM finds the optimal (feasible) production plan that would be expected in practice, taking into account the given natural conditions of each TAH. These parameters were defined at organized workshops explained in the previous chapter. However, in order to obtain a positive solution from the point of view of economic theory, an additional set of calibrating constraints was introduced. It is a partial optimization procedure presented by Žgajnar and Kavčič (2016). Average prices from 2016 to 2018 were considered for all purchased and sold inputs and outputs.

Scenario analysis

Using FM, we analyzed five sets of scenarios (Figure 1), shown below, related to different philosophies of production plan resilience and change in economic indicators. We used the same set of scenarios for all three typical farms. The main objective was to find possible improvements through technological adjustments. In the following, we briefly present each scenario with the main assumptions corresponding to the baseline condition of a single TAH.

In the first set of scenario analyzes, we were interested in how the change in milk yield per dairy cow (S_MY) affects the economics of TAHs. We assumed that milk yield could decrease (S_MY-15) or increase (S_MY+15) by 15% in relative terms.

All three TAHs are assumed not to raise young cattle for fattening. In the second scenario (S_YC), we therefore included raising young cattle for fattening as a possibility, with the aim of analyzing the impact of the included activity on the economics of the TAHs. The general technological assumptions for young cattle were the same as in the standard model calculation (AIS, 2021).

For the third set of scenario analyzes, it was assumed that additional tillage area could be leased on TAHs. In this scenario (S_FL), we wanted to analyze how additional farmland leasing would affect the economics of TAHs. We implemented two sub-scenarios for all three TAHs. In the baseline scenario, all three TAHs could lease up to 1 ha of permanent pasture and 1 ha of arable land. In the further two scenarios, we estimated the impact of increased leasing up to 15% (S_FL+15) or up to 30% (S_FL+30) compared to the baseline scenario. Given the possibility of leasing additional arable land, we assumed that TAHs could also hire additional labor, as this could be a limiting factor in such a scenario.

In a more comprehensive fourth scenario, we analyzed how economically stable TAHs' solutions to forage harvesting and conservation technology are (S_FH). We designed six sub-scenarios depending on the combination of different harvesting methods. In the first three sub-scenarios, we assumed that the model can only choose one type of hay harvesting on grassland (harvesting hay dried on the ground (S_FH_DG), hay dried on the ground and stored in bales (S_FH_B), or hay dried in cold air dryers (S_FH_DCA)). Thus, it is assumed that the TAH chooses one harvest type and the other two options (grass silage - bales and grass silage - silo) are available as defined in the baseline of each TAH. In the fourth sub-scenario (S_FH_G), we were interested in how the economics of the TAH would change if dairy cow grazing was included without changing the constraints on the other harvest methods. In the fifth and sixth sub-scenarios, we analyzed the impact on farm profitability of ensiling all forage from grassland in the form of bales (S_FH_SB) or in silos (S_FH_S).

In the fifth set of sub-scenarios, we analyzed how the quality of forage produced on the grassland affects the economics of the TAH. The quality of the crop on the grassland is calculated as the nutritional value of the forage in FM. The quality of the crop on the grassland is classified into four quality classes (poor, good, very good and excellent) in FM. In TAH1, the quality of the crop on grassland is assumed to be very good, and in TAH2 and TAH3, the quality is good. We designed three hypothetical sub-scenarios, namely how the economic outcome of TAH is affected by good (S_FQ_G), very good (S_FQ_VG) and excellent (S_FQ_E) quality of grassland yield, assuming that this is a consequence of management efficiency.

RESULTS AND DISCUSSION

Reconstructed baseline production plan for TAHs

In the following section, we briefly present the main economic and technological results for each TAH. Furthermore, we present the results of each analyzed scenario and summarize the main findings that could most effectively improve the economic situation of individual TAHs or, on the other hand, pose a risk if inadequate management is in place.

As shown in Table 2, the main differences between individual TAHs are the number of dairy cows, breeding dairy heifers and available farmland and its use.

Table 2. Baseline indicators of typical agricultural holdings

		TAH1	TAH2	TAH3
Economic indicators				
Revenue	(EUR)	40,661	45,729	81,090
Variable costs	(EUR)	20,851	21,216	38,831
Gross margin	(EUR)	19,810	24,513	42,259
GM per hour	(EUR/h)	11.01	12.38	13.66
GM per arable land	(EUR/ha)	2,476	2,169	2,348
GM per dairy head	(EUR/head)	2,201	2,043	1,690
Technological indicators				
Arable land				
Own/hired				
Arable land	(ha)	2/1	5/1.0	8/1
Grass land	(ha)	5/0	5/0.3	10/1
Labor				
Own	(h)	1,800	1,980	3,094
Production activities				
Livestock activities				
Dairy cows	(head)	9	12	25
Milk yield	(kg)	9,500	8,000	7,000
Heifers	(head)	3	4	8
Grass land activities				
Grass silage (S)	(ha)			3.95
Grass silage (SB)	(ha)	3.58	3.71	3.53
Grass silage (S, F)	(ha)			3.10
Hay (dried on the ground)	(ha)	0.51	0.53	
Hay (bales)	(ha)	0.51		3.53
Hay (CA)	(ha)		1.06	
Hay (CA, F)	(ha)	0.51		
Agricultural activities				
Wheat	(ha)		1.12	
Barley (fodder)	(ha)	1.00	0.38	
Barley (market)	(ha)			1.35
Corn for grain	(ha)		3.00	2.40
Corn silage	(ha)	0.81	1.15	2.15
Potato	(ha)	0.69	0.35	

TAH1 - typical agricultural holding 1; TAH2 - typical agricultural holding 2; TAH 3 - typical agricultural holding 3; S - trough silo; SB - trough silo bales; CA - cold air drying; F - field cultivation

TAH1 achieves a slightly lower turnover compared to TAH2, but the variable costs are almost the same. As a result, TAH1 achieves a relatively lower gross margin compared to TAH2. TAH3 achieves significantly higher sales compared to TAH1 and TAH2, mainly due to higher milk production. The high variable costs in TAH1 are due to large-scale potato production, which accounts for a significant proportion (17.53%) of TAH1's turnover. TAH2 achieves a significantly lower gross margin than TAH1 (Table 2). TAH3 achieves a higher gross margin per hour compared to TAH1 and TAH2. The economic and technological indicators of each TAH are the starting point for further scenario analyzes.

Change in milk yield

In the scenarios for achieving higher milk yield per dairy cow (S_MY), we mainly expected higher turnover, additional costs due to higher ration costs for dairy cows, more purchased feed and a change in forage production on grassland. As the level of milk yield on specialized dairy farms is one of the key factors, we analyzed within S_MY scenario what changes could occur from this perspective. It is expected that increased milk production will significantly affect the economic indicators of TAHs.

There are large differences in the gross margin achieved between TAHs (Table 3). The additional purchase of feed at higher milk yield of dairy cows increases variable costs on the farm, but in terms of achieving a higher gross margin, the solution in all TAHs is better than the baseline, as expected. By increasing milk yield, TAH2 has to significantly adjust the plan of each farming activity, i.e. reduce the production of wheat and potatoes and increase the production of feed barley and maize for cereals. The different level of agricultural activities leading to an optimal solution is due to the structure of the feed ration and the different nutrient requirements that dairy cows have due to higher milk yield. During the agricultural activities, the amount of potato production on TAH2 changes significantly with the change in milk yield. In the scenario of 15% decrease in milk yield of dairy cows, the quantity of production increases by 94.28% and in the scenario of 15% increase in milk yield (MY+15), the quantity of potato production decreases by 91.43%. The results show that potato production is an important activity on TAH2. As expected, given the improved economic indicators, the change in milk yield on TAHs has an impact on the economic outcome, so it would be useful to focus on further development to increase milk production, either by raising more genetically efficient animals, improving breeding technologies and to some extend feed quality.

Young fattened cattle

The breeding of beef cattle is suitable on TAH2 and TAH3. Raising one and four beef cattle (optimal) increases GM by 0.75% (TAH2) and 7% (TAH3), respectively. A

Table 3. Effect of changed milk yield (MY) on economic parameters on TAH

		TAH1			TAH2			TAH3		
		BA	MY-15	MY+15	BA	MY-15	MY+15	BA	MY-15	MY+15
R	(EUR)	40,661	39,027	42,294	45,729	44,266	47,207	81,090	73,885	88,258
VC	(EUR)	20,851	19,958	21,489	21,216	21,026	21,312	38,831	34,087	43,228
GM	(EUR)	19,810	18,910	20,805	24,513	23,240	25,895	42,259	39,798	45,031
GM/h	(EUR/h)	11.01	10.51	11.56	12.38	11.74	13.08	13.66	13.51	13.90
PM	(t)	22.19	18.03	25.66	/	/	/	30.58	15.73	43.76
PR	(t)	8.69	6.10	11.32	9.48	6.61	13.07	14.79	9.37	20.34

TAH - typical agricultural holding, R - revenue, VC - variable costs, GM - gross margin, PM - purchase of maize, PR - purchase of rapeseed; BA - baseline; MY-15 - scenario, where milk yield is decreased by 15%; MY+15 - scenario, where milk yield is increased by 15%

constraint in raising young beef cattle is the amount of labor required, e.g., for TAH3 the total labor hours are 3,094. In raising beef cattle, TAH3 would spend 34.66 hours per cattle per year, so four beef cattle is the optimal number that TAH3 can raise because they consequently use all 3,240 available family labor hours. When raising young beef cattle, cropping must be adjusted by reducing the amount of grain maize and increasing the amount of maize silage.

Farmland leasing

In the following scenarios, the effect of leasing agricultural land on the profitability of TAHs was analyzed. The achieved GM on TAH1 in scenario S_FL+15 increases by 4.63% and in scenario S_FL+30 by 5.63%. With the additional leasing of agricultural land, potato production on TAH1 is increased as potato production generates a higher GM per hectare, this is expected. Potato production in scenarios S_FL+15 and S_FL+30 increases by one hectare. Barley production on TAH1 with additional tillage area is not economically justified, so the volume of barley production on TAH1 decreases. The optimal volume of corn production for grain with additional lease of agricultural land on TAH1 remains the same. The achieved gross margin on TAH2 increases minimally, namely by 0.08% in scenario S_FL+15 and by 0.15% in scenario S_FL+30. Within the crop activities in the optimal solutions in scenarios S_FL+15 and S_FL+30, the production of grain maize and wheat increases and the production of feed barley decreases. On TAH3, GM increases minimally, namely by 0.57% in scenario S_FL+15 and by 1.15% in scenario S_FL+30. In scenario S_FL+15 and S_FL+30, the volume of grain maize production increases by 11.25% and 22.92%, respectively. Grain maize is an important component of the feed ration for dairy cows and breeding heifers on TAH3, and with increased farmland leasing, the volume of purchased maize decreases, as maize can be produced on the farm itself.

Harvesting method

Variable costs could be reduced by 7% in TAH1 if hay was not baled (B) or dried with cold air dryers (DCA), but dried exclusively in the meadow (DG; Table 4). This effect would be even higher if fixed costs for drying equipment, which are not considered in this analysis, were included. Drying hay in a meadow or field is economically optimal in TAH1 from a reduction perspective VC. In TAH1, grazing (G) should be considered because VC is reduced by about 5%. VC is reduced by 11% if silage is harvested in a trough silo (S). Of course, this does not take into account daily removal and possible problems with silage spoilage. In TAH2, it is also economically optimal to set up a grazing system for dairy cows and breeding heifers, as variable costs are reduced by 1.78% in this scenario. In TAH2, variable costs are significantly reduced by extensive ensiling (8.10%), while they are only slightly reduced by baling the silage (0.11%; Table 4). In TAH3 production plans, VC is reduced by about 9% when grassland is harvested exclusively as hay (DG), baled (B) or dried with cold air (DCA; Table 4). It is assumed that only one of the harvesting methods is used on TAH3. In TAH3, it is economically justified to harvest hay using only one of the options compared to combining each harvest method.

Table 4. Relative change in variable costs and gross margin due to different harvesting method scenarios compared to the baseline

Scenario		DG		B		DCA		G		S		SB	
Parameter		GM	VC	GM	VC	GM	VC	GM	VC	GM	VC	GM	VC
TAH1	(%)	5.71	-7.01	4.56	-3.01	-7.05	1.72	12.29	-4.92	9.43	-11.12	1.69	-0.54
TAH2	(%)	0.07	0.19	-0.30	1.81	-0.04	-0.10	4.24	-1.69	6.73	-8.10	0.54	-0.11
TAH3	(%)	7.62	-9.28	6.86	-8.58	7.59	-9.24	0.30	-0.37	-7.30	7.83	3.82	-4.10

TAH1 - typical agricultural holding 1; TAH2 - typical agricultural holding 2; TAH3 - typical agricultural holding 3; VC - variable costs; GM - gross margin; DG - harvest of hay dried on the ground, B - hay dried on the ground and stored in bales; DCA - hay dried on cold air dryers; G - grazing; S - silo; SB – silage bales

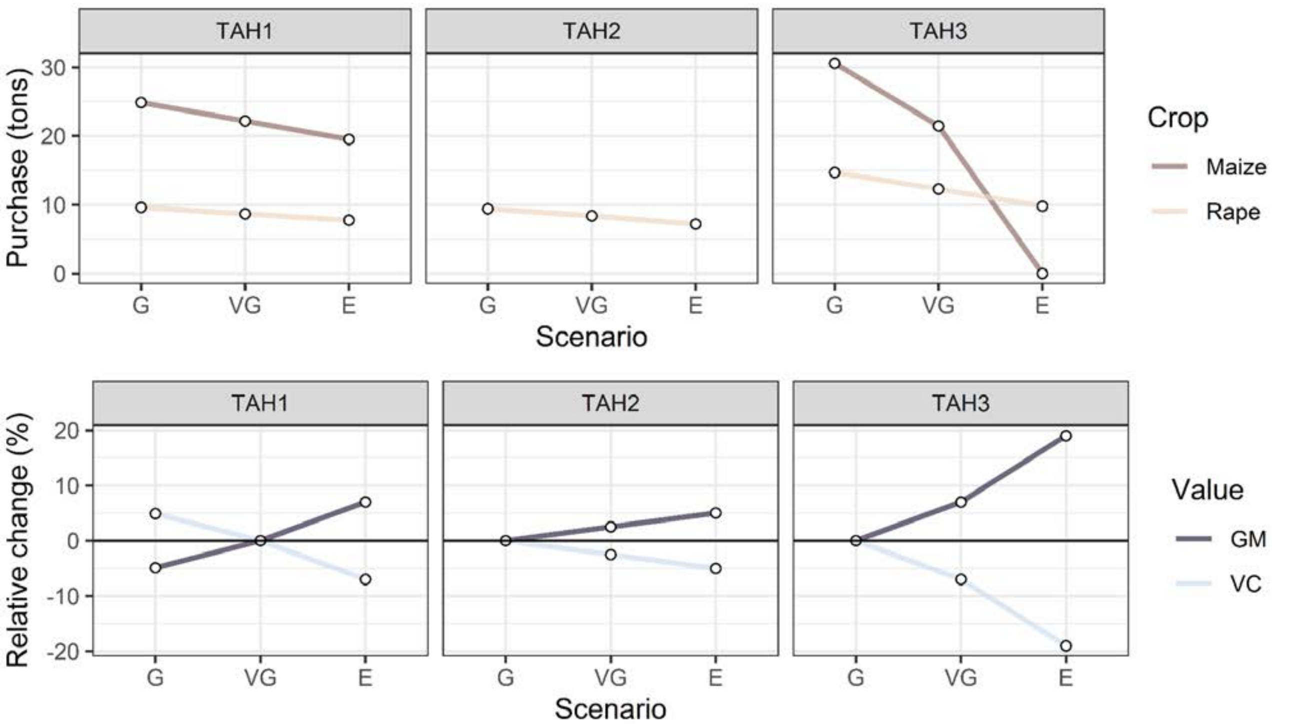
Harvest optimization results are economic parameters and do not apply to farms that cannot incorporate a particular harvest method into the production plan.

Quality of fodder grown on grassland

The importance of the quality and nutritional value of the forage produced on the grassland was simulated with the next set of scenarios (S_FQ). As expected, the higher the nutritional value of the grassland forage, the higher the gross margin, and less forage needs to be purchased from the TAH (Figure 2), as more nutrients are produced on the farm. The latter is mainly reflected in the need to purchase maize and rape and thus a significant reduction in VCs, but this also significantly reduces the production risk from large fluctuations in feed prices. However, there are differences in potential between TAHs. In TAH1, where quality of grassland forage is very good at the beginning, the necessary purchase of maize and rapeseed pomace is reduced by 12.12% and 10.59%, respectively, which is also reflected in an optimal solution, i.e. GM increases (7.92%, Figure 2). In TAH2, where only rapeseed pomace and no maize is purchased, 23.45% less rapeseed pomace needs to be purchased in the S_FQ_E scenario than in the baseline scenario and the relative change is +5.21% of the GM. There is significant potential for improvement in TAH3, where the gross margin is 20.56% higher in the excellent grassland nutrition scenario. The largest change (-33.09%) in rapeseed pomace purchase in TAH3 is estimated if better management succeeds in achieving excellent hay and grass silage quality. In such a scenario, there is no need to purchase as it would be entirely home grown. The reduced need for purchased feed preserves the variable costs identified.

Cross-comparison of the scenario analyzes

The results of the achieved variable costs (VC) and gross margin (GM) from all scenario analyzed are shown in Table 5. Among the selected scenarios for production plan reconstruction, the highest GM would be achieved on TAH1 if grazing was possible (Table 5, S_FH_G). The GM achieved could also be increased by additional renting of agricultural land (S_FL+15, S_FL+30).



VC - variable costs, GM - gross margin; G - a scenario in which the quality of grassland is good; VG - a scenario in which the quality of grassland is very good; E - a scenario in which the quality of grassland is excellent; TAH1 - typical agricultural holding 1; TAH2 - typical agricultural holding 2; TAH3 - typical agricultural holding 3

Figure 2. Effect of the fodder quality produced on grassland on the quantity of maize and rapeseed pomace purchase and the relative change in the level of variable costs and gross margin

Table 5. Synthesis of variable costs and gross margin achieved in different scenarios

		TAH1		TAH2		TAH3	
BASELINE	(EUR)	VC	GM	VC	GM	VC	GM
S_MY-15	(%)	-4.28	-4.54	-0.90	-5.19	-12.22	-5.82
S_MY+15	(%)	+3.06	+5.02	+0.45	+5.64	+11.32	+6.56
S_FC	(%)	-0.03	+0.14	+2.02	+0.75	+5.62	+7.07
S_FL+15	(%)	+22.43	+4.62	+2.16	+0.08	-0.30	+0.57
S_FL+30	(%)	+25.47	+5.63	+2.03	+0.15	-0.61	+1.15
S_FH_DG	(%)	-7.01	+5.71	+0.19	+0.07	-9.28	+7.62
S_FH_B	(%)	-3.01	+4.56	+1.81	-0.30	-8.58	+6.86
S_FH_DCA	(%)	+1.72	-7.05	-0.10	-0.04	-9.24	+7.59
S_FH_G	(%)	-4.92	+12.29	-1.69	+4.24	-0.37	+0.30
S_FH_SB	(%)	-11.12	+9.43	-8.10	+6.73	+7.83	-7.30
S_FH_S	(%)	-0.54	+1.69	-0.11	+0.54	-4.10	+3.82
S_FQ_G	(%)	+3.62	-3.81	/	/	/	/
S_FQ_VG	(%)	/	/	-1.55	+2.36	-6.13	+5.63
S_FQ_E	(%)	-6.99	+7.92	-5.30	+5.21	-19.80	+20.56

TAH - typical agricultural holding, R - revenue, VC - variable costs, GM - gross margin, PM - purchase of maize, PR - purchase of rapeseed; BA - baseline; MY-15 - scenario, where milk yield is decreased by 15%; MY+15 - scenario, where milk yield is increased by 15%

To achieve a higher gross margin, the production plan could be changed towards integrated silage harvesting trough silo, where a higher gross margin is achieved compared to baling, where the costs are higher. However, this is certainly a solution that is not acceptable in practice due to technological regularities, especially the insufficient removal of grass silage. It is expected that the obtained gross margin on TAH2, similar to TAH1, will be positively influenced by higher milk yield (Table 5, S_MY+15). Higher GM on TAH2 could be achieved with silage conservation trough silos. GM could also be significantly increased by increasing quality of grassland forage (S_FQ_E), which could lead to lower feed purchase, lower variable costs and consequently higher GM. Milk yield of dairy cows (S_MY) has a significant effect on GM achieved on TAH3 (Table 5).

CONCLUSIONS

The farm model and the applied mathematical programming allow the reconstruction of the production plan at the level of typical agricultural holdings and the measurement of the resilience of the farm plan. The calibration of the production plan is of great importance due to the complex farming system. In the applied approach, the optimization potential of linear programming is mainly used to generate the production plan and consider all nutrients balances and other inputs at the typical agricultural holdings, which greatly facilitates the analysis. The approach used allows for a relatively straightforward analysis of impacts under different assumptions, which was illustrated with a series of scenario analyzes. TAHs have different levels of economic efficiency, which is reflected in different scenarios and indirectly represents farm resilience. Gross margin (GM) could be increased by improving quality of grassland forage, leading to lower feed purchases, lower variable costs and consequently higher GM. Milk yield of dairy cows has a significant influence on GM, especially on larger farms. On smaller farms, GM increases most significantly when cows are kept on pasture, as variable costs are lower with other harvesting methods. The obtained results show that despite standardized scenarios and unchanged technological assumptions for TAHs and the same price level between scenarios, the economic outcomes differ, which is reflected in different TAH resilience potential. These results suggest that this approach could be further applied on other typical agricultural holdings representing other sectors of agriculture. Namely, these results could be informative for policy makers to get an information which farm types and in what extend are resilient and how much through adjustment of production plan and improved technologies could be adjusted to a given situation. And in such a manner this is an additional information in the process of creating more efficient policy measures that encourage farms to farm more economically. However, the main limitation of applied approach is that main production activities that also define production type have to remain fixed, even though in some circumstances in practice also they should be changed as they in some manner address structural changes. Another limitation is especially from technological perspective adjustment. Namely the possibility of change in some parameter is to the extent allowed by model calculations (AIS, 2021).

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