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GREENHOUSE VEGETABLE PRODUCTION IN THE FUNCTION OF SUSTAINABLE AGRICULTURAL PRODUCTION

Tamara Paunović*, Blaženka Popović, Radojka Maletić

University of Belgrade, Faculty of Agriculture, Belgrade, Serbia

ORCID iDs: Tamara Paunović https://orcid.org/0000-0003-4747-0678
Blaženka Popović https://orcid.org/0000-0001-5893-1973
Radojka Maletić https://orcid.org/0000-0002-3565-2733

Abstract

A significant segment within the sustainable development of agricultural production and economic prosperity is production in controlled conditions, such as production in greenhouses and glasshouses. In the Republic of Serbia, vegetable production is almost entirely concentrated on family farms. Considering the importance of family farms, the subject of this study is a comparative analysis of vegetable production on family farms and vegetable production in greenhouses, as well as open-air vegetable production. In this context, the paper presents two models for optimising the vegetable production structure, using the method of linear programming and the software package *LINDO*. The first model refers to vegetable production in greenhouses (variant I) and the second one is formulated for open-air vegetable production (variant II). The analysis and solving models have pointed to differences in the optimal sowing-planting structure, in the number of independent variables or vegetables included in models, but also in realised net income, wherein variant I achieves both higher net income per hectare and higher production economy.

Key words: sustainable agricultural production, vegetable production, family farms, model, optimization.

ПРОИЗВОДЊА ПОВРЋА У ЗАШТИЋЕНОМ ПРОСТОРУ У ФУНКЦИЈИ ОДРЖИВЕ ПОЉОПРИВРЕДНЕ ПРОИЗВОДЊЕ

Апстракт

Значајан сегмент у оквиру одрживог развоја пољопривредне производње и економског просперитета је производња у контролисаним условима, као што је производња у пластеницима и стакленицима. У Републици Србији производња

* Corresponding author: Tamara Paunović, University of Belgrade, Faculty of Agriculture, 6 Nemanjina street, 11080 Belgrade, Serbia, tamara@agrif.bg.ac.rs

поврћа је скоро у потпуности сконцентрисана на породична газдинства. С обзиром на значај породичних газдинстава, предмет ове студије је компаративна анализа производње поврћа на породичним газдинствима и производње поврћа у пластеницима, као и производње поврћа на отвореном. У том контексту, у раду су приказана два модела оптимизације структуре производње поврћа, применом методе линеарног програмирања и софтверског пакета *LINDO*. Први модел се односи на производњу поврћа у пластеницима (варијанта I), а други је формулисан за производњу поврћа на отвореном (варијанта II). Анализа и решења модела указали су на разлике у оптималној структури сетве-садње, у броју независних варијабли или броја култура укључених у моделе, али и у оствареном нето приходу, при чему варијанта I остварује и већи нето приход по хектару и већу економичност производње.

Кључне речи: одржива пољопривредна производња, производња поврћа, породична газдинства, модел, оптимизација.

INTRODUCTION

The concept of sustainability has become a key factor for the survival and progress of civilization and society. In order to achieve global sustainability, it is necessary to re-examine the opinion of ecology and the economy as opposing goals. Global thinking on this topic has also led to the first results related to agriculture, which are aimed at relieving global conventional production and eliminating the negativity of such development by focusing on alternatives based on biological or ecological principles (Kovačević, 2010).

To promote sustainable agriculture, we must move past focusing on these oversimplified relationships to disentangling the complex social and ecological factors, and determine how to provide adequate nutrition for people while protecting biodiversity (Ponisio and Ehrlich, 2016).

Sustainable intensification of agricultural production focuses on increasing yields, especially on land already used in agriculture (Pretty and Bharucha, 2014), or as some have called it ‘land sparing’ (Ceddia et al., 2014; Hulme et al., 2013). The overall strategy is to meet food needs while curbing agricultural expansion into marginal lands and into the relatively few remaining large tracts of land in natural habitat (Jordan et al., 2015; Doré et al., 2011).

Sustainable agricultural production as well as conventional agriculture relies on the application of various technologies in order to meet production needs (Tilman et al., 2011; Elliott and Firbank, 2013; Barnes and Thomson, 2014). They differ because sustainable intensification gives more importance to technologies and practices that reduce resource use, mitigate the effects of climate change and protect natural ecosystems (van Ittersum et al., 2013; Fish et al., 2014; Balwinder-Singh et al., 2015; Rochecouste et al., 2015).

In order to meet the growing demand for food globally, a large number of advocates of sustainable intensification of agricultural production consider that the use of biotechnology in food production is a key element in meeting the growing needs (Flavell, 2010; Bennett et al., 2013; Jacobsen et al., 2013; Teixeira et al., 2015).

According to some authors, the ways in which sustainable agricultural production can be realised in practice are specific techniques that define sustainable agriculture such as: biodynamic agriculture (Pechrová, 2014), integrated systems (Khan, 2011; Ogello et al., 2013) and permaculture (Ferguson and Lovell, 2014;Altieri et al., 2016). Some other authors believe that sustainable production can be realised in practice only on small and family farms (Kull et al., 2013; Dogliotti Moro et al., 2014; Woods, 2014).

The Republic of Serbia has the largest comparative advantage in the production of agricultural products and agro industry. Agriculture, as one of the carrying mega sectors, can contribute to economic development not only with its fast development, but also with its influence on the increase of the total level of productivity of a country, which does not oppose new employment (Marjanović and Marjanović, 2019).

Agriculture is one of the most important branches of Serbian economy. The share of agriculture in GDP, compared to the EU member states, is very high and amounts to 6.5% (Annual national accounts, 2022). In the Republic of Serbia, family farms are the most important production unit, both in production potentials and in production volume. The main contingent of workforce that determines the overall development of agriculture is concentrated on family farms. These farms should be a subject of special interest of agricultural policy. These are the farms which are engaged in different activities in the form of family business (tourism, trade services, trade, etc.), in the framework of rural households, and agricultural operation is secondary and not primary (Maletić and Popović, 2016).

The largest part of production potentials in agriculture is located on family farms, but as a whole, agricultural production on these farms is underdeveloped (Munćan and Živković, 2005). The Republic of Serbia is characterised by the relatively small size of land property and a large number of detachable parts and parcels, which indicates that the land is not rationally used as an objective condition for agricultural production and farm operation. Considering the importance of vegetable production for producers and for sustainable agricultural production, the basic directions of its future development are the optimal use of available production capacity, an increase in production volume, and the change of production structure (Novković et al., 2013).

Vegetable production is also very important from the aspect of using available natural resources and technological achievements, all in the function of creation and income growth in agriculture (Stefanović and Stefanović, 2005). In addition, vegetable production represents an important raw material base for various forms of processing, but also greatly affects the development of the food industry.

Besides open-air vegetable production – in the field, a significant place is intended for indoor vegetable production – in greenhouses, which allows the growth and replacement of several cultures during the year, the combined off-season production, provides a several times higher yield compared to open-air production, and represents the most intense type of production. This type of production involves a very intensive use of land and represents the most intensive branch of plant production. However, due to high production costs, unfavourable financing conditions, and the fragmentation of land property, this type of production in greenhouses is still underused in our country, although there are great production potentials.

In order to improve vegetable production on family farms, it is necessary to solve the basic and ever-present problem of determining the optimal production structure. It means that it is necessary to determine such a production structure that provides maximum economic results in a given production, technical and economic conditions (Bošnjak, 1997).

Accordingly, the objective of this research implies determining such a structure of vegetable production in greenhouses as well as open-air vegetable production, which provides maximum economic results in the given production, technical and economic conditions. In this context, two types of models for optimising vegetable production structure are formulated, one that relates to vegetable production in greenhouses (variant I), and the other formulated for vegetable production in the open air (variant II). The optimal structure of vegetable production both in greenhouses and in the open air was obtained using the method of linear programming, which is also the basic method used for experimenting on models in this research.

Linear programming is one of the most frequently used quantitative techniques. There are many practical problems in the field of agribusiness which could be solved by linear programming (Thornley and France, 2007; Vohnout, 2003; Vico and Bodiroga, 2017). The presence of Operational Research in Agriculture and Forest Management applications is already extensive, but the potential for development is huge in times where resources are becoming increasingly scarce and more has to be done with less, in a sustainable way (Carravilla and Oliveira, 2013).

A great number of authors have dealt with this problem of determining the optimal vegetable production structure. In order to point out the possibility of rational land use, and to achieve better economic effects, in his paper, Radojević presented the model of linear programming for the optimal planning of vegetable production structure intended for industrial processing (Radojević, 2003). Using the method of linear programming, Krasnić has performed model-based testing for optimising the vegetable production structure for industrial processing and for consumption in fresh condition (Krasnić, 2004). Novković et al. have paid special attention to the optimal structure of vegetable production on family farms (Novković et al., 2011). Aiming to define the optimal structure of vegetable production that will provide the best economic effects, which will meet the needs of the market and which will enable the intensive use of land, Nikolić analysed the vegetable production on family farms in Vojvodina (Nikolić, 2014).

MATERIALS AND METHODS

Taking into account a large number of limiting production factors, the process of determining the optimal production structure on family farms is a very complex task. In order to solve this problem, one of the most commonly used methods is the method of modelling. This method has been successfully used whenever it was not possible or was not rational to experiment on a real system, or on the research subject. It means that all relevant system attributes that are important for the research subject must be identified and analysed.

The primary method used for experimenting on the model is the linear programming method. Mathematically expressed, linear programming is a method for finding the optimum (minimum or maximum) of the linear function with the 'n' independent variables X_i (i = 1,2,3, ...) that are connected by linear relations (equations or inequalities), or limiting conditions – constraints (Mihajlović and Novković, 2009).

The general problem of linear programming can be mathematically presented as follows.

(1) The objective function:

$$\sum_{i=1}^{n} c_i X_i = Z \rightarrow \max \ (V \rightarrow \min)$$

wherein the symbols have the following meanings: X_i - independent variables; i – 1, n; n - the number of independent variables in the model; c_i - the objective function coefficients; Z - the maximum value of the objective function; and V - the minimum value of the objective function;

(2) The constraints matrix:

$$\sum_{i=1}^{n} a_{ij} X_{ij} \overset{\geq}{\leq} A_j$$

wherein the symbols have the following meanings: j - 1, m; m - number of constraints in the model; a_{ij} - technical coefficient of the independent variable Xi in the j constraint; and A_j - available resource (constraint) j;

(3) Non-negativity constraint:

$$X_i \geq 0$$

The activities in both models are independent variables and refer to different types of vegetables. Therefore, it may happen that vegetable crops from models are repeated several times, as a result of crop rotation, crop type and seeding order. The total number of independent variables in the optimisation model of vegetable production structure in greenhouses is 26, and 55 in the optimisation model of open-air vegetable production. For the purposes of this study, six basic groups of vegetable crops were defined: root vegetables, onion vegetables, tuberous vegetables, fruiting vegetables, legumes, and leafy vegetables. Certain variables appear more than once in the model and depend on the number of possible prerequisites. For example, the group of root vegetables includes some of the following independent variables: carrot wound, parsley, parsnip, beetroot, spring radish, winter radish after cucumber, autumn radish after green beans, and early chard.

The constraints of the models are related to the limiting conditions of land area (variant I -1 ha, variant II - 10 ha), labour, mechanisation (only variant II), and of course, sowing or planting time. Accordingly, there are 41 defined constraints for variant I and 71constraints for variant II. For example, the limitation of land capacity in the first sowing in the mathematical model is limited to 1 hectare and includes those activities, i.e. crops that are a prerequisite for the independent variables in the second sowing. The limitations of the land capacity of the second sowing must be less than or equal to the total area from the limitations of the first sowing, and the crops represented in the second sowing are at the same time independently variable prerequisites for the third sowing. A group of constraints in a mathematical model for optimizing the production structure in the field (variant II) includes the limitations of the means of mechanisation (medium tractors) and includes a period of nine months, which is assumed to represent the so-called 'work peaks' (February-October).

Given that the study relates to family farms, net income, which is also called the gross financial result, will be used as a determinant for optimization in defining the economic functions, or the objective function. Net income is the difference between the production value and direct variable costs, but it also represents coefficients of the objective function. Using these categories as determinants to maximise the objective function, the negative impact on the allocation of fixed costs of assumed activities is eliminated, which may cause us to obtain some incorrect solutions.

Based on the defined mathematical models and optimality criteria, and with the use of the software package *LINDO*, a solution relating to the optimal structure of vegetable production in greenhouses and outdoors is obtained.

In addition to this classical method of linear programming, the optimisation of vegetable production structure is also applied for both model variants, based on multiple criteria of optimality, which will, among other things, resolve the issue of the optimal production structure based on maximum efficiency, i.e., economy of production. Maximising the production efficiency due to nonlinearities of relation was achieved by applying fractional linear programming. Farm accounting records have been a valuable source of data for this analysis; the data consists primarily of the calculations of production, as well as the norms of working hours for the observed vegetable crops, both in greenhouses and outdoors.

RESULTS AND DISCUSSION

A comparative analysis or a comparative review of the obtained results was performed, based on defined models for the optimisation of vegetable production structure in greenhouses and in the open air. The comparative analysis of the solutions is primarily related to the presentation and analysis of the obtained optimal production structure for both variants of the model, and is aimed at showing the differences between the participation of certain groups of vegetables, in terms of direct involvement of the workforce, as well as in terms of economic indicators of effectiveness and efficiency. The criterion that was used for this analysis is maximisation of net income.

Table 1 shows a comparative review of the participation or share of certain groups of vegetables for all three different sowing-planting times for both model variants, since the initial models differ in the total area intended for this type of production.

Table 1. Participation (%) of certain groups of vegetables in models for variant I and variant II

Sowing - planting		Groups of vegetable crops						Total area (ha)
		Root vegetables	Bulb vegetables	Tuber vegetables	Fruit-bearing vegetables	Leguminous vegetables	Leafy vegetables	
I	Variant I	20	20	25	/	20	15	1
II		3	2	/	51	/	44	0.67
III		4	/	/	/	/	96	0.56
Total (%)		11	9	11	16	9	44	2.23
I	Variant II	30	10	10	/	40	10	10
II		52.92	0.25	/	18.63	2.36	25.84	8.05
III		/	15.32	/	/	/	84.68	6.33
Total (%)		30	8	4	6	17	35	24.38

Source: Authors' calculations

A comparative analysis of the participation of certain vegetable groups in both of variants of the model based on the maximisation of net income reveals differences in the vegetable production structure in all three sowing-planting periods. Comparing the results in the total amount, variant II exhibits a greater share of root vegetables (by 19%) and legumes (by 8%) than variant I.

On the other hand, in variant I, the participation of other groups of vegetables is higher: by 7% in tuber vegetables, 10% for fruit vegetables, and 9% in leafy vegetables. The difference in participation of bulb vegetables is negligible, and it is only 1%.

The next part of the comparative analysis refers to the direct involvement of the workforce, where we discussed the overall working hours of employees, working hours of employees per months, and working hours of employees per hectare. For the purposes of this study, it was assumed that all operations can be performed on time, and that there is no need to hire seasonal labourers. Based on this assumption, the required number of working hours per month was finally determined by solving the model.

Table 2. Number of working hours of direct workforce by month, variant I and II variant

Variant I			Variant II		
Months	Number of working hours	%	Months	Number of working hours	%
II	25.298416	2.04	II	788.899963	7.16
III	62.614334	5.05	III	1612.622314	14.64
IV	149.870529	12.08	IV	693.768860	6.30
V	140.282791	11.31	V	530.692505	4.82
VI	186.139969	15.00	VI	1267.591797	11.51
VII	289.276215	23.31	VII	1843.977905	16.74
VIII	223.797226	18.04	VIII	1179.676514	10.70
IX	127.730438	10.29	IX	2783.842041	25.28
X	35.800888	2.89	X	311.213348	2.83
Total	1240.810806	100	Total	11012.28525	100
Per hectare	556		Per hectare	452	

Source: Authors' calculations

The observation period for the direct involvement of the workforce is between February and October, because it is assumed that these are the months when most of the business operations are conducted, especially in the summer months, which are known to be the working peaks. That can be seen from the results in Table 2, and their comparative analysis indicated that the largest direct involvement of the workforce for both model variants is in the months of June, July, August and September. Observed by months, it can be seen that in almost every month, variant I exhibits a greater involvement of direct labour force. The exceptions are February, March and especially in September, when this difference is particularly evident in variant II and is higher by almost 15% compared to variant I.

The total number of working hours of the direct labour force is much higher in variant II, but given that the area on which this production is performed is ten times bigger than the area defined for variant I, this result is expected. On the other hand, the direct involvement of the workforce per hectare for the model for variant I is 556 working hours, and it is 452 working hours in the model for variant II, implying that it takes a greater involvement of the workforce for vegetable production in greenhouses – 104 working hours per hectare more compared to open-air vegetable production. The comparative analysis of involved agricultural mechanisation is not possible, given that mechanisation is involved only for open-air vegetable production, while the involvement of mechanisation in greenhouses was not necessary considering the area defined by the model.

The last part of the comparative analysis refers to no less significant indicators of the results obtained by the defined optimising models. Namely, they refer to economic categories that were taken into account for defining the objective function, and indicate the economic effectiveness and economic efficiency of vegetable production for both model variants. When defining the economic function, net income was used as a determinant for the optimisation of the mentioned function. The net income is the difference between the production value and the direct variable costs. At the same time, it represents the coefficients of the optimality criterion function. The calculated net income is presented in the form of calculations for individual types of vegetables.

The primary goal of a family farm's activity is certainly to maximise the economic impact of production. In addition to the analysis of the economic effectiveness of production, an analysis of the economic efficiency of production was also carried out with the aim of demonstrating the economic efficiency of production achieved on the family farm.

In this sense, a new criterion function was defined for the set model, and the maximum value of production economy was determined by solving it. Such an analysis based on multiple optimality criteria required the application of the fractional linear programming method.

The economic effectiveness of vegetable production is presented in the form of parameters of net income, and economic efficiency is shown based on calculated economy of production. This data is shown in Table 3.

Table 3 shows that the model for optimising the vegetable production structure in greenhouses achieves higher net income per hectare than the model for optimising the open-air vegetable production structure, but achieves lower net income per working hour of the workforce, which is in line with the greater involvement of direct workforce.

On the other hand, if production efficiency is observed, then the model for optimising the vegetable production structure in greenhouses is more expressed, and its production economy is 2.25 –almost twice the size of the economy of vegetable production that is performed in the open air.

Table 3. Indicators of effectiveness and efficiency in models for variant I and variant II

Model variants	Indicators		
	Net income per hectare (EUR)	Net income per working hour (EUR)	Economy of production
Variant I	34036	27.4	2.25
Variant II	31641	28.7	1.14

Source: Authors' calculations

Analysing and comparing the financial results of open-air vegetable production and vegetable production in greenhouses, different authors also concluded that vegetable production in greenhouses is financially more cost-effective despite higher investment costs (Oplanić et al., 2013; Hadelan et al., 2015; Stamenkovska Janeska et al., 2013). The tool for the optimisation of vegetable production with an objective function of maximising the expected return proved to be functional and gives plausible results in reference to the available working capital, farm size, and production structure, as well as the technological, market and policy constraints (Stamenkovska Janeska et al., 2013).

CONCLUSIONS

Vegetable production is very important for producers, but also for the overall agricultural production. In accordance with that, the basic directions of its future sustainable development should be focused on the optimal use of the available production capacity, on increasing the volume of production, and on changing the production structure.

Unlike crop production, vegetable production achieves more favourable effects in terms of all the components of rural sustainability. The revenues generated in vegetable production are several times higher than the revenues generated from maize and wheat production, which results in better financial effects and more stable economic sustainability of farmers. The significance of vegetable production is also reflected in the great need for human labour, thus creating preconditions for new jobs in rural areas, which is the basis of social sustainability.

Based on the results obtained by a comparative analysis of the models, it can be concluded that the models differ in the optimal sowing-planting structure, in the number of independent variables or vegetables included in the models, but also in realised net income. Also, the model for variant I requires a greater involvement of the direct workforce per hectare, and at the same time, there is no need for involvement of agricultural mechanisation. Accordingly, it is expected that the model for variant I would show the lower value of net income per working hour of the workforce compared to the model for variant II. However, when it comes to production efficiency, this model variant achieves production economy that is almost twice the size of the model for variant II.

In addition to their differences, we should point out what is common to both models. First of all, based on the obtained results, it can be claimed that the defined models are reliable, given the very wide limits of tolerance in the coefficients of the objective function. Another similarity is reflected in the fact that these models can be applied in real business conditions, or on a specific family farm. The analysis of the defined models is certainly facilitated by using modern computer techniques that enable fast and efficient data processing, thus obtaining relevant information related to the entire production process on a family farm.

Information obtained in this way is certainly a good information base for farmers, which can help them in the decision-making process. 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 reap the highest benefits given the resources available.

Although Serbia is generally a large vegetable producer, it still imports large quantities of off-season vegetables. With the further development of vegetable production in greenhouses, Serbia as an importer country could soon become an exporting country. Geothermal sources, mainly located in the territory of Vojvodina, Posavina, Mačva, Podunavlje, and the wider area of Central Serbia represent unused sources of energy that are necessary for this type of production. Production based on fossil fuels is not competitive due to high energy prices, but a competitive and profitable sustainable vegetable production could be achieved with the use of thermal energy sources.

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ПРОИЗВОДЊА ПОВРЋА У ЗАШТИЋЕНОМ ПРОСТОРУ У ФУНКЦИЈИ ОДРЖИВЕ ПОЉОПРИВРЕДНЕ ПРОИЗВОДЊЕ

Тамара Пауновић, Блаженка Поповић, Радојка Малетић
Универзитет у Београду, Пољопривредни факултет, Београд, Србија

Резиме

У Републици Србији производња поврћа је готово у целости сконцентрисана у породичним газдинствима, која представљају најзначајнију производну јединицу, како по производним потенцијалима, тако и по оствареном обиму производње. Основни циљ овог истраживања је утврђивање структуре производње поврћа у пластеницима (модел I) и на отвореном простору (модел II, која ће омогућити да се оствари максималан финансијски резултат и да се обезбеди пуна запосленост радне снаге, уз уважавање низа биотехничких, производних, технолошких и тржишних ограничења. У суштини, у истраживању је извршено упоређивање два начина производње поврћа, односно два нивоа интензивности производње, применом математичких модела да би се на основу такве упоредне анализе могле дати

препоруке за будућу производњу. На основу упоредних резултата добијених анализом оба модела утврђено је да се модели међусобно разликују по оптималној структури сетве-садње и по броју независно променљивих величина или врста поврћа које су укључене у моделе, али и по оствареном нето приходу. Решавање дефинисаних модела извршено је применом методе линеарног програмирања, уз коришћење програмског пакета ЛИНДО, која се показала као веома успешан инструмент за оптимирање структуре производње поврћа. Компарација добијених резултата, која се у првом реду односи на приказивање и анализу добијених оптималних структура производње за обе варијанте модела, имала је за циљ да покаже међусобне разлике у погледу заступљености појединих група поврћа, у погледу ангажовања директне радне снаге и средстава механизације, као и у погледу економских показатеља ефективности и ефикасности. Критеријум који је послужио за ову анализу је максимизација нето прихода. Економска ефективност производње поврћа представљена је параметром у виду нето прихода, а економска ефикасност је приказана на основу израчунате економичности производње. Резултати до којих се дошло показују да модел за оптимизацију структуре производње поврћа у пластеницима остварује већи нето приход по једном хектару од модела за оптимизацију структуре производње поврћа на отвореном, али и да остварује и мањи нето приход по часу рада радника, што је у складу са већим ангажовањем директне радне снаге. Са друге стране, ако се посматра ефикасност производње, онда до изражаја долази модел за оптимизацију структуре производње поврћа у пластеницима, чија економичност износи 2,25 и скоро је дупло већа од економичности производње поврћа која се обавља на отвореном простору. Моделе који су дефинисани у овом истраживању, уз евентуална минимална прилагођавања, могуће је применити на конкретним случајевима у пракси, односно у породичним газдинствима која се баве производњом поврћа како би се приказала могућност додатног искоришћавања расположивих производних ресурса.