Pak. J. Agri. Sci., Vol. 52(4), 971-979; 2015
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
http://www.pakjas.com.pk

A MULTI-GOAL MATHEMATICAL APPROACH FOR THE OPTIMIZATION OF CROP PLANNING ON ORGANIC FARMS: A SLOVENIAN CASE STUDY

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A combination of linear and weighted goal programming for crop rotation planning has been used in developing a tool/model for solving several management goals simultaneously. The model was implicated for the case of organic farming in Slovenia. The results yielded reasonably accurate information regarding different economic parameters and nitrogen off-take from calculated crop rotation. The model was tested in four different scenarios with the influence of various goals` weighting the results. From the obtained results, it is obvious that a combination of weighted goal programming and linear programming gives rise to a better solution from an economic perspective (i.e. higher total income per crop rotation and lower costs per crop rotation). It also provides a better solution for diversified and economically feasible crops for inclusion in crop rotation compared with the situation when farmers use only a linear mathematical technique. An investigation of the results showed that the model does not prefer mono-crop production strategies, which represent crucial drawbacks for organic agriculture, such as soil depletion, diseases and pests outbreak and soil degradation. The developed model can help farmers to obtain answers regarding four main issues in crop rotation planning; i) cropping strategy, ii) potential hiring of extra resources, iii) quantity of harvested crops and iv) quantity of fertilizer being saved in the second year of planning.
Keywords: Crop rotation, linear programming, weighted goal programming, decision making.

INTRODUCTION

Expert farmers plan and implement crop rotations on an annual, seasonal and last minute opportunistic basis. Their annual plans are based on clear priorities. Each year, the dominant challenge is to grow adequate quantities of profitable organic crops to ensure that the farm remains viable (Mohler and Johnson, 2009). In every growing season, producers must pay attention to numerous factors that influence their management decisions. Crop planning is related to many factors, including those that are measurable and non-measurable. These include factors such as types of land available for cultivation, yield rates irrigation system and availability of the agricultural inputs (Mohamad and Said, 2011). According to Sharma *et al*., (2007), the clarified factors stated below represent the most crucial factors of agricultural planning. In crop rotation, the planning process involves management and dealing with influences such as machinery, fertilizers, capital and labour and the cost of production, which directly affects farm profitability. The decision problems, such as crop area planning, are based on conflicting and non-commensurable criteria to "satisfy" the decision desired (Gupta *et al*., 2000) and expert farmers are continually balancing annual and multiyear (short and long-term) decisions, which must be optimized for annual returns and cash flow. These problems are called multi-criteria decision problems, where the decision maker generally follows a satisfying solution rather than attempts to maximize the objectives (Gupta *et al*., 2000). Nowadays, many decision-making approaches are available and have been implemented for solving concrete agricultural problems with the input of empirical data (Jafari *et al*., 2008; Chang *et al*., 1996; Tasuku *et al*., 2005; De Kock and Visagie, 1987; Žgajnar *et al*., 2009; Zhang and Roush, 2002). Other decision programs solve "soft" problems with the input of qualitative data (Prisenk *et al*., 2013; Rozman *et al*., 2009; Rozman and Pažek, 2005). Gupta *et al*. (2000) have also explained that numerous single and multiple-objective crop area allocation models were developed in the past and are well described in the literature (Maass *et al*., 1962; Hannan, 1981). These models were based on a mathematical approach that usually used traditional linear programming, as well as a fuzzy approach, integer programming and an algorithm technique.

Traditionally, the easiest way to solve crop planning problems is based on using linear programming with one target function (maximum output or minimum costs). However, it is not necessary that a maximization approach (total income or financial results) provide relevant results for objective estimation of crop rotation. The linear programming often chose the mono crop rotation practice including the culture with maximum income per hectare, and the crop rotation concept do not involve the explanation of jointly beneficial interrelationship among individual crop (El-Nazer and McCarl, 1986; Heady, 1948). There are numerous factors that could indirectly influence the profit and that are very important for commercial farmers who not only want to increase program output, but also want to reduce the amount of debt, to reduce their expenses and to expand the size of the farm. Conventional mathematical programming schemes, such as linear programming, clearly cannot handle all of these issues simultaneously (because of the characteristic for solving one target problems) (Mohaddes and Mohayidin, 2008), and the declaration of many goals at once is possible only with goal programming (Jafari *et al*., 2008). A good example of applying the similar mathematical techniques (fuzzy approach) was represented by Mohaddes and Mohayidin (2008), who developed a model for crop planning that, minimizes soil erosion and maximizes profit and employment.

However, crop rotation is especially critical for all organic cropping systems, as indicated by Mohler and Johnson (2009). The authors explain that rotation problems usually do not develop until well after the transition to organic rotation. Since the crops grown by organic farmers are often different and more diverse than those grown in the preceding conventional system, the organic transition itself often rotates away from the previous crops and their associated problems. Many strategies, such as linear programming, that depend on crop rotation principles are preferred to strategies that follow mono-crop production practices (Visagie *et al*., 2004). Most farmers are very tempted to plant excessive acreage of the most profitable crop or to overuse certain fields for one type of crop. Such practices can lead to costly problems, such as soil depletion, diseases and pests outbreak, and soil degradation, which that take many years to correct. The developed model can remedy these issues and help farmers to make decisions for organic rotation. Although rotating among a diversity of cash and cover crops has numerous advantages, it poses substantial management challenges and mathematically creates a huge number of potential crop sequences from which to choose (Mohler and Johnson, 2009). An important task in organic agriculture production is also to satisfy the required amount of nutrients in the soil, and different varieties within any crop may be more or less efficient at taking up nutrients. For solving the problems to satisfy the required amount of nutrients in crop rotation, farmers can, for example, include legume crops (Mohler and Johnson, 2009). On the one hand, the legume crops capture atmospheric nitrogen and “fix” it into forms available to plants, which can be used strategically in rotations to meet the needs of nitrogen-demanding crops. On the other hand, it means a lower profit for farmers. In generally, taking into account the nitrogen off-take from the crops during the planning of crop rotation can substantially contribute to reducing fertilizer use and consequently improve the financial results on the farm. From this reason, the nitrogen off-take by crops was recognized as an environmental externality that could indirectly influence the management aspect, which was taken for optimization in the developed model.

The aim of this paper is to represent the developed model based on a combination of traditional linear and weighted goal programming techniques, upgraded with weights and penalty functions. The model can make a good contribution to extended application of mathematical techniques in farm planning with relatively simple administration to help in decision-making processes on organic agricultural holdings. On the one hand, the model should optimize the economical parameters on the farm, and on the other hand, it should not follow mono-crop production practices. Mono-crop rotations are usually done by models based only on linear programming, which have only one target (i.e. maximization of profit) and include only one or two crops with higher total income per hectare. These shortcomings were delayed with the represented model in this paper and represent the contribution of this paper from a methodological perspective. The benefit of weighted goal programming methodology is recognized as making it possible to optimize several goals simultaneously in comparison with the linear mathematical programming method that is already used in food systems and food policy analysis (Igwe and Onyenweaku, 2013; Mohamad and Said, 2011). The model is tested and based on the relevant input data of Slovenian organic farm production, which was calculated in 2011. Slovenia represents the good case study because of quite small average farm size (6.5 to 7 hectares and more than 10 hectares in organic farms), which represent the good test for model accuracy and decision makers can expect that in the case of good model response it will be useful also in largest farming systems abroad. The objective of the planning model is to develop optimal crop planning that minimizes production costs and maximizes profit (represented as total income in the model). The model also incorporates an integrated function that minimizes the entry of fertilizers in crop rotation with the minimization of the value of crops` nitrogen dispossession. Organic farming aims to be self-sufficient in nitrogen supply, managing inputs and minimizing losses, also through harvesting of different crops (Briggs *et al*., 2013). The careful management of animal manure to minimize losses and optimize nutritional benefits is a key feature of stocked organic systems (Goulding *et al*., 2013). On the one hand, the supplies of organic fertilizers and to integrate legumes into crop rotation represent the options to satisfy nitrogen requirements, but on the other hand minimizing the final profit of farmers at a same time. The integrated function in this model can help farmers to improve the nitrogen requirements (especially in bad stocked organic systems), where the usage of organic fertilizers will be above the permitted limit.

The paper is organized into four sections. First, data sources are defined; this is followed by a description of the methodology and model development. Section three shows the application of the model for the case of organic farming in Slovenia. The results of applying the WGP model along with the discussion are described in section four. The paper concludes with our main findings and recommendations for further study.

MATERIALS AND METHODS

This section is structured from several sub-sections with the aim to present the model development methodology and mathematical background of the model as clear as possible. The first sub-section presents the contributions of introducing the WGP methodology in the model supported with deeply description of WGP sub-model development steps. Second, the sources of input data are presented and finally model development process with mathematical background of the model are clarified.

***Weighted goal programming methodology*:** Traditional methods/techniques are most often used for solving agricultural planning problems instead of new linear programming (LP) techniques, which were developed by many authors and in many variations (Jolayemi and Olaomi, 1995; El-Nazer and McCarl, 1986; Musser *et al*., 1985). In the case of LP, only one objective could be optimized at once, and all other constraints are written as inequalities (Zgajnar *et al*., 2010). In complex practical cases LP might give result in a useless solution (i.e. mono-crop rotation strategies, unbalanced feed ration) (Zgajnar *et al*., 2010). In the crop rotation, this shortcoming might be expected when the model does not include all available crops, but instead only includes a subset of them. Weighted goal programming (WGP) methodology is an appropriate tool to solve this problem, and it is structured from more than one goal simultaneously. The crucial difference between LP and WGP is in the positive and negative deviation for each goal separately and in defining the number of target functions. All restrictions and objective functions from LP are defined as goals in the WGP approach. After the LP approach, the WGP is structured via four steps, as shown in Table 1. The model in this paper is structured from the three sub-models, two LPs sub-models and a WGP sub-model. The first two LPs will be treated as one sub-model. The steps for the structuring of the model are described below in Table 1, and the mathematical formulation is followed.

In the first step of the model development, the previous restrictions from LP sub-models with signs "<=" or ">=" are transformed into the goals "=" in the WGP sub-model. Theoretically, the goals could be satisfied completely, partly or some of them might also not be met in some extreme cases (Zgajnar *et al*., 2009). This depends upon the deviation variables and the weights, which are defined during the second step of model development. All deviation variables are defined for each goal separately and represent the possible deviations in a positive and a negative way from the goals. By defining the weights, decision makers create a priority list to satisfy the separate goals.

After the second step, the crucial development process is a normalization process, where all deviations are expressed as a ratio difference (i.e. deviation/desired) and deviation values are calculated as desired/actual values. An example of a normalization process is described in sub-section *2.3 Model development*. In a third step, restrictions for the WGP sub-model are defined with a non-negative sign ">= 0" (i.e. deviations from the goals and the crops' cropped areas) and some other restrictions (penalty intervals) are defined for controlling deviations in the restricted size of the function. Finally, the last step is focusing on defining the target (objective) function. The objective function in a WGP sub-model minimizes undesirable deviations from the target goal levels and does not minimize or maximize the goals themselves (Ferguson *et al*., 2006).

Table 1. Description of steps of the WGP sub-model and activities for each step.

Step	Activity
1. Data transformation	All restrictions and target functions from the LP sub-models are defined as goals in the WGP sub-model
2. Defining deviations and weights for each goal	The deviations (penalty functions) and the weights (weights could be also defined in step 4) for separate goals from the first step are introduced
3. Defining restrictions	The restrictions of the WGP sub-model (see mathematical formulation
4. Defining target function	The target function is stated

***Input data model*:** The survey input data (Table 2) are supported by public publications (Jeric *et al*., 2011) based on data from organic farms in Slovenia. Part of the input data that represent the typical quantities of nitrogen (N) that are removed from the soil on organic farms was taken by Cuttle *et al*. (2003). The authors decided to include the N off-take in crop(s) criteria because they assumed that it contributed to minimizing the cost of fertilizer in the next year of crop rotation. Seven different crops with calculated data per hectare or per harvest are the core of the developed model and represent the available organic crops that could be included in the crop rotation. There is no limit on the number of crops that could be included in the model; this depends on the farmers` choice. Available crops that are included in the represented model are maize (*Zea mays* L.), rye (*Secale cereal* L.), barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.), wheat (*Triticum* spp. L.), potato (*Solanum* sp. L.) and grass silage. Input data for every crop also represents the total income (€/ha), the mechanical labour costs (€/ha) (calculated as a product between the quantity of

Table 2. Input data for both sub-models (Jeric *et al*., 2011).

LP AND WGP INPUT DATA						
Organic crops	**COSTS (€/ha)**					**Cropped area (ha)**
	Total income (€/ha)	**Mechanical labour costs (€/ha)**	**Manual labour costs (€/ha)**	**Fertilizers costs (€/ha)**	**Nitrogen off-take in crops (kg N/ha)**	
Maize	2430	274.4	192.5	260.8	78.0	? LP
Rye	1505	213.1	176.0	217.2	37.5	? LP
Barley	1470	217.2	176.0	215.8	56.0	? LP
Oats	1380	217.2	176.0	211.5	42.5	? LP
Wheat	1680	217.1	176.0	246.3	45.0	? LP
Potato	7350	501.7	786.5	381.3	112.5	? LP
Grass silage	1289	93.6	170.5	347.1	412.5	? LP
Restrictions	**= value from LP (€/total cropped area)	<=/=*1734 (€/total cropped area)	<=/=*1854 (€/total cropped area)	<=/=*1880 (€/total cropped area)	** =value from LP (kg N/total cropped area)	**[1,2]sum LP<=7

Notes: *The relevant signs for restrictions in the WGP sub-model are represented; **The restrictions are relevant only for the WGP sub-model; **[1,2]Restrictions are relevant for both sub-models.

mechanical hours per ha (h/ha) and the cost of mechanical hour per hour (€/h)), Manual labour costs (€/ha) (the same approach is used to calculating these as in the case of mechanical labour costs) and fertilizer costs (€/ha).

However, the input data represented in Table 2 are crucial and relevant for both sub-models, while some restrictions, such as the manual labour, mechanical labour and fertilizers costs, expected total income, maximum available cropped area on the farms and expected nitrogen off-take in crops (see notes below the Table 2, are quite different. Igwe and Onyenweaku (2013) determined the average number of each crop yielded per hectare and applied this to the total hectares of each mixture in the survey. The only restriction that was defined in the model by the authors is hectares of cropped area (<= 7 ha), which represents the average available cropped area on Slovenian farms. We did not include the average number of each crop per hectare, as we did not want to limit the model too much. The definition of cropped area for every crop could narrow the influence of the model` "decision-making" process to create an optimal crop mix and could crucially influence the results. At the bottom of Table 2, the restrictions for both sub-models are represented. Production cost restrictions (€/ha) in LP were limited and defined as "less or equal to" (<=) 1734€ for mechanical labour, 1854€ for manual labour and 1880€ for fertilizer. The calculation of the costs restrictions is based on the sum of all costs of available crops in the model, but farmers can use different restrictions suitable for their farms.

***Model development*:** An optimization tool for crop rotation planning has been developed using the Microsoft Excel framework with the "*Solver*" application and represents one of the basic and widely available supported tools on computers. The model is structured from three sub-models (Two of them are LPs, and one of them is a WGP sub-model.). The target function in the first LP (LP_1) maximizes the total income, and the other target function in the second LP (LP_2) minimizes the nitrogen off-take in crop rotation. All restrictions, including both target functions, are further transformed into the WGP sub-model as goals. Goals in WGP were represented with = ("strictly equal"), and there is no "lesser" option (<). The scheme of developing the process of the discussed model is represented in Figure 1.

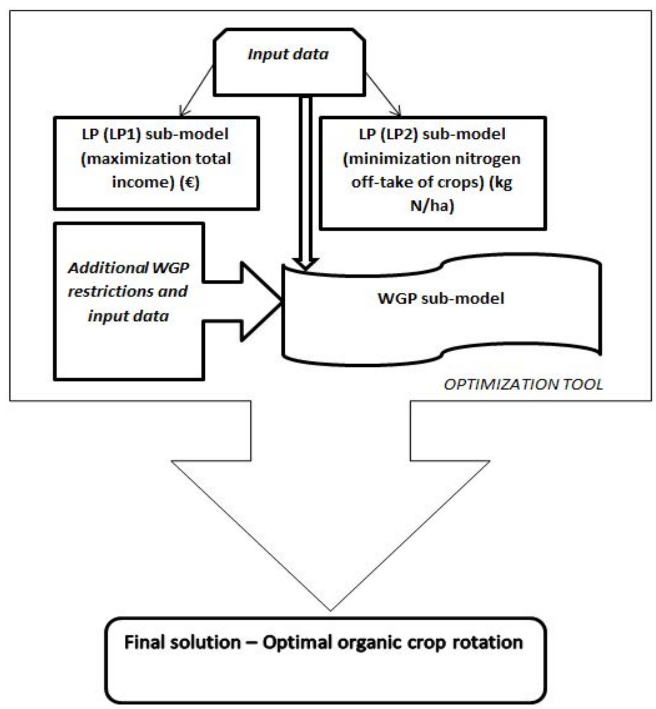

Figure 1. Scheme of optimization tool for organic crop rotation planning.

Table 3. Additional WGP restrictions and input data.

ADDITIONAL WGP RESTRICTIONS AND INPUT DATA									
Goals	**Deviations intervals from the goals**					**Weights (w_i)**			
	Unit	**Interval 1**		**Interval 2**		**Scenarios**			
						SC_1	**SC_2**	**SC_3**	**SC_4**
Total income	€/ha	19300.00	20000.00	19000.00	21000.00	100	100	5	50
Mechanical-labour costs	€/ha	1700.00	1800.00	1600.00	1850.00	5	5	100	5
Manual-labour costs	€/ha	1750.00	1900.00	1700.00	1950.00	5	5	100	5
Fertilizer costs	€/ha	1800.00	1900.00	1500.00	1950.00	5	5	100	5
Cropped area (CA)	ha	6.50	7.10	6.00	7.30	30	100	5	30
Nitrogen off-take in crop(s)	kg N/ha	400.00	430.00	350.00	450.00	50	5	5	100

In Table 3, some additional restrictions and input data, which are included in the WGP, are represented. It represents the weights for each goal separately and possible deviations from them. The deviations are represented as one tide and two tide intervals for each goal separately. With penalty intervals, we can create a flexible function and obtain the several-sided penalty function that was described by Rehman and Romero (1987). The optimization model was tested on four different scenarios (SC_1, SC_2, SC_3, SC_4), while the relative importance of goals is quite different between the scenarios (different weight values). The weight values could be between 0 and 100. The hierarchical scale (setting the standards that were given priority) was created by using the set of weights (w) (Prisenk *et al*., 2013).

A crucial process for WGP optimization is the normalization process of deviations of all objective-function coefficients into units of measurements, which were expressed as ratio differences. Objectives set as goals are usually measured using different units of measurement and could not therefore be easily summed up, as this would manifest in incommensurability (Tamiz *et al*., 1998). A solution for this kind of problem can be found using the normalization technique; for example, mechanical labour costs can deviate by approximately 2% from 1734€ in a negative way on the first interval and can be calculated as [(1734-1734*1.02)/1700], which is the quotient between the deviation and the desired value.

***Mathematical formulation of the model*:** In this sub-section, the mathematical formulation of the optimization tool is represented. In some papers (Igwe and Onyenweaku, 2013; Visagie *et al*., 2004; Sinha and Sen, 2011; Zgajnar *et al*., 2009; Zgajnar *et al*., 2010), the mathematical formulation of linear programming and goal programming are described in more detail and sometimes represented as a matrix approach in different study fields. In this section, we try to explain the formulation very clearly and simply in order to allow for the understanding of the mathematical background of the model. The first modules (LP) are formulated as shown in equations (1) through (2; 2.1 and 2.3). The main difference between LPs is in target function (1). One target function maximizes the total income (TI) and minimizes the nitrogen off-take (NO) of crops. An important component of LP is non-negative restrictions, which is shown by equation (3) and keep results in the non-negative range. The mathematical formulation of the LP models is written below:

(1)

(2)

(2.1)

For all i = 1 to n

(2.2)

(3)

Subject to:

= objective function (total income and nitrogen off-take of crops)

= total income of n^{th} crop (€/ha); = nitrogen off-take of crops (kg N/ha); = area of n^{th} crop (ha)

= the quantity of the m^{th} input of the n^{th} crop (i = 1…o), (j = 1…p)

= available amount of the m^{th} input (i = 1…o)

The farmer`s problem is to select the optimum combination of crop production strategies that satisfy differential resource availabilities and resource restrictions (Visagie *et al*., 2004). From this point of view, it is necessary to satisfy all requirements by applying one mathematical model. Having developed the first sub-model, the target functions and all restrictions from the LP models were transformed into the goals, considering positive and negative deviations from them [(4), (5) and (6)]. The goals in WGP represent *total income, mechanical labour costs, manual labour costs, fertilizer costs, cropped area and nitrogen off-take in crop(s)*. The link between LP and WGP was restored when the result of the LP's target function was transformed with the Excel function "*convocation on target cell*" into the WGP sub-model. The WGP formulation is shown with equations (4) through (13). The objective function (7) expresses the aggregate unwanted deviations from the observed goals and is therefore subject to minimization (Zgajnar *et al*., 2009). It is defined as the sum-product between the weights and the weighted deviations of the goals multiplied by the penalty coefficients (c_1 and c_2). The coefficients (c_i for i = 1 to n) are importance to keep the results during the intervals. For decision makers is importance that results of goals with high weights will be at least during the second interval, which is usually widely than first one. Consequently, the values of the second coefficient should be higher compare to the first one. Because of the normalization process, only goals that have nonzero target values (8) could be relaxed with positive and negative deviations (Zgajnar *et al*., 2010). Important restrictions are also represented with equations (9), (10), (11), and (12), which control the deviations in the penalty intervals. Additionally, as in the first sub-model, the non-negativity (12) is included into the WGP.

(4)

for all i=1 to 0

(5)

TI ≠ 0 for all i=1 to 0

(6)

(7)

(8)

(9)

for all i=1 to 0

(10)

for all i=1 to 0

(11)

for all i=1 to 0

(12)

for all i=1 to 0

(13)

Subject to:

= positive and negative deviations of i^{th} goal

= goals

= objective function

= weights of the i^{th} goal

= penalty coefficients for the first and the second level of over/underachievement of the goal

= penalty-function parameters defining the upper limit of the first and second intervals of the i^{th} goal

= penalty-function parameters defining the lowest limit of the first and second intervals of the i^{th} goal

However, the mathematical formulation of the represented model remains quite simple because the farmers have to formulate only the target functions and goals (i.e. change the signs from ">=" or "<=" in LP to "=" in WGP).

RESULTS AND DISCUSSION

The results of the optimization tool can be seen in Table 4. The table is structured from the three parts, where the first represents the amount of each of the goals from the LPs models and all four scenarios. The second part of the table represents the amount of each crop included into the crop rotation, and the last part at the bottom of Table 4 represents deviation from the restrictions (expressed in percentage values).

The results show the differences between the analyzed sub-models in formulated crop rotation. Deviations from the

Table 4. Obtained results and crop rotation formulation with LP and WGP scenarios.

Goals/Scenarios	**Unit**	**LP_1**	**LP_2**	**WGP**			
				SC_1	**SC_2**	**SC_3**	**SC_4**
Total income	€	19618.97	n/a	19227.45	19618.99	19618.99	17698.38
Mechanical-labour costs	€	1734.32	2045.82	1675.74	1999.37	1964.93	1734.33
Manual-labour costs	€	1853.54	2377.31	1853.50	1853.50	1853.50	1706.55
Fertilizer costs	€	1508.43	1879.91	1460.25	1879.97	1879.97	1646.07
Cropped area	Ha	5.11	7.00	4.91	7.02	6.91	5.98
N off-take in crop(s)	(kg N/ha)	n/a	423.83	423.81	553.81	653.93	423.81
Organic crop rotation							
Corn	Ha	3.64	0.00	3.00	4.00	4.20	2.64
Grass silage	Ha	0.00	0.00	0.00	0.09	0.34	0.00
Rye	Ha	0.00	2.00	0.00	0.00	0.00	0.00
Barley (winter)	Ha	0.00	0.00	0.00	1.07	1.43	0.00
Oats	Ha	0.00	1.12	0.00	0.15	0.00	0.00
Potato	Ha	1.47	1.88	1.54	0.91	0.93	1.00
Wheat	Ha	0.00	2.00	0.37	0.80	0.00	2.34
Deviation from restrictions							
Total income	%	n/a	n/a	-2.00*	0*	0*	-10.00*
Mechanical-labour costs	%	0.00	18.00	-3.00	-15.00	13.00	0.00
Manual-labour costs	%	0.00	29.00	0.00	0.00	0.00	-8.00
Fertilizer costs	%	-20	0.00	-22.00	0.00	0.00	-12.00
Cropped area	%	-27	0.00	-30.00	0.20	-1.00	-15.00
N off-take in crop(s)	%	n/a	n/a	0.00**	31.00**	54.00**	0.00**

goals are quite different in the scenarios and in connection with the weighted values of the different goals. The results from SC_1, when compared with LP_1, show a lower financial result of approximately 390€. However, the monetary loss could be compensated for with profit from lower mechanical labour costs (59€), fertilizer costs (102€) and a decreased cropped area of 0.2 ha. It could be assumed that 0.2 ha could make an additional profit (i.e. 276€ per crop rotation if the farmers substitute the reduced amount and chose the oats as a cereal with minimal total income per hectare). The amount of the cropped area in SC_2 is slightly higher, but it includes six different crops compared with LP_1, which only includes two crops. The crucial problems with the LP_2 results are the surpluses of the mechanical labour (311€) and manual labour (523€). With respect to this, the LP_2 scenario is completely unacceptable. In general, the WGP sub-model includes many more crops than the LP sub-models; consequently, crop rotation is more diverse. In the second and third scenarios, the model calculates the higher values of nitrogen off-take in crops. The calculations of the higher nitrogen off-take show a negative impact on the total income in the next year of crop rotation of approximately 186€ in SC_2 and of 105€ in SC_3 (0,81€/kg N). Negative results based on the nitrogen off-take could also be recognized in the case of LP_1, where the calculated crop rotation consumes about 25kg of nitrogen more than LP_2, SC_1 and SC_4.

***Model sensitivity*:** The important task of multi-objective models is to optimize the goals with higher weights in the penalty-function intervals. The results confirm the affirmation of Gass (1987), who explained that the results obtained strongly depend on the selection of preferential weights. In most cases, the solution obtained is a compromise between conflicting goals, which is made possible through deviation variables (Zgajnar *et al.*, 2010). Farmers should prefer the most important goal for them and place the highest weight on it and not place the similar weights on all goals.

Figures 2 and 3 represent the responsiveness, efficiency and applicability of the developed tool. The test is based on a simulation of scenarios with changing weight values. The results show that the goals are in the bounds of the intervals when they have higher values compared with other goals in the scenarios. In SC_4, total income becomes out of the bounds of the tolerance intervals when the weight value is 50 (Figure 2). As another example, the cropped area changes in a negative way (increases) in SC_2 (w_{sc2}=100) (Fig. 3). In general, the most favourable goal, where the weight is higher compared with the other goal weights, seems to take a goal inside the bounds of the intervals. However, sometimes lower weight values produce better results than higher values, which can be seen in SC_4 (Fig. 3). The weight for the cropped area is 30 in SC_4 and makes a good contribution in defining crop rotation (decreased by about -1.04 ha compared to SC_2, where the weight is 100). In contrast, the lower weight of total income in SC_4 (w_{sc4}=50) is calculated as a lower total income of about 1920€ compared to SC_2 (w_{sc2}=100) (Fig. 2). From the obtained results, it is obvious that in the case of the crop rotation, decision-makers should prefer the one or two main goals, which is/are most important to satisfying their expectations and makes several scenarios through which to obtain optimal results.

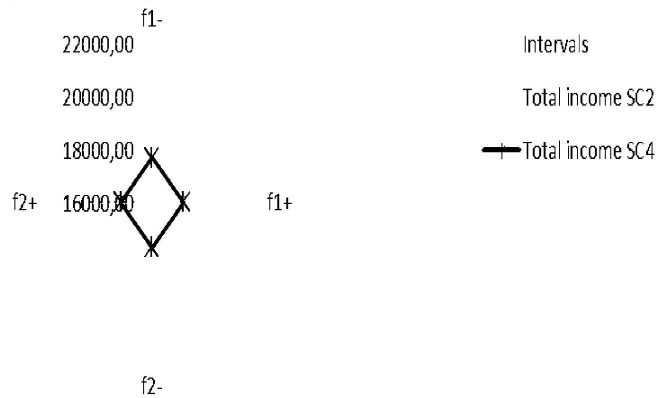

Figure 2. Deviations of total income from the penalty-function intervals in all analyzed scenarios.

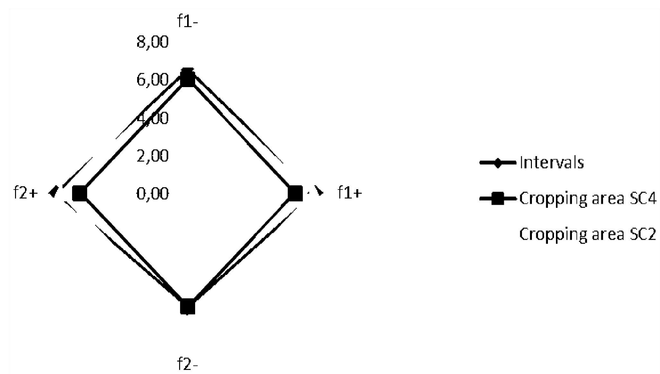

Figure 3. Deviations of cropped area from the penalty-function intervals in all analyzed scenarios.

***Conclusion*:** The complexity of the mathematical formulations in solving decision-making problems often alienates potential users, especially when they require buying special tools. The represented mathematical technology in this paper could be used by all farmers because it rests on a widely available tool (MS Office Excel). With knowledge of cropped area and other calculated results, farmers will be able to demonstrate different scenarios in the context of risk management. The tool's results can address some staple issues in pursuing crop rotation:

- What cropped strategies should be used and how much land should be allocated?
- What amount of extra resources (mechanical and manual labour, fertilizer, etc.) should be used?

- What proportion of the crops should be harvested and sold?
- What amount of the fertilizer could be saved to create crop rotation in the following year?

The model expresses a wide range of practical applicability and other goals that could be taken into consideration (e.g. Phosphor and Kalium off-take in crops, financial results and also economic and environmental parameters, such as soil erosion). The model was tested on a relative small (cropped) area in Slovenia, and it produced accurate and reliable results. The main advantage of the model was confirmed with a sensitivity test of the model and represents an opportunity for farmers to improve their results inside their defined goals` bounds. In the case of upgrading the model with specific fertilizers requirements results can help farmers in the fertilization and management planning on the farm. Because of its relatively simple usage, the model is suitable for a wide range of users, but in particular, it could be applied to local policy decision-makers and extension services. Calculating the crop rotation in the second year and years after could be also upgraded depends on farmer` requirements, such as including new organic crops or new restrictions. The model is open program in which farmers can create (with weights and penalty functions) a priority list of their goals and indicate the most important task on their farms. Therefore, the results indicate that making changes in crop rotation, as suggested by the WGP sub-model, facilitates an increase in farmers' profits.

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