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OPTIMISATION OF THE VEGETABLE PRODUCTION IN THE REPUBLIC OF MACEDONIA; LINEAR PROGRAMMING APPROACH

Ivana Janeska Stamenkovska[† ‡], Dragi Dimitrievski[†], Emil Erjavec[††], Jaka Žgajnar [††], Aleksandra Martinovska-Stojcheska [†]

[†]Faculty of Agricultural Sciences and Food, University Ss Cyril and Methodius, Skopje, Macedonia
[††] Biotechnical Faculty, University in Ljubljana, Ljubljana, Slovenia
[‡] Corresponding author: ijaneska@zf.ukim.edu.mk

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Abstract

The aim of the paper is to develop an optimization model to support the analysis of decision-making on Macedonian family farms. For this purpose, normative linear programming paradigm is applied, utilising its optimization potential. The model is tested and presented on vegetable farm level. Hence, the model provides optimal vegetable productions plan, taking into consideration relevant technological and resource limitations faced by the farm. The results are given in base scenario format and are compared with the optimum production plans within the alternative model scenarios. The optimal production structure in all scenarios indicates that the optimal solution is given on production of tomato, pepper, cabbage, carrot and bean, thus corresponding to the most frequent types of vegetables in the Macedonian agriculture. The optimal production plan also confirms the diversification as a characteristic of the Macedonian agriculture. The base scenario reveals a total net return over the variable costs of 17,924 € which is highest compared to other scenarios. The working capital available is a binding constraint in second and third scenario, where the optimal solution reveals that the land resource is not exhausted i.e. an arable land of about 3 ha remains. Furthermore, the analysis of the crop rotation reflects the seasonal character of the vegetable production. Gross margin sensitivity was examined using the working capital parameterisation. The model is quite flexible thus enabling different crop enterprises to be added additionally.

Key words: linear programming, vegetable farms, production planning
JEL classification: Q12

Introduction

The dynamic circumstances in which farmers operate lead to considerable complexity in the decision making process. Questions like, how to organise production plan to achieve better results or economic efficient production is continues issue in farm management. Both agricultural enterprises and individual farm households therefore make simultaneous management decisions concerning production, procurement, marketing and finances. Applying just the right technology is often not enough, hence farmers need certain knowledge in farm business planning (Boehlje and Eidman, 1984). Farm production planning itself is a complex process, wherein the input-output relations, the input-output cost price ratios, the available farm natural resources, as well as the farmer's preferences should be taken into consideration (Zgajnar, 2011). Therefore the problem of production planning could be addressed as common problem of optimisation and allocation of production resources.

Macedonia is a country where crop production is dominant, contributing with around three-fourths to the total value of agricultural production. Vegetables take the most significant share in the value of agriculture production with 39.4% or 418 million euro in 2010 (SSO/EAA, 2011). The climate in the Republic of Macedonia facilitates successful production of several types of vegetables. Regarding the statistical data (SSO, 2011) the most frequent types of vegetables are: potatoes (22%), tomatoes (18%), green peppers (18%), cabbage (16%), watermelons (14%), cucumbers (5%) and onions (5%), and they are produced mainly on open fields (91%).

In Macedonia there are 15 thousand specialized vegetable farms, representing 8% of the total number of farms in terms of specialised typology (SSO, 2011). Additionally, vegetables are grown on mixed farms, which are the most common type of farm in the country. The average size of family farms is 1.37 hectares (SSO, Ag Census, 2007). Macedonian farms are highly fragmented and with diversified production structure. Most of them are individual family farms, often with insufficient awareness of the importance of farm production and business planning. Their decisions are most frequently made intuitively, based on their experiences and seldom with analytical models, such as decision support systems and tools that are often recommended and developed by researchers. They are also regularly applied even by farm advisors and policy makers.

In this context, the aim of the paper is to develop and present an optimization model to support the analysis of decision-making on Macedonian family farms. For this purpose, normative linear programming paradigm is applied, utilising its optimization potential. The model is tested and presented on hypothetical vegetable farm, providing an optimal production plan.

This paper is structured in four parts. The first part provides the theoretical background regarding mathematical programming models with focus on the linear programming approach. The methodological part captures two aspects; input data and description of the hypothetical farm for testing the model, as well as explanation of the developed tool with its activities and constraints. The third part of the paper focuses on the results and their discussion. Final conclusions are given in the end.

Concept and theory behind

The mathematical programming as a method chooses between farm enterprises on the basis of determined objective function considering a set of fixed farm constraints, thus representing the preferences of the farm (Zgajnar *et al.*, 2007). Optimisation is commonly used approach to solve problems of production planning in the sense of optimal resource allocation given the changing conditions that farms face. Based on the type of the research problem and basic assumptions, the models could be grouped into deterministic and probabilistic or stochastic (Strauss *et al*, 2008). When all required information is supposed to be known with certainty, the model is deterministic supposing there is no risk (variability) and the decision-making is done under complete certainty (Lee and Olson, 2006). Additionally, the theory distinguishes between positive and normative models, wherein normative models are designed to show what the optimal economic result should be (Howitt, 2005).

Linear programming (LP) is the most often used mathematical programming method, even due to its simplified linear and normative nature, it shows quite accurately what the farmers do or how their behaviour changes if the production conditions change (Hazell and Norton, 1986).

The LP has been introduced by Dantzig in 1947 (Lee and Olson, 2006) and since then it has been successfully used in finding an optimal production plan in different areas, most often with an objective function for maximizing the total gross margin or net income. LP has been already proven as useful method in farm production planning (Scarpari M.S. and Beauclair E.G.F, 2010; Alabdulkader A.M. *et al*, 2012; Kebede E. and Gan J., 1999; Majewski E. and Was A., 2005) , whereas Boehlje and Eidman (1984) stressed that this method can be applied to all resource allocation problem the farmer is faced with. It also proved to be more applicable for solving complex problems than other more simple methods as budgeting and marginal analysis.

The linear programming is a mathematical procedure utilising the simplex algorithm which aims to find the optimal combination of farm enterprises under maximisation or minimisation of the linear objective function (Kay *et al.,* 2008). LP models require clear definition of farm activities, resource requirements and specific constraints such as market and policy constraints (Hazell and Norton, 1986). It gives solution that is combination of activities which maximize the value of the objective function (gross margin or net revenue) within a predetermined list of opportunities and constraints (land, labour and capital) (Turner and Taylor, 1998).

The mathematical formulation of a standard linear programming model is

$$\max Z = c_1x_1+c_2x_2+\ldots+c_nx_n, \text{ subject to} \quad (1)$$

$$a_{11}x_1+a_{12}x_2+\ldots+a_{1n}x_n \leq b_1 \quad (2)$$
$$a_{21}x_1+a_{22}x_2+\ldots+a_{2n}x_n \leq b_2$$
$$a_{m1}x_1+a_{m2}x_2+\ldots+a_{mn}x_n \leq b_m$$
$$x_1\ldots x_n \geq 0 \quad (3)$$

Equation (1) determines the objective function of the model for which extreme point should be found, in this formulation maximal total gross margin (Z) per farm annually. The value of objective function, is calculated as sum products of the total gross margin ($c_1,\ldots,c_n$) per activity and the level of the solution ($x_1,\ldots,x_n$)., such as hectares of vegetable crop, kilograms of fertilizers, etc.). The LP model is subject to fixed resource constraints (2), imposing restrictions on the activities in optimizing the objective function. a_{mn} refers to the quantity of the m-th resource required for production of one unit of the n-th activity; and b_m is the extent m-th of available resource (hectares of land, etc.). The common requirement for linear programming models in respect to the nonnegative values of the decision variables is expressed in equation (3).

Method and data

Model for optimisation of vegetable production

For the purpose of this research, a model based on linear programming approach was developed. It is constructed as a general production model that can be adjusted to different vegetable farm situations. It enables analyses of changing optimal vegetable production structures at the farm level in different production conditions. Optimal solution is found under assumption of maximising total expected gross margin, subject to different equality and inequality constraints that define production margins of the farm analysed. The model is set in MS Excel and Visual Basic, using Excel solver for calculation of optimal solution.

Defined production activities (processes) are initially fed into the model, which the solver can choose from. Important part in this step is to define the technological coefficients that resume the key characteristic of technology applied for a specific crop – vegetable. Each production activity included into the model is supported by a detailed enterprise budgets that include the income and costs, as well as the expected gross margin. The budgets are developed on one hectare basis arable land. With the increasing number of activities, the complexity of the model also increases. Therefore, at this stage the model is focused only on the vegetable sub-sector in the Macedonian agriculture.

The model includes 162 decision variables divided into four groups. The first group of activities refers to the most representative vegetable crops thus reflecting the typically diversified production structure on Macedonian vegetable farms. In this regard, eight vegetable crops are included in the model: tomato, pepper, cabbage, carrot, watermelon, potatoes, onion and beans. Different production technologies are considered (open field and plastic tunnel) and a possibility for cultivating tomato and pepper as a second crop is applied as specific activity into the model. Input related activities are presented in the second group of decision variables, reflecting the use of fertilizers, manure, land and labour. The third group of activities captures the infrastructure capacity of the farm. Balance activities, as a fourth group, are determined in order to assure integrity of the solutions. The model offers additional possibility to choose whether certain activities to be included in the given optimisation or not.

Farmers are expected to make decisions under a number of constraints. One set of constraints deals with the production factors scarcity. In this sense, constraints for available land use are incorporated according to the current farming practice, as well as the possibility for land rentals. The labour availability constraint is considered according the seasonal character of the vegetable production, with possibility for hiring extra non-family labour if needed. Kay *et al* (2008) support the determination of the required labour resources on a monthly basis; this is especially important in vegetable production, since in addition to being very labour intensive, there is an uneven distribution of the labour requirement throughout the year, with labour peaks in the seedling phase and in the harvest phase. This uneven distribution justifies the hiring of occasional labour supporting the work in the peak seasons, instead of hiring permanent labour. Many of the processes are performed manually and are not automised, which further pressures the need for manual labour. Conceptually, mechanization becomes economical when the labour required for carry out farming operations increases due to intensification to the point where either it exceeds labour supply or its cost exceeds that of mechanizing operations (Binswanger and Pingali, 1988). Furthermore, as an important endogenous constraint available the working capital for covering the annual variable costs is considered, as separate constraint in the model.

Additionally, agronomic constraints are determined. The first part of constraints is assuring that mineral nutrient requirements are met. In other words that enough fertilisers and manure is applied, of course according to technology assumed by each vegetable activity. In this group also the set of crop rotation constraints could be gathered. They assure that maximal share of different groups of vegetable is not violated.

Another group of constraints captures the external factors that affect the production structure (market and policy constraints). The market limitations are viewed through marketable quantity thresholds, while the policy constraints take the current national agricultural criteria into consideration. Finally, set of balance constraints supplement the model, such as the maximum available land per crop and minimum number of crop enterprises.

Input data and description of hypothetical farm

A combination of different sources of data was used for supporting the model. Basic data for calculating the enterprise budgets were obtained through several relevant sources. A panel of relevant experts was consulted: researchers, crop technology specialists, extension agents, input suppliers and vegetable farmers. The budgets were calculated using the average current farming practice approach (Monke *et al.*, 1989) and supplemented with the data obtained through the Farm Monitoring System (FMS) for 2010. FMS is an annual survey carried out by the National Extension Agency which collects production, income and cost related data from 300-400 farms in the country, spread out in six regions. The system not only provides aggregated data per household but also detailed data per farm enterprise (Martinovska Stojceska *et al.*, 2011). Additionally, in order to acquire more detailed information on the inputs and outputs while constructing the budgets for each vegetable farm enterprise, annual reports from the State Statistical Office and the Ministry of Agriculture were used. Fifteen enterprise budgets are available for optimisation at the hypothetical farm, out of which four provide the possibility for second vegetable crop on the same in the late summer months.

The tool is applied on hypothetical farm, thus reflecting the typical situation on vegetable family farms in Macedonia. The case farm was owns four hectares of open field area[1]. It is supposed that farm owns infrastructure for production under plastic tunnels that could be utilised at maximum on one hectare of arable land, however if need farmer can also invest in additional hectare of plastic tunnels infrastructure. We also supposed that farm could rent additional hectare of arable land, so in maximum it can tillage 5 ha of arable land. Moreover, labour availability is taken in consideration with a threshold of 4,400 hours per annum and equally distributed per seasons. Additional out of farm labourers can be hired; there is no limitation for the hired labour availability. The hired labourers are paid on a daily basis. The crop rotation is also determined; open field production of tomato could have the largest share with 80% of the total land, and on the other side the production of carrot is least intensive and requires around 10% of the total land. The capital constraint is included, as the minimum amount the farmer should have in order to cover the variable costs of the farm; in the hypothetical case farm the working capital amount is set on 13.000 €. We suppose that all enterprise activities in the model could be included into the optimal production plan of the case farm, although the model offers possibility to exclude certain activity if needed.

Model scenarios

In searching for an optimal production plan, it is important to see how stable is the given solution and how it is going to change in different conditions. In addition to the base case scenario, three different scenarios have been introduced to analyse the effect of the most binding constraints on the optimal production plans and signalise which resources have been fully used in the solution (Turner and Taylor, 1998).

All scenarios have the objective function of maximisation of annual total gross margin. The main difference between scenarios is in market and capital constraints. A brief explanation of these scenarios is presented in Table 1.

[1] This corresponds to 15% of all Macedonian vegetable farms with a farm size from three to five hectares (SSO, Ag. Census 2007). As Macedonian farms are small and with highly fragmented and mixed structure, these characteristics are mirrored in the definition of the farm. The average size of family farms is about 1.37 hectares (SSO, Ag. Census 2007).

Table 1. Description of model scenarios

No.	Abbreviation for scenario	Market constraint	Working capital constraint	Scenario specifics
1	S0	x	x	Area under vegetable crops limited to max 5 ha and the labour is restricted on 2 workers annually. No restrictions on market demand and capital available
2	S1	x	√	Working capital available restricted to 13,000 Euros in addition to S0
3	S2	√	√	Market constraint of 20 tonnes for cabbage introduced in addition to S1
4	S3	√	x	Capital constraint relaxed, only demand for cabbage fixed to 20 t for cabbage

Results and discussion

With presented LP model described hypothetical farm has been analysed. The base scenario (S0) outcome provided an optimal production plan that was then compared with the optimum production plans within the alternative scenarios. The main results are presented in Table 2 and Table 3. The production structure in all scenarios indicates that the optimal solution should include production of tomato, pepper, cabbage, carrot and beans. This structure actually corresponds to the most frequent types of vegetables in the Macedonian agriculture. The optimal production plan also confirms the diversification as a characteristic feature of the Macedonian agriculture. The farmers often avoid the monoculture i.e. they produce a number of vegetable crop enterprises, in order to distribute the market risk and to use the labour more efficiently. The base scenario disclosed a total farm gross return over the variable costs of 17,924 €, which is highest compared to other scenarios and logical due to the fact that there is no limitation in the available capital and the market demand. The land resource is fully exhausted; an additional hectare for production under plastic tunnels would increase the farm gross margin by 3,000 €, as shadow price by which the total gross margin would be increased if one more unit of land is brought into the production (Key *et al,* 2008). The production of cabbage (open field and under plastic tunnel) dominates the optimal production plan with 25%, and 20% respectively (Figure 1). However, the production of pepper under plastic tunnel is the most profitable single crop with total gross margin of 11,219 € corresponding to 60% of the total gross margin on the farm. The labour availability is satisfactory, though there is a need of hiring extra labour in the peak seasons.

The working capital reveals to be a binding constraint in S1 and S2, where the gross margin changed from 17,924 € in the base scenario to 9,479 € in S1 and 7,871 € in S2, with drop of about 50% and 43%, respectively. This result corresponds to the average gross margin of Macedonian vegetable farm (8,000 €), thus confirming the practice (Martinovska Stojcevska *et al* 2011). The optimal solutions in S1 and S2 do not exhaust the land resource *i.e.* an arable land of about 3 ha remains unused. This solution actually corresponds to the average size of Macedonian vegetable farms; about 1 ha open field production and 0.7 ha under plastic tunnels in both scenarios. Compared to the base model, the farmer produces the same crops, only the share of land varies in S1 and S2 (Figure 1). The high yield of cabbage and the lower market demand imposes the need for introducing a marketable quantity restriction as a binding constraint in S2, hence limiting the demand for cabbage on 20 tonnes per year. There from, the production of tomato in S2 dominates. In both scenarios the labour is slack, explained by the seasonal character of the vegetable production.

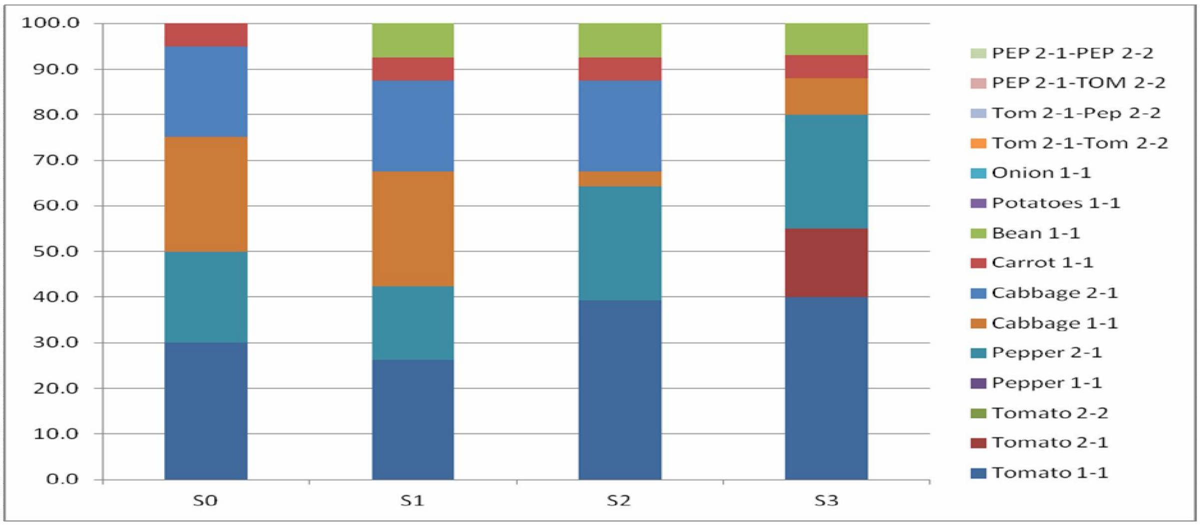

Figure 1: Optimal vegetable production within different scenarios

By relaxing the capital constraint in S3, the production plan is promptly taken by tomatoes with 55% of the total arable land. The land resource is fully used up and an additional 1 ha under plastic tunnel is necessary for tomato production. The shadow price is around 960 €/ha. Considering there are no restrictions in the working capital available, the hired labour in the peak seasons is very high with around 12,000 hours, thus suggesting the need for introducing an additional labour constraint into the model for maximum hired labour per season.

Overall, the analysis of the crop rotation reflects the seasonal character of the vegetable production. The vegetable production is more intensive during the first half of the year, and therefore most of the land is utilised during this period. The analysis of the production inputs shows that three types of fertilizers are used in the production, while getting the nutritients from the manure revealed to be very expensive and affects the profitability of the farm. However, in practice farmers use manure for vegetable production since they already have it on the farm (many vegetable farms would have few heads of livestock).

Table 2. Optimal vegetable production structure under different scenarios

	S0		S1		S2		S3	
	ha (%)	GM (€)	ha (%)	GM (€)	ha (%)	GM (€)	ha (%)	GM (€)
Crop								
Tomato 1-1[a]	30.0	7,092	26.1	2,428	39.2	2,932	40.0	9,456
Tomato 2-1[b]	0.0	0	0.0	0	0.0	0	15.0	7,615
Tomato 2-2[c]	0.0	0	0.0	0	0.0	0	0.0	0
Pepper 1-1[a]	0.0	0	0.0	0	0.0	0	0.0	0
Pepper 2-1[b]	20.0	11,219	16.4	3,610	25.0	4,436	25.0	14,024
Cabbage 1-1 [a]	25.0	6,446	25.0	2,534	3.3	268	8.0	2,063
Cabbage 2-1 [b]	20.0	6,363	20.0	2,501	20.0	2,013	0.0	0
Carrot 1-1[a]	5.0	716	5.0	281	5.0	226	5.0	716
Bean 1-1 [a]	0.0	0	7.5	58	7.5	46	7.0	137
Potatoes 1-1[a]	0.0	0	0.0	0	0.0	0	0.0	0
Onion 1-1[a]	0.0	0	0.0	0	0.0	0	0.0	0
Tom 2-1 [b]-Tom 2-2 [c]	0.0	0	0.0	0	0.0		0.0	0
Tom 2-1 [b]-Pep 2-2 [c]	0.0	0	0.0	0	0.0	0	0.0	0
Pep 2-1 [b]-Tom 2-2 [c]	0.0	0	0.0	0	0.0	0	0.0	0
Pep 2-1 [b]-Pep 2-2 [c]	0.0	0	0.0	0	0.0	0	0.0	0
Total farm gross margin (€)		**17,924**		**9,479**		**7,871**		**11,720**

Symbols on activities used: [a] open field production, [b] production under plastic tunnel I crop, [c] production under plastic tunnel II crop

Table 3. Resource requirements and yields in different scenarios

Working capital (€)								
Per farm		44,881		13,008		13,008		65,247
Land (ha)								
Open field	3.00		1.25		0.87		3.00	
Under plastic tunnel	2.00		0.71		0.71		2.00	
Labour (h)								
Own	4,331		3,424		3,188		3,651	
Rented	7,023	11,419	637	1,036	846	1,376	12,382	20,133
Production (kg)								
Tomato	75,000	7,092	25,673	2,428	31,005	2,932	160,000	17,071
Pepper	55,000	11,219	17,698	3,610	21,746	4,436	68,750	14,024
Cabbage	117,500	12,809	46,183	5,035	20,000	2,281	20,000	2,063
Carrot	8,750	716	3,439	281	2,768	226	8,750	716
Beans	0	0	221	58	178	46	525	137
Potatoes	0	0	0	0	0	0	0	0
Onion	0	0	0	0	0	0	0	0

The farm gross margin sensitivity was further examined using the working capital parameterisation[2]; the available working capital has significant effect on the optimal farm size. However, investing more than 40,000 Euros would not bring additional profit to the vegetable farming business (Figure 2). Seasonal hired labour is not needed up to the level of around 10000 Euros of working capital invested in the farm (Figure 3); beyond that amount, there is growing need of hiring labour and at this moment is not restricted in terms of availability. The land restriction of 5 hectares hinders increase in the farm size, and at the farm gross margin also stagnates from this point.

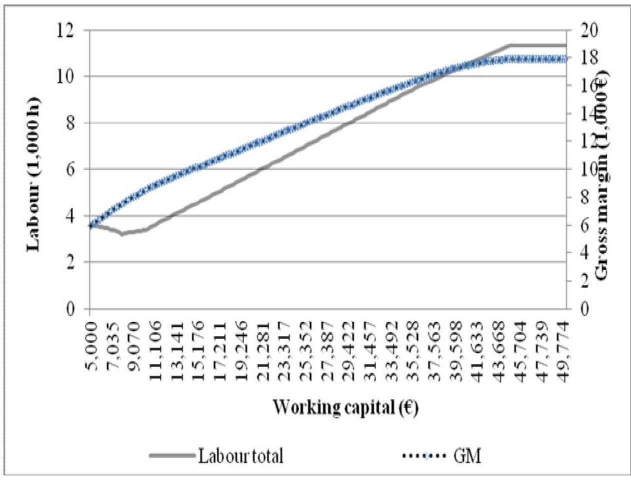

Figure 2: Working capital parameterization

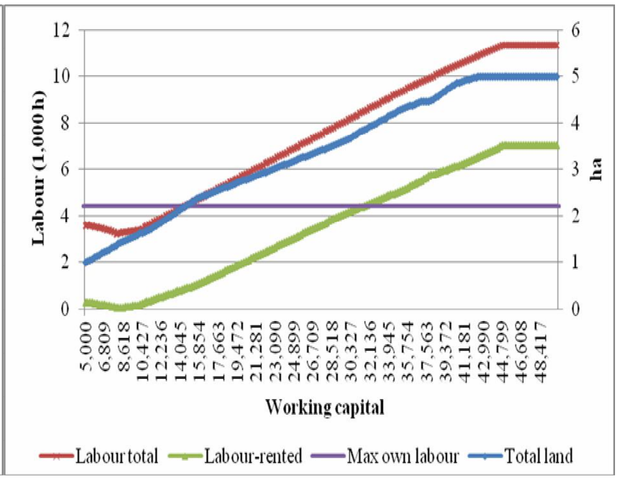

Figure 3: Relation between working capital and land/labour

[2] Parameterisation includes 200 runs of the solver within given range of working capital.

Conclusions

Developed model for optimisation of vegetable production proved to be useful when analysing a farm management problem in Macedonia. Having an appropriate decision making tool is important for farmers in order to determine their production structure and make a combination that will bring the highest benefit, given the resources available. Additionally, such a tool could be used by policy makers for impact assessment of different agricultural policy measures. Considering the benefits of such tool for the post (transition) economies as the Macedonian one, the tool for optimisation of vegetable production with an objective function of maximising the expected return (gross margin) is functional and gives plausible results in reference to the available working capital, farm size, production structure as well as the technological, market and policy constraints.

The hypothetical case farm findings simulated to a large extent the situation in practice. The model revealed that the labour is not a binding constraint, i.e. however, in the peak seasons the farm cannot fulfil the requirements, and hence seasonal labour is hired. The most binding constraint is the available working capital on the farm. Its influence on optimal production structure as well as on expected return, land and labour has been analysed with parameterisation. As the working capital increases the farm size stops at the maximal land constraint, and the farm gross margin also stagnates from this point.

The model is quite flexible thus enabling different crop enterprises to be added additionally. It could be also applied for optimising the crop production in the countries in the region considering the similar structure of their agricultural production as well as similar production technologies.

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