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Optimization Models of Operation of Agro-Industrial Enterprises

Optimización de modelos de operación en empresas agroindustriales

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Content

ABSTRACT:

The article dwells upon specific features of operation of agro-industrial enterprises involved in cultivation of agricultural products under the conditions of protected ground. The most significant factors which place significant restrictions on the economic component of activity are seasonal demand for the products, and, consequently, significant fluctuations in prices, limited number of areas of protected and heated plots of ground, as well as the need to sell considerable volume of yield through the wholesale buyers due to limited storage life of products. These factors must be taken into account in the formulation of economic and mathematical problems of optimization of the operating activities of these enterprises. The article is aimed at simulating the productive-economic activity of agro-industrial enterprises under the conditions of protected ground. The authors have developed the optimization model for the utilization of agriculturally used areas by the enterprises which cultivate agricultural products with the use of hothouses, taking into account the restrictions on the area of the piece of land, yield values, possible volume of sales and assortment policy during a particular period of time. This model allows forming the optimal program of cultivation of products which ensures the maximum economic effect. In addition, an optimal pricing model has been developed for the products sold which allows harmonizing the economic interest the interests of the producer and the wholesale buyers and receive additional economic effect in the system under consideration.

Keywords: agro-industrial enterprise, protected ground, optimization model, production program,

RESUMEN:

El artículo se basa en las características específicas de la operación de las empresas agroindustriales involucradas en el cultivo de productos agrícolas bajo las condiciones de un terreno protegido. Los factores más importantes que imponen restricciones significativas al componente económico de la actividad son la demanda estacional de los productos y, en consecuencia, fluctuaciones significativas en los precios, un número limitado de áreas de parcelas de terreno protegidas y climatizadas, así como la necesidad de vender considerables Volumen de rendimiento a través de los compradores mayoristas debido a la limitada vida de almacenamiento de los productos. Estos factores deben tenerse en cuenta en la formulación de problemas económicos y matemáticos de optimización de las actividades operativas de estas empresas. El artículo tiene como objetivo simular la actividad productiva-económica de las empresas agroindustriales en condiciones de suelo protegido. Los autores han desarrollado el modelo de optimización para la utilización de áreas de uso agrícola por parte de las empresas que cultivan productos agrícolas con el uso de invernaderos, teniendo en cuenta las restricciones en el área del terreno, los valores de rendimiento, el posible volumen de ventas y el surtido. política durante un determinado período de tiempo. Este modelo permite formar el programa óptimo de cultivo de productos que garantiza el máximo efecto económico. Además, se ha desarrollado un modelo de precios óptimo para los productos vendidos, que permite armonizar el interés económico de los intereses del productor y de los compradores mayoristas y obtener un efecto

pricing, reconciliation of economic interest.

económico adicional en el sistema considerado.
Palabras clave: empresa agroindustrial, terreno protegido, modelo de optimización, programa de producción, precios, conciliación de intereses económicos.

1. Introduction

The agricultural industry is booming in the Russian Federation today. In terms of output of certain types of products, the country established itself as a leader in the world market in 2017. The output of agricultural products in Russia at year-end 2017, taking into account the refined data on the production of certain types of agricultural products, has increased as compared to the indicator for the previous year by 2.4% and reached RUB 5.098 trillion [1]. For example, the volume of production of wheat has increased by 12,569 thousand tons, the volume of production of barley has increased by 2,606 thousand tons, the volume of production of oil-bearing-crops has increased by 236.6 thousand tons. The production of vegetables occupies a special place in agriculture. The harvesting of vegetables cultivated on the field and in protected ground increased by 108.4 thousand tons in 2017 [1]. Severe climatic conditions in many regions of Russia preclude from fully meeting the demand for these products in the winter and spring period. For example, according to the Ministry of Agricultural Development, 2.3 million tons of tomatoes on the field and 330 thousand tons in protected ground [2] were grown in 2017 in Russia. Hence, self-sufficiency in tomatoes grown on the field within the country, according to the estimates of agricultural department, amounted to 56%. The market saturation with domestic products is approximately one half as high in winter, and it amounts to no more than 20−25% during the peak winter season. This circumstance necessitates the importation of products in greater volume. The total area of the hothouses in the country has increased by almost 10% - up to 2.6 thousand ha in 2017 [3].

Hence, the rapid development of production of agricultural products under the conditions of protected ground necessitates the development of economical and mathematical tools that allows forming the decision models for the organization of industrial and business activity. These models, along with the direct use of agricultural technologies of cultivation of products [4], allow making reasonable decisions on the optimum utilization of the ground areas, the development of the product line and the comprehensive production program, the development of mechanisms for the optimally reconciled interaction between the producers and consumers of products. The article will further dwells upon the models of optimization and improvement of the effectiveness of business activity of agricultural enterprises under the conditions of protected ground and hothouse facilities.

2. Main part

Let's consider the economic and mathematical model of optimization of utilization of the agriculturally used area under the conditions of protected ground. As a rule, the agro-industrial enterprise is involved in cultivation of several kinds of agricultural products [5,6]. Let's denote the number of crop titles in the product range of the enterprise through m. Each i-th crop occupies the hothouse area s_i and is characterized by the crop yield q_i kg/m². As can be seen from the analysis, according to the scientific and practical research, revegetation is carried out according to the plan in the same months [7]. Then we may consider the yield as dependant from the month t=1,2,...,12 [8]. Hence, the output of products can be determined from the following expression:

$$x_i = q_i(t) \cdot s_i.$$

It is evident that the enterprise has a certain level of costs $z_i(t)$ for the output of products the amount of which depends on the month as well [9-12].

Let's select the annual profits from the sales of m types of products for the price $p_i(t)$ as a criterium of maximization of economic effect of the enterprise:

$$\begin{cases} \Pi = \sum_{t=1}^{12} \left[\sum_{i=1}^{m} p_i(t) \cdot q_i(t) \cdot s_i(t) - z_i(t) \right] \to \max \\ \sum_{i=1}^{m} s_i \le S \\ x_i(t) \le V_i \\ x_i(t) \ge x_{ar}(t) \end{cases}$$

The following restrictions apply in this formulation of the problem:

1) the total area of pieces of land under each crop must not exceed the total area S:

$$\sum_{i=1}^{m} s_i \le S$$

2) the production volume of each crop in each month must not exceed the amount of demand for it (possible volume of sales) in this month:

$$x_i(t) \le V_i$$

3) the production volume of each type of products must not less than the required volume in accordance with the assortment policy of the enterprise:

$$x_i(t) \ge x_{na}(t).$$

Let's consider the last condition. Both of its parts can be determined through the area under crop as well as through the yield of this crop. Therefore:

$$q_i(t) \cdot s_i(t) \ge q_i(t) \cdot s_{ar}(t)$$

$$s_i(t) \ge s_{ar}(t).$$

Hence, the area under crop must not be smaller than the required area in order to achieve the planned range of products.

Let's consider the sales of the proposed approach to the utilization of the agriculturally used area through the example of the enterprise of the Samara region Teplichnyi JSC.

Table 1 presents the reference data by the yield values of the cultivated crops depending on the month provided that the areas are resoiled each year according to the sam plan, and the average selling price of products per month.

Table 1

Dependence of the yield in kg/m2 from the month/average price, RUB

Month	Tomatoe	Cucumber variety "Atlet"	Cucumber variety "Kurazh"	Pepper	Eggplant	Lettuce
1		3,11/129,37				0,56/20,42
2		26,62/94,21				0,52/19,04
3	2,74/136	31,13/64,46		1,96/145,15	2,44/150	0,63/20,19
4	24,98/88,93	32,74/53,58		5,87/150	15,78/145,53	0,50/19,85

5	26,80/70,91	29,27/44,78		9,78/122,16	18,03/118,08	0,47/14,50
6	12,57/31,83	7,59/27,94		4,36/87,76	14,2/94,05	0,4/10,19
7	6,78/18,66	0,16/20,68		2,23/	6,77/64,45	
8	2,73/9,23		3,82/16,41	1,27/33,7	3,46/33,15	
9	3,37/16,94		5,54/7,62	1,21/23,73	3,18/28,10	0,25/14,97
10	4,12/26,46		3,19/11,99	0,72/23,86	1,46/43,37	0,24/14,78
11			0,14/20,87			
12						

Please note that the absence of the yield values means that the plant grows in the hothouse during this period, but doesn't bear any fruit. The total area of the hothouses amounts to 13800 m². In order to maintain the technological process of processing and revegetation, the required area for the cultivation of for tomatoes shall be as follows: from January to June - 3000 m², from July to October - 1000 m²; the minimum required area for the cultivation of cucumber variety "Atlet" shall be as follows: from January to May - 4000 m², from June to July - 2000 m²; the minimum required area for the cultivation of cucumber variety "Kurazh" shall be as follows: from July to November - 2000 m²; the minimum required area for the cultivation of pepper shall be 250 m², the minimum required area for the cultivation of eggplants shall be 250 m², and the minimum required area for the cultivation of lettuce shall be 100 m².

The computational solution to this problem allowed us to determine the following values of the optimal areas presented in Table 2.

Table 2

Optimal area values, m2

Month	Tomatoe	Cucumber variety "Atlet"	Cucumber variety "Kurazh"	Pepper	Eggplant	Lettuce	Total
1	3,000	10,700	0	0	0	100	13,800
2	3,000	10,700	0	0	0	100	13,800
3	3,000	10,200	0	250	250	100	13,800
4	3,000	10,200	0	250	250	100	13,800
5	3,000	10,200	0	250	250	100	13,800
6	3,000	10,200	0	250	250	100	13,800
7	1,000	10,200	2,000	250	250	100	13,800
8	1,000	0	2,000	250	250	0	3,500
9	1,000	0	2,000	250	250	0	3,500
10	1,000	0	2,000	250	250	100	3,600

11	0	0	2,000	0	0	100	2,100
12	0	0	0	0	0	0	0

In addition, a restriction was introduced consisting in the fact that the area under crop in the following month must not exceed the area in the preceding month, which means that partial crop harvesting is possible, while additional planting is not possible.

We can see from Table 2 that the most profitable crop – cucumber variety “Atlet” – occupies the maximum possible area which remained after planting of the other crops at the minimum required area. Moreover, the area of the hothouses is fully divided between these crops during the first seven months. The change in the areas utilized for the cultivation of tomatoe and cucumber varieties “Atlet” is due to the decrease in the yield of vegerables and seasonal drop in prices. That's why the upkeep and maintenance of the hothouses with the maximum total area becomes unprofitable. Meanwhile, the areas which became free are resoiled and prepared for the new planting of vegetables.

Moreover, the total revenue will amount to 161335335 rubles which is 19.7% higher than the revenue received by the enterprise.

Further, let's consider the optimization model of the product pricing strategy. Table 3 presents the statistical information about the structure, volume and revenues from the volume of sales of cultivated products of Teplichnyi JSC. As can be seen from the presented data, the maximum volume of products is sold through the wholesale buyers and small-scale wholesale buyers. It is mainly caused by the limited storage life of products. Therefore, the most urgent problem is the formation of the release prices for the products for the wholesale buyers.

Table 3
Statistics of sales of products for 2017

Product name	Unit	Wholesale trade			Small-scale wholesale trade			Itinerant trade		
		Qty	Revenues thousand rubles	Average price	Qty	Revenues thousand rubles	Average price	Qty	Revenues thousand rubles	Average price
Cucumber variety “Atlet” (grade 1)	t	1,546	85,268	55.15	30	2,780	93.31	19	1,999	103.17
Cucumber variety “Atlet” (grade 2)	t	570	13,844	24.31	3	298	92.10	3.1	302	96.12
Cucumber variety “Kurazh” (grade 1)	t	773	8,243	10.67	5.5	199	36.36	8.6	465	53.72
Cucumber variety “Kurazh” (grade 2)	t	88	376	4.25						
Tomatoe										

variety "Makarena" (grade 1)	t	576	20,149	34.96	35	3,068	88.40	23.6	1,966	83.02
Tomatoe variety "Makarena" (grade 2)	t	36	670	18.49						
Lettuce	thousand packs	375	6,010	16	15.5	519	33.36	5.9	204	34.46
Eggplant	kg	1.4	115	82.91	1.9	173	92.67	1.5	106	69.93
Pepper	kg	4.3	251	58.95	2.6	282	108.22	2.6	154	58.91

Let's consider the system which consists of the manufacturing enterprise and the wholesale buyers. As a result of the optimization of the use of the pieces of land under the hothouses, the above enterprise turns out products in a volume of its production capacity *Q*. The products are sold to *n* wholesale buyers in a volume of x_i for the wholesale price p_i^{who}. Moreover, the wholesale price is inversely related to the volume of purchases $p_i^{who} = f(x_i)$. The enterprise retails the products which remained unsold after wholesale sale, that is, the following formula holds:

$$x_{ret} = Q - \sum_{i=1}^{n} x_i, \quad (1)$$

where x_{ret} is the volume of retail sales.

Moreover, the enterprise has costs $z(x_{ret})$, associated with the retail sales of products [13]. The objective function of the producer which is descriptive of its revenues after deduction of costs to sell, is presented below in the following expression:

$$\Pi = \sum_{i=1}^{n} x_i \cdot p_i(x_i) + P_{ret} \cdot (x_{ret}) - z(x_{ret}) \to \max, \quad (2)$$

where P_{ret} is the average retail price.

Taking into account the expression (1), costs to sell *z* are inversely related to the total volume of wholesale sales. Thus, the objective function of the enterprise can be expressed as follows:

$$\Pi = \sum_{i=1}^{n} x_i \cdot p_i(x_i) + P_{ret} \cdot \left(Q - \sum_{i=1}^{n} x_i \right) - z(\sum_{i=1}^{n} x_i) \to \max. \quad (3)$$

The optimal volumes of sales for the producer can be determined from the extremum condition of the objective function:

$$\frac{\partial \Pi}{\partial x_i} = 0.$$

Let us suppose that the wholesale buyer resells the products in a volume of x_i for its fixed retail price P_i, concurrently bearing the costs for the purchase of products from the producer and costs to sell. Hence, the objective function of the wholesale buyer is presented below in the following expression:

$$\pi_i = x_i \cdot \left(P_i - p_i^{who}(x_i)\right) - z_i(x_i) \to \max, \quad (4)$$

where $z_i(x_i)$ is the costs associated with the sales of products to the end-consumer.

Let's apply the main provisions of the Cournot oligopoly model [14] to this system. Let's consider the situation in which the wholesale buyers aim to maximize their profits and operate without cooperation. The total quantity of the wholesale buyers in the market *n* is assumed to be known to all participants. Each wholesale buyer considers the volume of purchases of the other companies as a preset parameter (constant) when taking their decision. The functions of costs to sell the products to the end-consumers for the wholesale buyers $z_i(x_i)$ can be various and are assumed to be known to all participants as well.

For the sake of simplicity which does not affect the logic of reasoning, let's assume that the wholesale price is determined by a linear function with a negative coefficient of proportionality:

$$p_i^{who} = A - bx_i. \quad (5)$$

According to [15,16], let's select the nonlinear relation of the second order as a function of cost of sales of products. Then the costs of the wholesale buyers and the producer will amount to $z_i(x_i) = c_i \cdot x_i^2$ and $z(x_{ret}) = C \cdot x_{ret}^2$. respectively. Taking into account (1), the costs of the producer will amount to:

$$z(\sum_{i=1}^{n} x_i^{who}) = C \cdot \left(Q - \sum_{i=1}^{n} x_i^{who} \right)^2. \quad (6)$$

Having analyzed the economic interest of the participants in the system, the Producer is seeking maximization of profits from wholesale and retail trade. Taking into account the expressions (3), (5), and (6), the objective function of the producer is presented below in the following expression:

$$\Pi = \sum_{i=1}^{n} \left(Ax_i - bx_i^2 \right) + P_{ret} \cdot \left(Q - \sum_{i=1}^{n} x_i \right) - C \cdot \left(Q - \sum_{i=1}^{n} x_i \right)^2 \to \max.$$

Let's determine the optimal volume of wholesale sales from the maximum condition of the objective function:

$$\frac{\partial \Pi}{\partial x_i} = A - 2bx_i - P_{ret} + 2CQ - 2C \sum_{i=1}^{n} x_i = 0 \quad (7)$$

Since this expression holds for all x_i, let's sum its left and right parts by *i* from 1 to *n*. We'll deduce the following:

$$nA - 2b\sum_{i=1}^{n} x_i - nP_{ret} + 2nCQ - 2Cn\sum_{i=1}^{n} x_i = 0$$

whence it follows that

$$\sum_{i=1}^{n} x_i = \frac{nA - nP_{ret} + 2CnQ}{2b + 2Cn} = \frac{A - P_{ret} + 2CQ}{2b + 2Cn} \cdot n$$

Let's insert this expression into expression (7):

$$A - 2bx_i - P_{ret} + 2CQ - 2nC \cdot \frac{A - P_{ret} + 2CQ}{2b + 2Cn} = 0;$$

$$\frac{A - P_{ret} + 2CQ}{2b} - 2nC \cdot \frac{A - P_{ret} + 2CQ}{2b \cdot (2b + 2Cn)} = x_i;$$

$$(A - P_{ret} + 2CQ)\left(\frac{1}{2b} - \frac{2nC}{2b \cdot (2b + 2Cn)}\right) = x_i;$$

$$(A - P_{ret} + 2CQ)\left(\frac{2b + 2Cn - 2Cn}{2b \cdot (2b + 2Cn)}\right) = x_i;$$

whence it follows that

$$x_i^* = \frac{A - P_{ret} + 2CQ}{2b + 2Cn}. \qquad (8)$$

Hence, the profits of the producer will be maximum if each wholesale buyer will buy the products in a volume of x_i^*. Since all the parameters which are included into expression for x_i^*, are common for all buyers, the purchase amount will be the same under optimal conditions for the producer, i.e. $x_i^* = x_j^* = const,\ i, j = \overline{1,n}$.

Let's consider the economic interest of the wholesale buyer. The wholesale buyer is interested in maximization of profits from the resale of products [16]. Taking into account the expressions (4)-(6), the objective function of the wholesale buyers is presented below in the following expression:

$$\pi_i = P_i \cdot x_i - Ax_i + bx_i^2 - c_i x_i^2 \to \max$$

Let's determine the optimal volume of purchases of i-th buyer from the maximum condition of its objective function:

$$\frac{\partial \pi_i}{\partial x_i} = P_i - A + 2bx_i - 2cx_i = 0$$

whence it follows that

$$x_i^* = \frac{P_i - A}{2(c_i - b)}. \qquad (9)$$

Let's consider the possibility of reconciliation of economic interest of the producer and the wholesale buyers. The interest will be reconciled if the optimal volume of purchases by each wholesale buyer will be equal to the optimal volume of sales of the producer. Taking into account (8) and (9),

$$\frac{A - P_{ret} + 2CQ}{2b + 2Cn} = \frac{P_i - A}{2(c_i - b)}.$$

However, the situation in which all wholesale buyers purchase the same volume is impossible [17,18].

Let's pass on to the consideration of average values of retail price and the coefficient of function of costs to sell $\overline{P}$ and $\overline{c}$. Then

$$\frac{A - P_{ret} + 2CQ}{2b + 2Cn} = \frac{\overline{P} - A}{2(\overline{c} - b)}. \qquad (10)$$

In order to promote coherence, it is possible to determine such wholesale price at which equality (10) is satisfied. The determination of the price consists in determining the parameters *A* and *b*. Let's suppose that the initial price *A* is fixed. Let's determine parameter *b from expression (10).*

$$\frac{A-P_{ret}+2CQ}{b+Cn}=\frac{\overline{P}-A}{\overline{c}-b}$$
$$(A-P_{ret}+2CQ)\cdot(\overline{c}-b)=(\overline{P}-A)\cdot(b+Cn)$$
$$(A-P_{ret}+2CQ)\cdot\overline{c}-(A-P_{ret}+2CQ)\cdot b=(\overline{P}-A)\cdot b+(\overline{P}-A)\cdot Cn$$
$$b\cdot(\overline{P}-A+A-P_{ret}+2CQ)=(A-P_{ret}+2CQ)\cdot\overline{c}-(\overline{P}-A)\cdot Cn$$
$$b=\frac{(A-P_{ret}+2CQ)\cdot\overline{c}-(\overline{P}-A)\cdot Cn}{\overline{P}-P_{ret}+2CQ}$$
$$b=\frac{A\cdot\overline{c}-\overline{c}\cdot P_{ret}+2CQ\cdot\overline{c}-\overline{P}Cn+ACn}{\overline{P}-P_{ret}+2CQ}$$
$$b=\frac{\overline{c}\cdot(\overline{P}-P_{ret}+2CQ)+A\cdot\overline{c}-\overline{P}Cn+ACn-\overline{P}\cdot\overline{c}}{\overline{P}-P_{ret}+2CQ}$$
$$b=\overline{c}+\frac{\overline{c}\cdot(A-\overline{P})+Cn\cdot(A-\overline{P})}{\overline{P}-P_{ret}+2CQ}$$
$$b^{*}=\overline{c}-\frac{(\overline{c}+Cn)\cdot(\overline{P}-A)}{\overline{P}-P_{ret}+2CQ} \qquad (11)$$

If we take the retail price *A* as the initial price P_{ret}, the optimal value of parameter *b* will amount to:

$$\frac{P_{ret}-P_{ret}+2CQ}{b+Cn}=\frac{\overline{P}-P_{ret}}{\overline{c}-b}$$
$$\frac{2CQ}{b+Cn}=\frac{\overline{P}-P_{ret}}{\overline{c}-b}$$
$$2CQ\cdot(\overline{c}-b)=(\overline{P}-P_{ret})\cdot(b+Cn)$$
$$2CQ\cdot\overline{c}-2CQ\cdot b=(\overline{P}-P_{ret})\cdot b+(\overline{P}-P_{ret})\cdot Cn$$
$$b\cdot(\overline{P}-P_{ret}+2CQ)=2CQ\cdot\overline{c}-(\overline{P}-P_{ret})\cdot Cn$$
$$b=\frac{2CQ\cdot\overline{c}+2CQ\cdot Cn-(\overline{P}-P_{ret}+2CQ)\cdot Cn}{\overline{P}-P_{ret}+2CQ}$$
$$b^{*}=\frac{2CQ\cdot(\overline{c}+Cn)}{\overline{P}-P_{ret}+2CQ}-Cn$$

Moreover, if the average retail price of the wholesale buyers is equal to the retail price of the producer, the optimal value of parameter *b* will be equal to the average value of the coefficient of function of costs to sell, i.e. $b^{*}=\overline{c}$.

Let's consider the implementation of the proposed pricing model in Teplichnyi JSC. Let's consider the pricing strategy selection when selling cucumber in March as an example.

The output of this type of products in this month amounted to *Q*=399288,38. Let us assume that initial price A is equal to retail price, i.e. $A=P_{ret}=113$ rubles. The producer's coefficient of function of costs to sell amounted to *C*=0,00032. As follows from the analysis of statistics, it was found that the average retail price for the products of the wholesale buyers amounts to $\overline{P}=135{,}16$ rubles in March, and the average value of the cost function coefficient amounted to $\overline{c}=0{,}000426$. The volume purchases from Teplichnyi OJSC are made by 5 companies.

Then the optimal value of parameter *b* will amount to:

$$b^{*}=\frac{2\cdot 0{,}00033\cdot 399288{,}38\cdot(0{,}000426+0{,}00033\cdot 5)}{135{,}16-113+2\cdot 0{,}00033\cdot 399288{,}38}-0{,}00033\cdot 5=0{,}000263$$

The values of retail price and cost function coefficient of the wholesale buyers are presented in Table 4.

Table 4

The values of retail price and cost function coefficient

	ci	*Pi*
1	0.00038	128
2	0.00042	130
3	0.00035	140
4	0.00046	139
5	0.00052	140

Based on this data, as well as the original price *A* and parameter *b*, let's determine the optimal volume of purchases and wholesale price using formula (9), as well as the profits of the buyers and the revenues of the producer from the sales of products to the wholesale buyers. The results are presented in Table 5.

Table 5
Calculation of the optimal volume of purchases, wholesale price
as well as the profits of the buyer and the revenues of the producer

	c_i	P_i	x_i^*	p_i	$p_i \cdot x_i^*$	$\pi_ø$
1	0.00038	128	64,302.94	96.06	6,177,254.06	482,272.02
2	0.00042	130	54,266.14	98.71	5,356,514.28	461,262.20
3	0.00035	140	155,825.41	71.96	11,213,368.89	2,103,643.01
4	0.00046	139	66,112.20	95.59	6,319,558.51	859,458.58
5	0.00052	140	52,603.81	99.15	5,215,458.06	710,151.38
Σ			393,110.49		34,282,153.80	

In this case, the wholesale buyers receive the maximum possible profits with this price mechanism.
According to expression (3), let's determine the value of the objective function of the producer:

$$\Pi = \sum_{i=1}^{n} \left(Ax_i - bx_i^2 \right) + P_{ret} \cdot \left(Q - \sum_{i=1}^{n} x_i \right) - C \cdot \left(Q - \sum_{i=1}^{n} x_i \right)^2 = 34967660{,}51$$

The obtained value is descriptive of the profits of the producer from the sales of cucumbers in March. The actual value profit in the month under consideration amounted to $\Pi^{\Phi} = 28905670{,}79$.

Hence, the use of pricing optimization model allows us to increase the profits of the enterprise by approximately 20%, which is indicative of expediency of its practical application.

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3. Conclusions

Hence, the authors of the article have proposed the efficient methods for management of operations of agro-industrial enterprises carrying out their activities under the conditions of protected ground. The results obtained allow us to increase the profits significantly due to optimization of the utilized areas with due account for yield and seasonal fluctuations in product prices. Besides, a model for the determination of the optimal product prices has been proposed, which ensures the reconciliation of the economic interest of the producer and the wholesale buyers, allowing us to determine the optimal values of the volumes of purchases and release prices. All the proposed models have been tested and endorsed at the particular enterprise of the Samara region. The calculations have demonstrated the possible increase in profits of the enterprise as a result of the use of these pilot projects by approximately twenty per cent.

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