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Optimization of production on vegetable farm in the Republic of Macedonia

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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. Normative linear programming paradigm is applied, utilising its optimization potential. The model is applied on a hypothetical vegetable farm case. The optimal structure in all scenarios indicates that the optimal solution is the production of tomato, pepper, cabbage, carrot and bean. The base scenario reveals a gross margin 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. 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, hypothetical vegetable farm, production planning, Republic of Macedonia

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 are common issues in farm management. Both agricultural enterprises and individual farm households 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.

The Republic of 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 agricultural production with 39.4% in 2010 (SSO/EAA, 2011). The climate facilitates successful production of several types of vegetables. According to 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%).

There are 15 thousand specialized vegetable farms in the country, 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. The 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.

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.

MATERIAL AND METHODS

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. 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). 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. Boehlje and Eidman (1984) stressed that this method can be applied to all resource allocation problem the farmer is faced and often proved to be more applicable for solving complex problems than other more simple methods as budgeting and marginal analysis.; LP has been revisited as useful method in farm production planning in recent studies (Scarpari and Beauclair, 2010; Alabdulkader et al., 2012; Kebede and Gan, 1999; Majewski and Was, 2005).

Model for optimisation of vegetable production

A tool based on linear programming approach was developed for the purpose of this research, 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 environment, 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 detailed enterprise budgets that include the income and costs, as well as the expected gross margin. The budgets are developed on a hectare basis. With the increasing number of activities, the complexity of the model also increases.

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. At this stage, eight vegetable crops are included in 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. 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. 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, as well as 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.

The optimisation model gives also the possibility for calculating the shadow prices, defined as the social opportunity costs of the resources used (Dreze and Stern, 1994). In an LP model the shadow prices as dual variables indicate the marginal values of the right-hand side coefficients representing the resources used, under the assumption of nondegeneracy (Ho, 2000). The model calculates the shadow prices by which the total gross margin would be increased if one more unit of land resource is brought into the production (Key et al., 2008).

Input data and description of hypothetical farm

Different sources of data were used for supporting the tool. Basic data for calculating the enterprise budgets were obtained consulting a panel of relevant experts: researchers, crop technology specialists, extension agents, input suppliers and vegetable farmers, and calculated using the average current farming practice approach (Monke et al., 1989). Furthermore, they were supplemented with the Farm Monitoring System (FMS) data for 2010. FMS is an annual survey carried out by the National Extension Agency which collects production, income and cost related data per farm enterprise from 300-400 farms in the country.

The tool is applied on hypothetical farm with four hectares of open field area[1]. The assumption is that the farm has infrastructure for production under plastic tunnels that could be utilised at maximum on one hectare of arable land; however there is fitted possibility to invest in additional hectare of plastic tunnels. Labour availability is taken with a threshold of 4,400 hours per annum and equally distributed per seasons. The hired labourers are paid on a daily basis. The crop rotation is also determined. The capital constraint is included, as the minimum amount the farmer should have in order to cover the variable costs of the farm.

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 family 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

The base scenario (S0) provided an optimal production plan that was later compared to the optimum production plans within the alternative scenarios. The main results are presented in Tables 2 to 4. 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 a shadow price. The production of cabbage (open field and under plastic tunnel) dominates the optimal production plan with 25%, and 20% respectively (Table 2). 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

Table 2. Land allocation within different scenarios (in ha)

Scenario	Tomato 1-1	Tomato 2-1	Tomato 2-2	Pepper 1-1	Pepper 2-1	Cabbage 1-1	Cabbage 2-1	Carrot 1-1	Bean 1-1	Potatoes 1-1	Onion 1-1	Tomato 2-1-Tomato 2-2	Tomato 2-1-Pepper 2-2	Pepper 2-1-Tomato 2-2	Pepper 2-1-Pepper 2-2
S0	30.0	0.0	0.0	0.0	20.0	25.0	20.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S1	26.1	0.0	0.0	0.0	16.4	25.0	20.0	5.0	7.5	0.0	0.0	0.0	0.0	0.0	0.0
S2	39.2	0.0	0.0	0.0	25.0	3.3	20.0	5.0	7.5	0.0	0.0	0.0	0.0	0.0	0.0
S3	40.0	15.0	0.0	0.0	25.0	8.0	0.0	5.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0

*1-1open field production, 2-1 production under plastic tunnel I crop, 2-2 production under plastic tunnel II crop 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 (Table 2). 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.

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).

A working capital parametrisation was done for sensitivity analysis of the farm gross margin. The parametrisation captures 200 runs of the solver within the given range of working capital. The re-

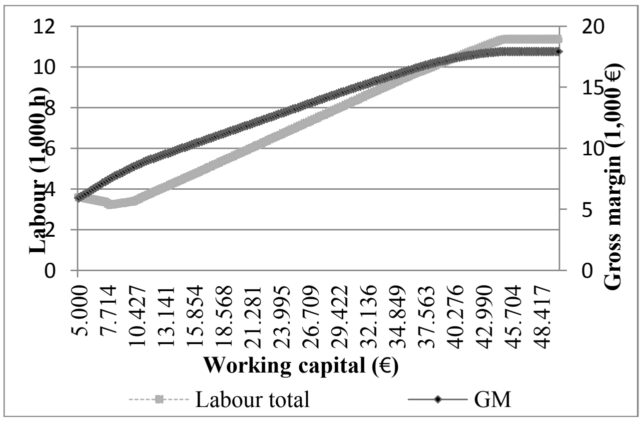
Table 3. Optimal vegetable production structure under different scenarios

	S0			S1			S2			S3	
Crop	ha (%)	GM (€)		ha (%)	GM (€)		ha (%)	GM (€)		ha (%)	GM (€)
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	0.0	0		0.0	0		0.0	0		0.0	0
Pepper 2-1	20.0	11,219		16.4	3,610		25.0	4,436		25.0	14,024
Cabbage 1-1	25.0	6,446		25.0	2,534		3.3	268		8.0	2,063
Cabbage 2-1	20.0	6,363		20.0	2,501		20.0	2,013		0.0	0
Carrot 1-1	5.0	716		5.0	281		5.0	226		5.0	716
Bean 1-1	0.0	0		7.5	58		7.5	46		7.0	137
GM Per farm		17,924			9,479			7,871			11,720

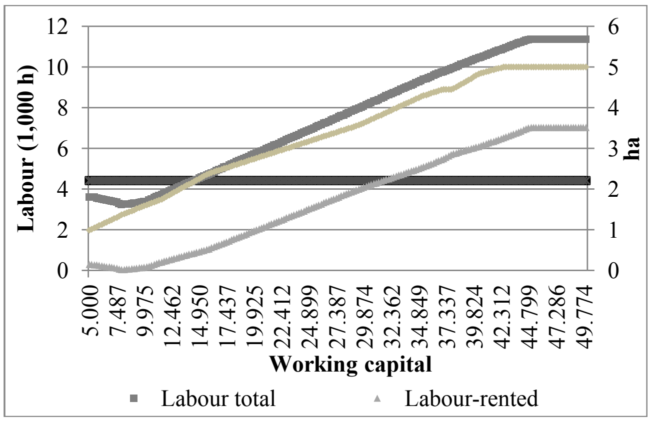
Symbols on activities used: [a] open field production, [b] production under plastic tunnel I crop, [c] production under plastic tunnel II crop

Table 4: Resource requirements and yields in different scenarios

		S0		S1			S2			S3	
Working capital (€)		44,881			13,008			13,008			65,247
Land (ha)											
Open field	3.00			1.25			0.87			3.00	
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		2,382	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



Graph 1: Working capital parameterization



Graph 2: Relation between working capital and land/labour

sults reveal that the working capital influences the optimal farm size, i.e. investing more working capital increases the land use. However, the restriction of 5 hectares hinders the increase in the farms size and therefore the profit also stagnates at this point (Graph 2). Investing more than 10,000 Euros imposes a need of hiring extra seasonal labour (Graph 1).

CONCLUSIONS

The developed model for optimisation of vegetable production proved to be useful when analysing a farm management problem in Macedonia. It is important for farmers to have an appropriate decision making tool 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, an analysis of typical/hypothetical farms is also enabled. The tool for optimisation of vegetable production with an objective function of maximising the expected return (gross margin) proved to be 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 farm findings simulated to the situation in practice a large extent. 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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Optimizacija proizvodnje na farmama za proizvodnju povrća u Republici Makedoniji

SAŽETAK

Cilj ovoga rada jest razvijanje modela optimiranja kako bi se pružila potpora analizi donošenja odluka na makedonskim obiteljskim farmama. Primijenjen je normativni obrazac linearnog programiranja, pri čemu se koristio njegov potencijal optimiranja. Model je primjenjen na hipotetski slučaj farme za proizvodnju povrća. Optimalna struktura, prema svim scenarijima, ukazuje da je optimalno rješenje proizvodnja rajčice, paprike, kupusa, mrkve i graha. Osnovni scenarij ukazuje da je bruto marža od 17,924 € najviša u odnosu na ostale scenarije. Postojeći obrtni kapital obvezujuće je ograničenje u drugom i trećem scenariju, u kojima optimalno rješenje ukazuje da zemljišni resursi nisu iscrpljeni. Osjetljivost na bruto maržu ispitivala se parametrizacijom obrtnog kapitala. Ovaj model je prilično fleksibilan, tako da pruža mogućnost naknadnog dodavanja poduzeća koja se bave proizvodnjom različitih kultura.

Ključne riječi: linearno programiranje, hipotetske farme za proizvodnju povrća, planiranje proizvodnje, Republika Makedonija