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Weighted goal programming and penalty functions: whole-farm planning approach under risk

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Abstract

The paper presents multiple criteria approach to deal with risk in farmer's decisions. Decision making process is organised in a framework of spreadsheet tool. It is supported by deterministic and stochastic mathematical programming techniques applying optimisation concept. Decision making process is conceptually divided into seven autonomous modules that are mutually linked up. Beside the common maximisation of expected income through linear programming it enables also reconstruction of current production practice. Income risk modelling is based on portfolio theory resting on expected value, variance (E,V) paradigm. Modules dealing with risk are therefore supported with quadratic and constrained quadratic programming. Non-parametric approach is utilised to estimate decision maker's risk attitude. It is measured with coefficient of risk aversion, needed to maximise certainty equivalent for analysed farms. Multiple criteria paradigm is based on goal programming approach. In contribution focus is put on benefits and possible drawbacks of supporting weighted goal programming with penalty functions. Application of the tool is illustrated with three dairy farm cases. Obtained results confirm advantage of utilizing penalty function system. Beside greater positiveness it proves as useful approach for fine tuning of the model enabling imitation of farmer's behaviour, which is due to his/her conservative nature not perfect or rational. Results confirm hypothesis that single criteria decision making, based on maximisation of expected income, might be biased and does not necessary lead to the best - achievable option for analysed farm.

Keywords: goal programming, risk modelling, risk aversion, production planning

1. Introduction

Production planning is a complex task, since decision has to be taken considering input and output physical relations, farm natural resources, input and output cost-price ratios and also farmer's preferences. Role of mathematical programming models can be crucial in the analysis of decision making and in searching for possible alternatives at the farm level. Namely, mathematical modelling captures very good agriculture production theory and modelling (Buysse et al., 2007).

The objective of the paper is to present innovative approach of linking relatively simple mathematical methods into complete programming tool to resolve resource allocation problems. Developed modular toll for farm production planning applies different methods. In this way it should enable potential users (policy decision maker, advisers and researchers) systematic analysis of changes at hypothetical model farms. Beside potential applicability of the tool its purpose is also to test different mathematical methods and possibilities of their combination into whole analysing approach. It is expected that obtained results will confirm theoretical and empirical benefits of combining methods for analysis of multidisciplinary impacts on farm decision making under risk. Possible benefits and drawbacks of supporting weighed goal programming with penalty functions will be analysed as well. In contribution we tested also hypothesis that larger farms are less risk averse than smaller farms.

For whole-farm planning approach different methods could be applied. The simplest and most often applied one is common deterministic linear programming approach. The main assumption of this method is linearity of all relations. Hardaker et al. (2007) are stressing that numerous optimization problems could be simplified with linear relations. Further, Ziolkowska (2009) is pointing on its straightforwardness and possibility of displaying and modelling decisions in a simple and transparent way. Nevertheless, no method is free of disadvantages. In some analysing cases assumption of single criteria optimization is too strong and might result in bias solution deviating from expected situation (Gomez-Limon et al., 2003). The process of production planning is quite a complex process and the reduction of several objectives into only one – income or gross margin maximization – might prove too rigid. This is beside fixed (rigid) constraints assumption (deviations are not allowed irrespective of deviation level) one of the main LP drawbacks (Rehman and Romero, 1984; Rehman and Romero, 1987; Lara, 1993).

The reason of using multiple criteria decision making paradigm in the context of the farm production planning can be deduced from the variety of criteria that should be taken into account by farmers. There are different essential factors to be included in decision making - not only economic indicators (expected gross margin or revenue), but also resource allocation (land, labour etc.), risk criteria-parameters, environmental impacts and other public goals that are indirectly captured in different policy measures and laws.

Pioneers in considering more than one conflicting goal in farm production planning in the late seventies of previous century were Wheeler and Russell (Romero and Rehman, 2003). In literature one could find numerous multiple criteria methods based on quantitative approach. Among them goal programming (GP) is most widely used (Azmi and Tamiz, 2010). It was introduced by Charnes and Cooper (Tamiz et al., 1998) and has reached its swing in mid-1970 with a large number of applications (Jones and Tamiz, 2010). Many authors are pointing on two facts that are crucial for its popularity. One is that GP is a generalisation of LP, with basic and very straightforward philosophy. The second one is that common GP model can be solved with conventional (single criterion) optimization software (Aouni and Kettani, 2001; Jones and Tamiz, 2010; Martel and Aouni, 1998). However, in line with its popularity also its criticism and pitfalls arised. Tamiz et al. (1998) exposed the problem of Pareto-inefficient solutions related with axiom of prior definition of target values (Caballero et al., 2006). Steuer and Na (2003) see another pitfall in prior definition of priority levels for goals. Crucial is also that normalisation process is applied to avoid incommensurability (Tamiz et al., 1998). Many authors (Caballero et al., 2006; Romero and Rehman, 2003; Romero, 2004) are stressing on significant impact of proper achievement function' selection on final solution.

In general terms GP minimizes undesired deviations from target values. It is a special compromise multi-criteria method assuming that farmer knows goals' values and their relative importance (Liu, 2008). It is designed to consider many goals simultaneously when searching for compromise solution and is supported by mathematical programming optimisation potential (Martel and Aouni, 1998). Applied philosophy of compromise solution searching defines variety of goal programming technique (Jones and Tamiz, 2010). Each type of achievement function utilised leads to different GP variant. In this study weighted goal programming (WGP) will be applied.

WGP is resting on Archimedean achievement function minimizing the sum of weighted deviations from target values (Equation 1). They are measured using positive and negative deviation variables defined for each goal separately, presenting either over- or underachievement of the goal (b_q). Negative deviation variables (n_q) are included in the objective function for goals that are of the type 'more is better', and positive deviation (p_q) variables are included in the objective function for goals of the type 'less is better'. Since any deviation is undesired, the relative importance of each deviation variable is determined by belonging weights. Kettani et al. (2004) are pointing on two components that weighted factor is composed of and have two different roles in optimisation process. The first one that prevents incommensurability is "normalization[1]" (k_q) and the second one is "valorisation" (u_q and v_q), reflecting decision maker's preferences among goals. For the objective function it is

[1] In the literature different normalisation techniques could be met. For more details see Jones and Tamiz (2010).

typical that it minimises undesirable deviations from the target goal levels and does not minimise or maximise the goals themselves (Ferguson et al., 2006).

$$
\begin{aligned}
& Min\ a = \sum_{q=1}^{Q} \left(\frac{u_q n_q}{k_q} + \frac{v_q p_q}{k_q} \right) \quad s.t. \\
& f_q(x) + n_q - p_q = b_q \qquad q = 1, \dots, Q \\
& x \in F \\
& n_q, p_q \geq 0
\end{aligned} \tag{1}
$$

Within WGP, all deviations are expressed as a ratio difference (i.e., (desired – actual)/desired) = (deviation)/desired)). In this case, any marginal change within one observed goal is of equal importance, no matter how distant it is from target value (Rehman and Romero 1987). From decision making point of view this addresses another issue, namely larger deviations from target level are less acceptable as smaller ones. To keep deviations within acceptable limits and to distinguish between different levels of deviations, a penalty function might be introduced into WGP model (Rehman and Romero 1984). To illustrate the shapes of these marginal changes, different penalty functions could be proposed (for more details see Chang and Lin, 2009).

Penalty functions enable one to define allowed positive and negative deviation intervals separately for each goal. Depending on goal's characteristics these intervals might be different what enable distinction between different deviations within one goal. Sensitivity is dependant on the number and size of defined intervals and the penalty scale utilised.

Risk modelling

Decision making process at farm level demands due to complex nature of agriculture production beside multiple criteria approach also attention to risk. For most farmers risk management is a challenging task. It demands thinking in 'ranges', namely inputs and outputs my take on a range of values. This is related to decisions farmers have to take, ranging from everyday practice to once-in-a-lifetime investment decisions (Hardaker et al., 2007).

Beside common sources of risk like in other sectors (price risk, market risk, institutional risk etc.), important part of total risk in farming could be assigned to uncontrollable "natural factors", such as climate conditions (long term issue), weather volatility, animal and plant diseases, insects invasion (Aimin, 2010). For agricultural production planning it is also typical that decisions have to be made far in advance, much earlier than the market prices for outputs are usually known. The later is even more significant and important in line with market liberalisation that finally manifests in more fluctuating agricultural commodities' prices (Huirne et al., 2007).

Risk modelling could be addressed in different ways. In this paper we are concerned with possible reduction at farm level, particularly those possibilities that farmer has available in the process of production planning. For this purpose expected value and variance (E,V) model is going to be applied. Basic idea has been developed by Markowitz in fifties of previous century. The method applies mathematical concept of variance as a measure of risk. The latter is justified under conditions of normally distributed expected income and farmer's utility function that could be expressed by negative exponential function. In such a case it could be assumed that farmer takes decision on the basis of expected income (average value) and variance (standard deviation, respectively) as a measure of risk (Hardaker et al., 2007). From mathematical point of view the problem could be addressed by quadratic programming (QP) or quadratic constrained programming (QCP).

Variability is measured according to different states of nature defined through various sources of instability (yield, price, variable costs and subsidies). Decision maker may use historical data, expert advice or other data in forming personal probabilities (Backus et al., 1997). In principle independent of the 'stage' where risk enters into the production process it reflects as income risk (Hazell and Norton, 1986).

The proper estimation of farmer's risk attitude (coefficient of risk aversion) is crucial to find the optimal production plan or to locate farms decision margins in expected value – variance (E,V) space. Production plan could be determined by maximizing certainty equivalent (CE). A variety of methods have been developed to measure the risk attitudes of agricultural producers (Antle, 1987). From the literature three different generally known aspects could be husked (Gomez-Limon et al., 2003). In this paper observation approach by tuning the models to fit actual data will be discussed, which is particularly beneficial if one analyses hypothetical constructed farms (Žgajnar and Kavčič, 2011). Lien (2002) is an example of non-parametric estimation of risk aversion values based on imitating actual farmers' behaviour.

The paper continues with concise characteristics of each module taking part in developed modular tool. It is followed by description of main set of activities, constraints and goals as well as basic characteristics of analysed farms. The contribution concludes by obtained results and discussion.

Methodology applied

Developed modular tool could be considered as starting-point to fill the gap in Slovene farm planning analyses under risk. The scheme of modular tool is presented on figure 1. Besides linear programming (LP) resting on maximizing expected income, other more general (goal programming, non-linear – quadratic) methods were utilised. In such a way common linear production planning could be extended into multiple criteria analysis under risk.

Modular tool is supported by seven modules (Figure 1). The **first module** is an example of classical production planning focused on maximization of expected return (expected gross margin or expected income). It is based on common deterministic linear programming (LP) approach. The same principle (LP) is applied in the **second module** searching for unknown or missing values of final and 'transfer' activities. Its crucial aim is not to optimise production plan, but to reconstruct economic situation and production plan of analysed farm. Partial term (PLP) is connected with available data (number of breeding animals, selling/purchasing activities, maintenance of arable land etc.) that are known and therefore also fixed in the optimization process. Optimization is therefore performed just for those activities on grassland (how much is gathered as hay, silage, pasture etc.) where only intensity of production is known and for fodder purchasing activities.

Since efficiency of production plan could also be judged through achieved expected income per hour, the nonlinear **module 3** is entering the modular tool.

Among different sources of risk mainly production risk is considered in the tool. The main idea is to analyse how efficient a farm could be in risk reduction and what kind of attitude to risk analysed farm has. Purpose of **module 4** is to calculate efficient curve for analysed farm. It is based on original Markowitz formulation of the mean – variance approach (Hardaker et al., 2007), whereby the objective is to minimize the total variance expressed as standard deviation and to parameterise the expected income (EI). It is an example of quadratic model (QP). The solution from the first module is taken as a starting point of efficient curve.

To find the optimal solution on the efficient curve, indifference curve has to be plotted in E,V space. It slope defines coefficient, known as absolute risk aversion (r_A). For this purpose a non-interactive modelling approach has been applied, based on mathematical model representing farmers' decision behaviour. The main idea of applied approach was to take into account actual farmers' behaviour without any questionnaires or other direct instruments. Applied methodology has been developed by Lien (2002). His approach has been slightly adopted in the phase of current farm situation estimation (partial-optimization in module 2) (for more details see Žgajnar and Kavčič, 2011). Therefore **module 5** is supported with quadratic programming (QP) and quadratic constrained programming (QCP). Namely, to approximate decision maker's absolute risk aversion coefficient proposed by Lien (2002) two points on E,V efficient frontier have to be located. First one is derived by minimising variance (QP) at the observed farm level of total income, while the second point is calculated by maximizing expected income (QCP) keeping variance at the level reached by current production plan. Since current (reconstructed) farm situation is essential, this module is linked with the module 2.

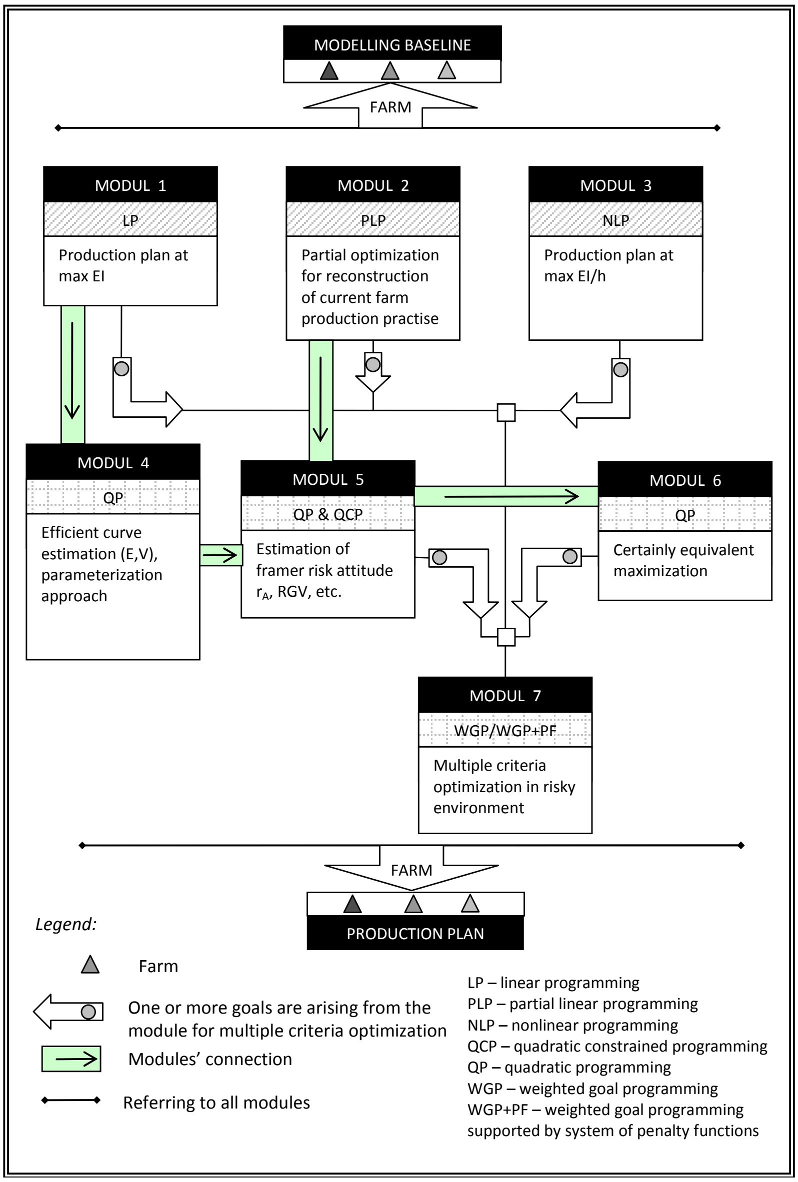

Figure 1: Scheme of modular tool with main modules' approach

Estimated farm risk attitude enters into the **module 6** that is resting on quadratic programming (QP) approach maximizing certainty equivalent (CE).

The main purpose of all these modules (except module 4) is to calculate goals' target values for the multi-criteria **module 7**. Concept of multi criteria decision making has been applied through weighted goal programming (WGP) and weighted goal programming supported by system of penalty functions (WGP+PF). In the frame of multiple criteria optimization under risk, two different risk parameters (certainty equivalent (CE) and standard deviation (SD)) were included. Priority weights for particular goals have been estimated on the basis of pairwise comparisons with integer-valued 1-9 scale, applying AHP method (Saaty, 1980).

As presented on the Figure 1, modular tool is designed in a way that modelling baseline of analysed case is the same for all modules (farm type, production characteristics, technologies, depreciation costs etc.). Consequently obtained results from all modules refer to the same analysed farm. This is important, since it enables simple and automated updating of all seven modules at the same time. In such a way also possibilities of systematic errors are reduced.

All modules and modular tool have been developed as spreadsheets in MS Excel framework. This enables their simple linkage, achieved by macros in VBA (Visual Basic for Applications). To solve all types of mathematical models taking part in separate modules, common MS Excel solver has been upgraded with Frontline system's solvers.

Modular tool has been developed as an open system. In one sense it means that different linking and combinations of the modules is enabled, not necessarily the one applied in this analysis. Another advantage is that list of activities and constraints could be extended. Changes and adjustments of technologies and production parameters are linked also with the process of preparing calculations (per activities). They are based on simple production functions that, beside technological coefficients required for optimisation matrix, yield economic parameters. Emphasis in model specification has been put to livestock activities with detailed sub-module for estimation of animal nutrition requirements. The latter depend on technology applied, breed and production characteristics (daily milk yield, daily weight gain etc.). This sub-module is applied also to calculate expected gross margin per activities for particular year or couple of years.

The main data source concerning prices and costs was prepared by Agriculture Institute of Slovenia. Modular tool enables different approaches of expected gross margins calculations. In this paper expected gross margin, calculated as weighted average due to different probabilities by states of nature, will be considered. Nevertheless, at the farm level either total expected gross margin or expected income (if also depreciation cost is deducted) could be considered.

Activities

With developed modular tool different farm types could be analysed. In this paper we have focused on those activities that are most important from Slovene agriculture viewpoint and also most frequently applied on farms. They could be merged into four groups: livestock activities, activities on arable land and grassland, purchasing activities and transfer – endogenous activities. The last group includes also subsidies and other CAP measures that are not coupled to production.

Constraints

Agriculture firm is like other businesses confronted with available production resources: agricultural land, labour and different types of capital (land, buildings, machinery, breeding herd etc.). Beside those also outer constraints are important to be considered, like production quotas, environmental and market constraints. With both types of restrictions farm production margins are defined. Basic set of constraints could be divided into following groups: constraints connected with available area, crop rotation constraints, constraints regarding grass gathering, livestock constraints, nutrition balancing constraints, labour constraints, infrastructure capacity constraints and balance constraints.

Goals

The current tool version allows for ten possible goals (G) consideration. Quality of obtained result is mainly dependent on the articulation of target values for set goals and on their relative importance. Target value for the first goal (G1) is obtained in module 1 and presents maximal expected income (EI) that could be achieved in given circumstances. Risk that is acceptable by the farmer enters as the second goal (G2). Its value is estimated with module 4 and is expressed as standard deviation (SD). Certainty equivalent (CE) is considered as the third goal (G3). Its target value is estimated with the module 6 and it caries also information of farmer's risk attitude (r_A). Next three goals (G4, G5 and G6) ensure that optimised production plan is from 'own' resource viewpoint similar to current production situation. Goal four (G4) tries to ensure that family labour is more or less employed. Beside unemployment crucial reason for its consideration is objective to minimise problems of hired labour. Target value arises from reconstructed situation (module 2) what holds also for the value of the fifth (G5) and sixth goal (G6). Both of the latter goals ensure that own land is utilised. Next group of goals (G7, G8 and G9) is related to so called public goals. Goal 7 (G7) tends towards greater employment of the off-farm labour, with the maximum up to 30 % of own capacities. The same upper limit is put for the eighth (G8) and ninth goal (G9) that favour renting of additional arable and grass land. In module 7 as the tenth goal (G10) enters result from the module 3 demanding maximal expected income per hour.

To ensure better model behaving, system of penalty functions could be included by all the goals. However, due to additional complexity that they cause we decided to support only G1, G3 and G10 for negative deviations (control of underachievement of target values) and G2 for positive deviations (overachievements). In all four cases due to nature of goals, single-three phase penalty function has been applied.

Characteristics of analysed farms

The modular tool has been tested on three typical Slovene dairy farms, constructed on the basis of FADN data and model calculations, prepared by Agriculture institute of Slovenia (Rednak et al., 2009). The main principle applied in performed analysis is searching for the optimal production plan for a one year planning horizon. This assumes that farmer could decide what to produce at the beginning of each year based on his/her expectations of returns (expressed as income per farm and expected gross margins per activities) on production at the end of the year. No investment activities are presumed. Expectations are based on expected (average) gross margins and their variances and co-variances, calculated on the basis of historical data.

Set of historical data (ten year time series) prepared by Agriculture Institute of Slovenia has been utilised as a source of risk for decision variables in the model. The set of historical data has been updated for possible changes in technology applying 'de-trend' process described by Hardaker et al., (2007). Further price deflator index has been applied to express nominal prices in real terms (2008).

Table 3: Main production characteristics of analysed typical farms

		Farm 1	Farm 2	Farm 3
Production resources				
Labour available	(h)	9,000	3,240	2,700
Agricultural area				
Arable land	(ha)	27	8	4

Grass land	(ha)	22	9	10
Activities on arable land				
Grain maize	(ha)	7	2	0
Maize silage	(ha)	10	2	2
Grass and legume mixtures	(ha)	10	4	2
*No. of grass utilisation**		4 (3)	3 (4)	2 (3)
Livestock				
Dairy cows				
Breed**		HF	HF	SIM
Milk yield/lactation	(l)	7,800	6,900	5,200
Current number	(heads)	58	21	16
Pregnant heifers				
Current number	(heads)	18	7	3
Bulls fattening				
Current number	(heads)	0	0	11
Depreciation cost	(€)	16,900	6,813	5,972

**First number is related to prevailing part of grassland and the second to the rest.*

*** HF stands for Holstein-Friesian breed and SIM for Simmental breed*

All three analysed farms are dairy farms, but with different production conditions (Table 1). First farm has intensive production and beside dairy cows breed also calves and pregnant heifers. With Holstein-Frisian breed it achieves 7,800 litters of milk production. Farm is located in flat area and cultivates 49 ha of land. Second farm is smaller in extent of cultivated land, but is also located in flat region. With the same breed it achieves a bit lower production per cow (6,900 l). The third farm it is an example of small farm, located in hilly area. Fodder is produced with own capacities (14 ha), majority on grassland. Third farm breeds less intensive Simmental cows, with 5,200 l per lactating cow. Bulls fattening contribute important share of total income. When extending the set of possible activities (besides purchasing activities only activities on grassland and arable land) to be included into optimal solution, we considered the philosophy of similar production intensity. All new fodder activities not included into current (reconstructed) production plan (Table 1) were adjusted according to intensity of maize production.

In Table 1 also annual labour available per each farm is presented. Since production period is divided into four equal quarters, available labour has been divided as 20 %, 30 %, 30 % and 20 % respectively to simulate day length in different seasons. It was presumed that up to 30 % of labour required could be hired. The same constraint has been considered also for renting land, mainly due to physical constraints of available machinery (expressed through depreciation cost) as also remoteness of agricultural area. We also presumed to have enough capacities for foreseen extent of production. Accounted fixed costs include only machinery and farm building depreciation cost and are presumed to be constant for observed short term planning horizon.

Results and Discussion

Due to space limit only the most important results for all three analysed farms are presented. In the first part of this section focus is put on optimal production plans considering ten goals. Results are obtained either by WGP or WGP+PF. Emphasis is put on goals aspiration levels and deviations. Along the economic indicators and risk aversion coefficients also livestock activities involved in production plan are presented. In the second part some results from other modules are graphically illustrated in the context of expected values and standard deviations.

Table 2: Multiple criteria optimisation under risk for the first, second and third farm; comparison based on WGP and WGP+PF

		Farm 1		Farm 2		Farm 3	
GP type		WGP	WGP+PF	WGP	WGP+PF	WGP	WGP+PF
Risk attitude							
r_A / r_R		0.000156 / 15.64		0.000502 / 20.09		0.000697 / 20.90	
Economic indicators							
EGM	(€)	158,970	165,454	53,563	53,834	33,616	35,619
Direct payments	(€)	25,242	25,242	8,146	8,146	6,115	6,115
EGM/h	(€/h)	17.7	17.5	16.5	16.8	15.4	16.5
Multiple criteria optimisation							
Total penalty		7.75	10.55	24.69	41.60	16.54	32.41
Total deviation	(%)	101.02	109.92	128.87	131.47	167.30	177.48
Goals achieved levels							
EI	(€)	142,070	148,554	46,750	47,021	27,644	29,647
SD	(€)	29,513	31,555	10,150	10,257	6,256	6,770
Family labour	(h)	9,000	9,447	3,240	3,207	2,178	2,156
Own arable land	(ha)	27.0	27.0	8.0	8.0	4.4	5.2
Own grassland	(ha)	22.0	22.0	9.0	9.0	10.0	12.0
Total labour	(h)	9,000	9,447	3,240	3,207	2,178	2,156
Total arable land	(ha)	27.0	27.0	8.0	8.0	4.4	5.2
Total grassland	(ha)	22.0	22.0	9.0	9.0	10.0	12.0
CE	(€)	73,956	70,690	20,878	20,597	14,012	13,679
EI/h	(€)	15.79	15.73	14.43	14.66	12.69	13.75
Goals deviations							
EI	(%)	-17.28	-13.50	-16.71	-16.23	-22.07	-16.42
SD	(%)	9.00	16.54	23.69	25.00	15.50	25.00
Labour	(%)	0.00	4.96	0.00	-1.03	-19.35	-20.13
Arable land	(%)	0.00	0.00	0.00	0.07	10.29	30.00
Grassland	(%)	0.00	0.00	0.00	0.00	0.00	20.11
Hired labour	(%)	-23.08	-19.26	-23.08	-23.87	-37.96	-38.56
Rented arable land	(%)	-23.08	-23.08	-23.08	-23.02	-15.16	0.00
Rented grassland	(%)	-23.08	-23.08	-23.08	-23.08	-23.08	-7.61
CE	(%)	-0.61	-5.00	-3.39	-4.69	-2.94	-5.24
EI/h	(%)	4.90	4.50	-15.85	-14.48	-20.97	-14.41
Activities							
Livestock							
Labour	(h)	6,320.2	6,797.7	2,290.5	2,194.2	1,347.8	1,233.0
Dairy cows	(No.)	66.5	71.6	22.9	19.7	8.2	5.8
Heifers	(No.)	0.0	0.0	15.3	27.5	29.4	35.6
Bulls fattening	(No.)					14.1	17.8

Larger and more specialised agricultural holdings with more intensive production turned out to be less risk averse as smaller agricultural holdings with less intensive production (Table 2). For the first farm calculated relative risk aversion coefficient (r_A) is 15.64, while coefficients for the second and the third farm are higher, 22 and 25 % respectively. Range of calculated coefficients deviates from the values reported in the literature, which Meyer D.J. and Meyer J. (2006) assigns to different definitions of functions' arguments (in this analysis approximation of expected income).

Goal programming approach in tactical-operative production planning at farm level improves applicability of obtained results, which is apparent mostly from economic indicators and goals' aspiration levels (Table 2). In spite of greater complexity, system of PFs improves reality of obtained solutions. By all three farms financial situation is improved due to decreased deviations from the first goal (EI). The later is particularly evident in the case of the first and the third farm. Higher expected return (EI) demands also higher risk and therefore it is expected that deviations from the third goal (SD) increase in all three analysed cases. In the second and third production plan, the limit defined by second interval of the penalty function system is reached (25 %). Therefore also greater discrepancy between aspiration and target levels of certainty equivalent (CE) is expected. For the first farm it deteriorates for 4 %, and on the second and the third farm it decreases for only 1 and 2 % respectively.

It is surprising that in terms of expected income per working hour the first farm achieves even more efficient production plan. This is not the case for the second and the third farm where EI is deteriorated. However, it improves if the system of penalty function is considered. On the second farm production plan improves for 0.23 €/h and on the third farm for 1.05 €/h respectively. From Table 2 it is apparent that with exception of the third farm, no significant differences appear between both approaches (WGP and WGP+PF) concerning own and rented area, considering in 'conservative' and 'public' goals (G5, G6, G8 and G9).

In all three analysed cases it is obvious that system of penalty function increases total penalty and deviations from target values. These indicators define the 'quality' of obtained compromise solution, which is due to farmers' preferences and considering additional rules (positiveness) a bit deteriorated.

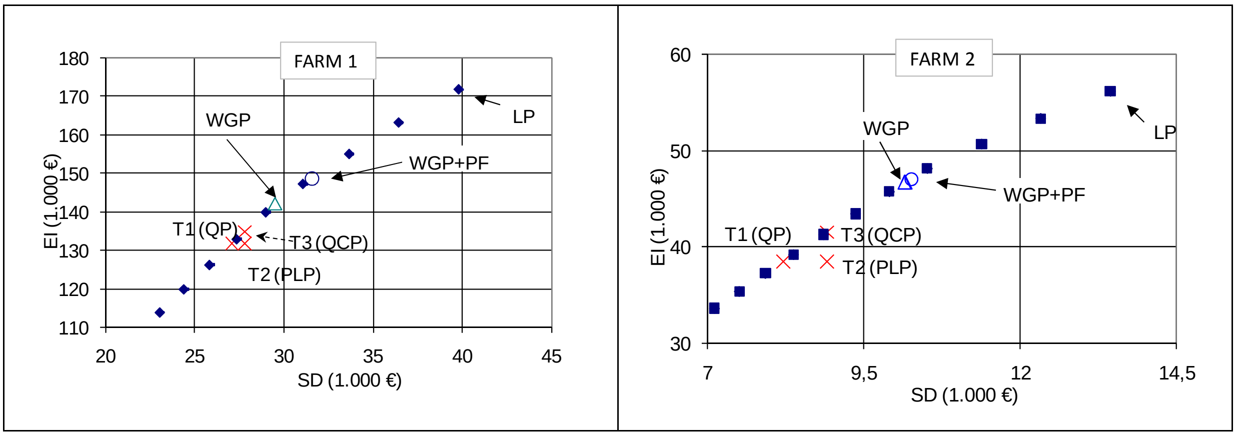

Figure 2: Obtained solutions for the first and the second farm in expected values and standard deviations space

In all three cases production plan (Table 2) comparing to current production practice (Table 1) change. On the first farm only dairy production is interesting and the number of dairy cows increases. For smaller second and third farm opposite trend for dairy cows is obvious, along with increased number of heifers and on third farm also fattened bulls. Similar holds also when WGP is supported with PF.

The difference between both approaches (WGP and WGP+PF) is obvious also from Figure 2. Model results indicate the problem of possible biased solution if planning is based on single criteria paradigm (Figure 2). It proves that maximization of expected income results in better outcome comparing with current situation (30.4 %, 45.8% and 49.2% for analysed farms, respectively). Obtained improvements go in proper direction; however, they are not reachable especially if conflicting goals are considered in the process of planning.

Conclusions

Developed modular tool for multi criteria analysis under risk links relatively simple and already applied mathematical methods for different decision analysis at the farm level. Applied approach is suitable for systematic analysis of hypothetical or typical farms, for which most of information could be calculated with modules. Obtained results confirm benefits of combining these methods, based on different philosophies, which mainly manifests in more realistic solution. Model results show also on the problem of single criteria optimisation based on maximization of expected income (LP). It gives the best possible solution, which is usually not attainable due to other conflicting criteria also important to be considered in the process of production planning. Paper focus also on searching for benefits and drawbacks of penalty functions. In addition to increase in complexity of the optimisation model and slight deterioration in total deviations from target goal values, it improves the positivness of obtained results.

Considering data availability in agriculture applied methods are reliable enough for decision analysis. In the paper focus has been put mainly on methodological issues and less on practical farm issues. However, this does not mean that developed tool could not be applied in practical analysis or individual modules utilised autonomously.

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