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Article

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RESEARCH

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A systemic comparative economic approach efficiency of fodder production

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Abstract

The purpose of the study is to determine the optimal volume of fodder and grain-fodder crops of appropriate quality to meet the needs of the livestock industry using a systemic comparative economic approach. For the economic assessment of crops for fodder purposes, a systemic comparative economic approach to their production efficiency has been developed. Accounting was carried out according to the three most important indicators in fodder units: quantitative indicators—productivity per hectare of sowing, qualitative—the content of vegetable protein and cost—the production cost. Oats were taken as the primary culture. Their comparison made it possible to determine economically interrelated partial indices, which are reduced to the index of the systemic comparative economic approach, which contributes to optimizing the structure of the cultivated areas of these crops. This technique allows to determine each forage crop's location in each farm or region's conditions, analyzing the real situation and assessing the prospects for the development of production. The optimal structure of sown areas for grain-fodder and fodder crops, focused on the cultivation of high-protein crops, for the enterprises of the Northern forest-steppe zone of the Republic of Bashkortostan is proposed. Due to a change in sown areas' structure, the gross harvest increases by 8%, digestible protein by 2%, and reduced production costs by 48%.

Keywords: Systemic comparative economic approach, Economic efficiency, Crops, Agro-industrial complex, Fodder production, Index, Sown area

Introduction

In the complex of measures aimed at increasing livestock products' production, it is essential to create a solid feed base to fully provide animals with highly efficient feed, balanced in proteins and other components. According to the Alltech Global Feed Research, in 2021 compared to 2020, feed production increased by 1%, i.e., to 1187.7 million tons. China showed an increase of 5% and regained its position as the leader in feed production with an indicator of 240 million tons. Then there are ten feed-producing countries: the USA (215.9 million tons, percentage of growth + 1%), Brazil (77.6 Mt, + 10%), India (39.3 Mt, + 5%), Mexico (37.9 Mt, + 4%), Spain (34.8 Mt), Russia (31.3 Mt, + 3%), Japan (25.2 Mt), Germany (24.9 Mt) and Argentina (22.5 Mt, + 7%). In

general, these countries account for 63% of world feed production, and they can be considered an indicator of general trends in agriculture (Alltech, n.d.).

When raising farm animals, 55–60% of all costs in their cost structure are fed. Consequently, the rearing efficiency is mainly due to an increase in the conversion rate of feed into muscle, adipose and bone tissue, ensuring a high level of productivity of young animals. The feed composition must be balanced in all nutrients and include the required amount of concentrates, hay, silage and green feed (Aligazieva et al., 2020; Zakirova et al., 2020).

An analysis of the feed industry segments begins with a look at the feed market. Saving grain consumption for forage purposes plays an essential role in fattening livestock. The livestock industry in the USA, Canada, and the European Union has achieved substantial results thanks to the feed industry's continuous improvement. In these countries, regional specialization can be traced to the production of grain-fodder crops. The allocation of boundaries depends on the soil and climatic conditions. Take the United States as an example, where grain corn is grown in 47 states. At the same time, 75% of its gross collection is formed by five compact states. That is, there is a process of concentration of production in the feed industry in this country. Its increase affected the reduction in transport costs (Wolf & Cappai, 2021).

The market economy encourages agricultural producers to choose the best technological options. There is a selection of promising types of forage crops—corn, barley, oats and sorghum (Ayupov et al., 2019; Egorova, 2019). The production of these crops is export-oriented, so their production has always exceeded the needs of livestock. In Russia, 240 enterprises are engaged in the feed industry, 10% of which are independent. The rest of the enterprises are part of livestock complexes and farms. In animal feed used in Russia, the digestible protein content is about three times less than in the European Union and the USA countries. It leads to high grain use for fodder purposes (2.0–2.5 times) (Gidenne et al., 2017).

The purposeful use of by-products from other industries in animals' diet is a feature of economically developed countries. In the European Union countries, feed consists of 25%—from by-products of the food industry, of which 9%—from imported corn-gluten feed and 2%—from citrus waste; 35% is made from corn kernels; 12% are from imported cassava. Waste from edible vegetable oils (soybean and sunflower meal) (Gaillard et al., 2020) is actively used to prepare high-grade and inexpensive compound feeds.

One of the reasons for the backwardness of domestic feed production is the dependence on import additives. Premix manufacturers are dependent on:

- suppliers of their main components (vitamins, amino acids, trace elements);
- producers of concentrates and compound feed.

As of the end of March 2020, the Russian Agricultural Control registered 2,955 feed additives, of which 20% are domestic. In Russia, the feed additives market includes products from 160 Russian and more than 700 foreign manufacturers. The Ministry of Agriculture of the Russian Federation has developed a subprogram, "Development of the production of feed and feed additives for animals", within the Federal Scientific Technical Program framework to develop agriculture for 2017–2025. With the

successful implementation of the subprogram, it is possible to create a solid forage base. Fodder resources will be used more rationally, modern technologies of raw materials processing and production of vitamins, enzymes, essential amino acids and minerals (Techart Consulting Group, n.d.; Zakirova et al., 2019) will be applied.

In all countries, livestock production's intensification is influenced by factors that characterize the livestock industry's organizational and structural restructuring, breeding and improvement of living conditions for animals (King, 2019; Semin, 2020). One of the most important factors is the creation of a complete food base. It is necessary to grow such fodder crops that will provide local conditions, with minimal labor and material costs, the enormous amount of fodder per unit area (Ibragimov, 2019; Insua et al., 2019; Lukianova & Araslanbaev, 2019). And such crops will ultimately affect agricultural producers' financial well-being to strengthen the fodder base. A rational choice favoring one or another forage crop in a particular area allows us to propose a systemic comparative economic approach to their production efficiency (Kuznetsov, Alimgafarov, et al., 2020; Kuznetsov, Davletov, et al., 2020). The novelty of the developed methodology lies in the problematic use of quantitative, qualitative and cost indicators.

This study aims to determine the optimal volume of forage and forage crops of appropriate quality to meet the livestock industry's needs.

The essence of the efficiency of forage crops is an integral part of the efficiency of agricultural production. On the one hand, for crop production, fodder crops are the end product of the industry; and on the other hand, in animal husbandry, fodder crops are used as livestock feed and act as a means of production. Therefore, the essence of the effectiveness of forage crops lies in the formation of a set of conditions for ensuring expanded reproduction, which allows the branches of plant growing and animal husbandry to develop interconnectedly and harmoniously.

Most of the feed (up to 70%) is produced on arable land. The main problem in fodder production is the lack of protein in fodder. Sources of fodder protein are: grain and leguminous crops—50%, meadow and pasture plants—18%, sown grasses—11%, silage crops—6%.

With the existing methods of harvesting and storing feed, 30–50% of nutrients are lost. Imbalance in protein feed and their loss of up to 30% are observed at the low productivity of arable land.

Increasing the production of vegetable protein is a multifaceted task and must be solved by implementing a set of measures, of which the following are the main ones:

- improvement of the structure of sown areas—expansion of crops of high-protein (legumes) and fodder crops;
- reduction of protein losses due to violation of the recommended terms and technologies of harvesting;
- increasing the yield of forage crops based on improving the culture of agriculture, further strengthening the material and technical base, using highly productive crops and varieties, land reclamation;
- increasing the protein content in the crop with appropriate agricultural technology, correct placement of forage crops in the subregions of the republic, etc.

Therefore, to obtain high-performance indicators in the production of forage crops with high quality and at the lowest cost, it is necessary to develop a comprehensive comparative economic assessment of forage and grain forage crops. Its introduction allows, by optimizing the structure of sown areas, to increase the gross harvest of these crops and yield of vegetable protein, reduce the cost of manufactured products.

The objectives of this study were:

1. development of a methodology for a systemic comparative economic approach to the efficiency of feed production;
2. determination of the required structure of sown areas of grain-fodder and forage crops;
3. conducting an economic assessment of applying the systemic comparative economic approach for gross harvest, production costs and digestible protein.

Methods and materials

Such indicators are used as net productivity per hectare of sowing, the yield of digestible protein and the cost of a unit of production to determine the economic efficiency of crops for fodder purposes. But the parallel use of these indicators does not allow determining its total value. It is explained that different fodder crops are not simultaneously equal in several respects, and not only separately in yield, protein yield, cost price. Without the simultaneous consideration of these aspects based on a single synthetic indicator, it is impossible to determine the actual place of each fodder crop in specific natural-economic and organizational-economic conditions. Therefore, in research, we use a statistical method—an index approach—which allows us to compare different levels of complex indicators or their units, which are not directly subject to summation. The paper also examines the comparison of indicators of forage crops over time, which speaks of the indices of dynamics. These conditions distinguish the considered methods of comparative economic assessment of the effectiveness of forage crops from the method of comprehensive comparative economic assessment of the effectiveness of forage crops. The maximum yield of production and vegetable protein at the lowest cost is used as an assessment criterion.

The indicators characterizing feed production efficiency (in feed units) are used to develop a systemic comparative economic approach to feed production efficiency. The first is a quantitative indicator—the net productivity of a hectare of crops. The second indicator characterizes feed production in terms of the quality component—the content of digestible protein. And the third indicator is cost—payment of costs by-products. Oats were taken as the primary culture. It is possible to determine economically interconnected unidirectional private indices by comparing them, which are reduced to the systemic comparative economic approach (Gusmanov & Lukyanova, 2008; Lukyanova, 2008):

$$I_{\text{fea}} = I_{\text{fp}} \times I_{\text{dp}} \times I_{\text{ep}} = \frac{N_s \times P_s^2 \times C_b}{N_b \times P_b^2 \times C_s}, \quad (1)$$

where I_{fea} is the index of the systemic comparative economic suit of crops for forage purposes (forage economic assessment); I_{fp} is the index of net fodder productivity [productivity of a hectare of sowing of the basic (N_b) and studied crops (N_s), centner of fodder unit]; I_{dp} is the index of the content of digestible protein [the content of digestible protein in a feed unit in the basic (P_b) and studied (P_s) crops, g], and I_{ep} is the index of expenses paid by fodder products [the cost of a centner of fodder units of the basic (C_b) and studied (C_s) crops, rubles].

Almost all crops are used commercially at the same time. The formula for the systemic comparative economic approach of crops for commercial purposes is as follows:

$$I_{cea} = I_{np} \times I_p \times I_{ep} = \frac{N_s \times P_s^2 \times C_b}{N_b \times P_b^2 \times C_s}, \quad (2)$$

where I_{cea} is the index of the systemic comparative economic approach of crops for commercial purposes (commercial economic assessment); I_{np} is net production index, rubles [net production per hectare of sowing of basic (N_b) and studied (N_s) crops, rubles]; I_p is product sales price index [selling price of a centner of basic (P_b) and studied (P_s) crops, rubles], and I_{ep} is an index of expenses paid by cash proceeds [the cost of a centner of production of the basic (C_b) and studied (C_s) crops, rubles].

The index of the systemic comparative economic approach of crops used for seeds can be equated to one.

The developed methodological approach, based on the generalization of indicators of the systemic comparative economic approach to crops for forage, commercial and seed purposes, taking into account the share of each direction of product use in the total gross harvest, is as follows:

$$I_{ea} = \frac{I_{fea} \times Y_f + I_{cea} \times Y_c + I_{sea} \times Y_s}{100}, \quad (3)$$

where I_{ea} is the index of the systemic comparative economic approach of crops for feed–commodity–seed purposes (economic assessment); I_{fea} , I_{cea} , I_{sea} are indices of the systemic comparative economic approach of crops for fodder, commercial and seed purposes, and Y_f , Y_c , Y_s is the specific gravity of the product used, respectively, for feed, commodity and seed purposes, %.

With the index of the systemic comparative economic approach of crops for fodder purposes, it is possible to calculate the required structure of sown areas for grain-fodder and fodder crops:

$$A_c = \frac{I_c}{\sum_{i=1}^n I_{ki}} \times 100\%, \quad (4)$$

where A_c is the share of crops in the structure of the total sown area,%; I_c is the index of the systemic comparative economic approach of the studied crop for forage purposes; $\sum_{i=1}^n I_{ki} = I_{rye\ to\ oats} + I_{winter\ wheat\ to\ oats} + \dots + I_{barley\ to\ oats}$ is the sum of the index of the systemic comparative economic approach of all cultures, and n is the number of crops.

The research object is a typical agricultural enterprise named after Lenin of the Municipal District of Tatyshlinsky District of the Republic of Bashkortostan, located in the Northern forest-steppe zone. The interest in testing this farm technique is because much attention is paid to the development of the livestock industry and directly to the production of forage crops. Therefore, this economy's study results are of great interest to other organizations with similar production conditions.

The study's information base was made up of the data of the annual accounting reports of the enterprise for 2011–2020, as well as data on the nutritional value of forage and grain crops from reference books.

Results

Agriculture in general and livestock, in particular, plays a primary role in ensuring food security. The main condition for the sustainable functioning and dynamic development of this sub-industry is the availability of high-quality feed. In Russia, the feed industry includes three main segments: production of finished feed for farm animals and poultry; premix production; production of feed additives.

The achieved level of feed production does not meet the needs of animal husbandry, which leads to a reduction in the livestock and a decrease in animal productivity. The main reasons for this situation are a decrease in the volume of fodder crops, an increase in the cost price, significant overspending of fodder for obtaining livestock products due to the deterioration of their structure and quality.

In modern conditions of the development of the agricultural economy, a unique role belongs to fodder production, which accounts for about 40% of land resources. In the structure of the cost of livestock products, feed costs reach 50%. In essence, the level of development of fodder production determines the general state of the economy of livestock enterprises. The stable growth in feed production volume is due to the development of animal husbandry in our country. Today, domestic agricultural producers fully provide the population with pork, poultry and eggs. In 2020, the number of pigs in Russia was 25.2 million heads (from 2010 to 2020, the number of pigs increased annually by 3.8%). Last year, domestic enterprises produced 3.9 million tons of pork. CAGR (compound annual growth rate) in the period from 2010 to 2020 amounted to 6.3%.

The compound feed market demonstrates stable positive dynamics. The average annual production growth rate is 6.7%. The main factor in the development of the feed industry is the constantly growing demand for products from the main consumer—the livestock complex. Against the background of the import substitution program implemented by the government and ensuring the country's food security, the poultry and pig industries have been actively developing in recent years. The number of poultry in 2020 reached 54.5 million heads (CAGR₂₀₁₀₋₂₀₂₀—2.4%), poultry meat production—5 million tons (CAGR₂₀₁₀₋₂₀₂₀—7.2%), eggs—44.9 million units (CAGR₂₀₁₀₋₂₀₂₀—1.5%).

Unfortunately, the number of cattle in Russian farms has not increased (in 2020—18.1 million heads, CAGR₂₀₁₀₋₂₀₂₀—minus 1.2%) and, accordingly, beef production has not increased (in 2020—1, 6 million tons, CAGR₂₀₁₀₋₂₀₂₀—minus 0.6%) and milk (in 2020—31.3 million tons, CAGR₂₀₁₀₋₂₀₂₀—minus 0.3%).

The Republic of Bashkortostan is an exporter of fodder crops in the Russian Federation, so in 2020 357,000 kg of fodder crops were exported, which is 1.02% higher than

in 2019. Therefore, at present, both in scientific research and in practical work on the development of agriculture, special attention should be paid to increasing the efficiency of the feed industry (Alltech, n.d.).

The territory of the Republic of Bashkortostan is not homogeneous in terms of natural and climatic conditions (Bulat & Bulat, 2013; Stovba & Kolonskikh, 2019; Sultanova et al., 2019). Zones of the republic differ in soil fertility and cultivation, relief, provision of precipitation and heat, which affects agricultural production. Directly increasing the efficiency of the livestock industry depends on the zonal conditions of feed production. The structure of livestock production must be adapted to them.

The initial averaged enterprise data for the last 10 years (2011–2020) using our method are presented in Table 1.

From the data in Table 1, it can be seen that all the necessary fodder crops are cultivated on the farm to compile a balanced diet for farm animals. The net productivity of a hectare of sowing for some crops is significantly higher than the average republican values (alfalfa—by 25%, eastern Galega—by 16%, winter rye in green mass—by 10% and hybrid clover—by 8%). The presented forage crops are competitive in terms of digestible protein content (alfalfa—50.7 g, eastern Galega—37.1 g, vetch-oats—36.0 g and sweet clover—35.9 g).

Using formula 1, we calculate the indices of the studied crops' systemic comparative economic approach for forage purposes. Let us give calculations using the example of the basic crop—vetch-oats and alfalfa; for the rest of the crops, the calculations are made similarly:

Table 1 Baseline indicators for the cultivation of forage crops on the farm for the last 10 years (2011–2020)

Crop	Feed units per 1 kg of feed	Yield per hectare, centner	Pure productivity of 1 hectare of crops, the centner of feeding unit	Cost price 1 centner of production, rub	Cost price of 1 centner unit products, rub	Content of digestible protein in 1 kg, g	Content of digestible protein in 1 kg of feeding unit, g
Vetch-oats	0.30	120.0	36.0	17.5	62.4	36.0	128.4
Alfalfa	0.38	163.7	62.2	13.9	38.6	50.7	140.9
Timothy grass	0.23	110.0	25.3	18.6	88.7	20.4	97.2
Corn	0.16	135.2	21.6	13.6	96.9	19.6	140.3
Sweet clover	0.21	139.2	29.2	18.6	98.1	25.4	133.8
Fodder beet	0.12	154.7	18.6	41.3	412.9	13.5	135.4
Winter rye in green mass	0.28	159.8	44.8	17.8	68.5	30.3	116.6
Hybrid clover	0.29	145.7	42.3	19.0	70.3	35.9	132.8
Eastern Galega	0.32	153.7	49.2	14.4	48.0	37.1	123.5

$$I_{\text{fea Vetch - oats}} = \frac{N_{\text{Vetch - oats}} \times P_{\text{Vetch - oats}}^2 \times C_{\text{Vetch - oats}}}{N_{\text{Vetch - oats}} \times P_{\text{Vetch - oats}}^2 \times C_{\text{Vetch - oats}}} = \frac{36.0 \times 128.4 \times 62.4}{36.0 \times 128.4 \times 62.4} = 1.000,$$

$$I_{\text{fea Alfalfa}} = \frac{N_{\text{Alfalfa}} \times P_{\text{Alfalfa}}^2 \times C_{\text{Vetch - oats}}}{N_{\text{Vetch - oats}} \times P_{\text{Vetch - oats}}^2 \times C_{\text{Alfalfa}}} = \frac{62.2 \times 140.9 \times 62.4}{36.0 \times 128.4 \times 38.6} = 3.363.$$

Let us calculate the coefficient of the systemic comparative economic approach of all cultivated forage crops on the farm:

$$\sum_{i=1}^9 I_{\text{ea } i} = 1.000 + 3.363 + 0.283 + 0.461 + 0.560 + 0.087 + 0.935 + 1.116 + 1.644 = 9.449.$$

Let us determine the optimal structure of the sown areas of forage crops according to Formula 4. Let us give the calculations using the example of the basic crop—vetch-oats and alfalfa; for the rest of the crops, the calculations are made similarly. The structure data are shown in Fig. 1.

$$A_{\text{Vetch - oats}} = \frac{1.000}{9.287} \times 100\% = 10.6\%,$$

$$A_{\text{Alfalfa}} = \frac{3.363}{9.287} \times 100\% = 35.6\%.$$

Let us translate each crop’s share into the sown area and evaluate the application of the method of the systemic comparative economic approach in the farm (Table 2).

The recommended structure of sown areas is dominated by high-protein forage crops, such as alfalfa, which is more durable in crops (increased by 15.4%), hybrid clover (by 3.4%). The most reliable source of inexpensive vegetable protein and raw materials for harvesting winter forage is eastern Galega (by 7.4%). These crops are indeed distinguished by high productivity per hectare of sowing and vegetable protein. These green manure in crop rotation leave behind the most nutritious and fertile soil in limited resource supply conditions. The change in the structure of sown areas contributed

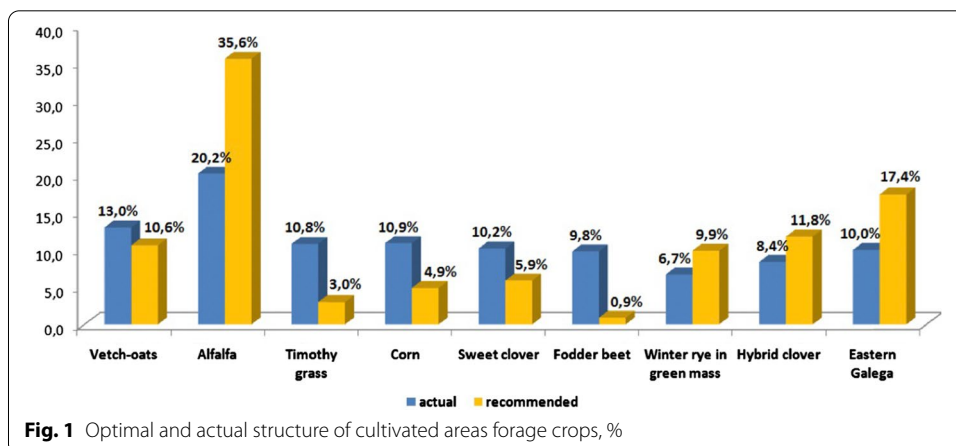


Table 2 Assessment of the application of the method of systemic comparative the economic approach to forage crops

Crop	Sowing area, ha		Digestible protein, centner		Whole yield, center of feeding units		Cost per feeding unit price, thousand of rubles	
	optimal	actual	optimal	actual	optimal	actual	optimal	actual
Vetch-oats	793.7	975.0	101.9	125.2	28,573.2	35,100.0	28.6	60.8
Alfalfa	2669.6	1515.0	376.1	213.5	166,049.1	94,233.0	166.0	58.5
Timothy grass	224.9	810.0	21.9	78.7	5690.0	20,493.0	5.7	71.8
Corn	366.2	817.5	51.4	114.7	7909.9	17,658.0	7.9	79.2
Sweet clover	444.7	765.0	59.5	102.4	12,985.2	22,338.0	13.0	75.0
Fodder beet	68.9	735.0	9.3	99.5	1281.5	13,671.0	1.3	303.5
Winter rye in green mass	742.0	502.5	86.5	58.6	33,241.6	22,512.0	33.2	34.4
Hybrid clover	885.5	630.0	117.6	83.7	37,456.7	26,649.0	37.5	44.3
Eastern Galega	1304.6	750.0	161.1	92.6	64,186.3	36,900.0	64.2	36.0
Total	7500	7500	985.4	968.8	357,373.6	289,554.0	357.4	763.6

Table 3 Main indicators of grain feed crops

Indicator	Barley	Spring wheat	Millet	Winter rye	Buckwheat	Oats	Peas	Vetch and vetch mixtures for grain
Digestible protein in 1 kg of feed, g	16.1	21.3	6.6	18.6	8.6	25.9	23.5	16.5
Feeding units in 1 kg of feeds	94.4	102.0	91.4	99.2	75.5	78.8	157.7	122.7
Yield from 1 ha, centner	17.5	24.3	6.1	19.5	7.9	24.9	24.5	17.8
Sales price, rub/centner	86.6	89.4	99.3	94.5	82.1	82.1	151.7	113.5
Cost price, rub/centner	147.8	234.6	217.9	198.3	270.5	126.1	226.3	226.2
Net productivity of 1 ha of plantings, centner of feeding units	135.6	205.8	236.8	188.9	294.0	131.3	217.6	209.4
The cost price of 1 centner of feeding unit, rub	313.8	429.9	265.1	297.6	552.8	282.0	513.9	300.6
Grain use, %								
For feeds	10	9	17	10	8	13	10	15
For sale	33	39	31	20	85	47	14	25
For seeds	57	52	52	70	7	45	76	60

to an increase in the yield of digestible protein by 2%, the gross yield of cultivated crops increased by 23%. As for the cost indicator—the cost in terms of feed units, there is a decrease of 53.3%.

Let us make similar calculations for grain-fodder crops using the initial data in Table 3.

Considering the yield per hectare of sowing, the top three include the basic crop—oats (24.9 c/ha), leguminous crops—peas (24.5 c/ha) and spring wheat (24.3 c/ha). These crops

also contain the most vegetable protein in 1 kg of feed: oats (25.9 g), peas (23.5 g) and spring wheat (21.3 g). It can be concluded that among grain-fodder crops, legumes, and cereals have the best indicators.

Let us present the calculations of the indices of comparative economic assessment using the example of barley using the data in Table 3 and formulas 1, 2 and 3; for the rest of the crops, the calculations are made in the same way. Due to the early maturity, barley contributes to creating a rhythmic harvesting conveyor even in insufficiently humid conditions:

$$I_{\text{fea of barley}} = \frac{N_{\text{of barley}} \times P_{\text{of barley}}^2 \times C_{\text{of oats}}}{N_{\text{of oats}} \times P_{\text{of oats}}^2 \times C_{\text{of barley}}} = \frac{135.6 \times 94.4^2 \times 282.0}{131.3 \times 78.8^2 \times 313.8} = 1.332,$$

$$I_{\text{cea of barley}} = \frac{N_{\text{of barley}} \times P_{\text{of barley}}^2 \times C_{\text{of oats}}}{N_{\text{of oats}} \times P_{\text{of oats}}^2 \times C_{\text{of barley}}} = \frac{135.6 \times 86.6^2 \times 282.0}{131.3 \times 82.1^2 \times 313.8} = 1.121,$$

$$I_{\text{ea of barley}} = \frac{I_{\text{fea}} \times y_f + I_{\text{cea}} \times y_c + I_{\text{sea}} \times y_s}{100} = \frac{1.332 \times 10 + 1.121 \times 33 + 1.000 \times 57}{100} = 0.073.$$

The indicators of the systemic comparative economic approach of all grain crops are given in Table 4.

It is more profitable to cultivate spring wheat (1.193), peas (1.187) and vetch mixtures (1.459) among grain and leguminous crops for fodder purposes. It proves the highest value of the index of complex comparative economic assessment. These recommended crops in the studied farm have a higher protein content and yield per hectare of sowing.

Let us calculate the index of the comparative economic approach of all cultivated crops for fodder–commercial–seed purposes:

$$\sum_{i=1}^8 I_{\text{ea } i} = 1.073 + 1.193 + 1.662 + 1.082 + 1.061 + 1.000 + 1.187 + 1.459 = 9.723.$$

The optimal sown area of grain-fodder crops in relative terms is determined by formula 4. Let us give the calculations for the example of barley; for the rest of the crops, the calculations are made in the same way:

$$A_{\text{of barley}} = \frac{1.073}{9.723} \times 100\% = 11.0\%.$$

Figure 2 shows the structure of grain-fodder crops, and their absolute values are presented in Table 5.

Table 4 The total values of the indicators for cereals

Indicators	Barley	Spring wheat	Millet	Winter rye	Buckwheat	Oats	Peas	Vetch and vetch mixtures for grain
I_{fea}	1.332	1.723	2.581	2.161	1.049	1.000	3.642	3.628
I_{cea}	1.121	1.329	2.268	0.829	1.597	1.000	0.446	1.261
I_{sea}	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
I_{ea}	1.073	1.193	1.662	1.082	1.061	1.000	1.187	1.459

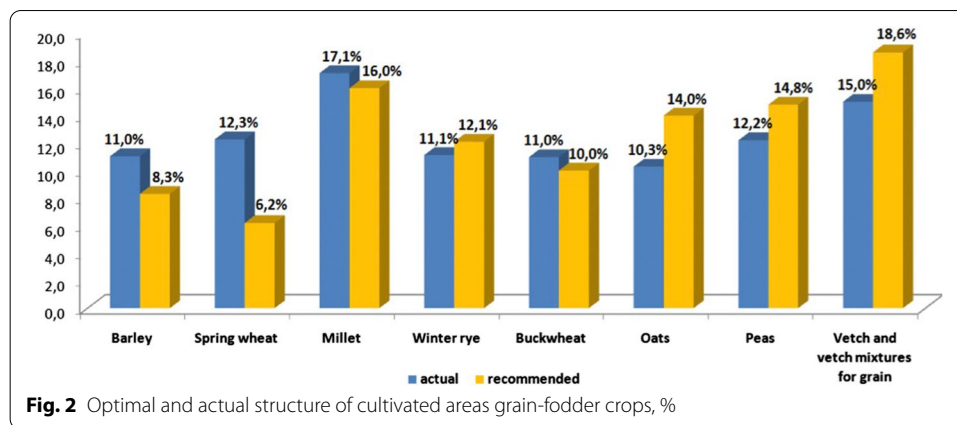


Table 5 Assessment of the application of the method of systemic comparative economic approach of forage crops

Crop	Sowing area, ha		Digestible protein output, centner		Whole yield, centner of feeding units		Cost per feeding unit price, thousand of rub	
	Optimal	Actual	Optimal	Actual	Optimal	Actual	Optimal	Actual
Barley	207.5	275.9	19.6	26.0	28,137.0	37,412.0	28.1	86.6
Spring wheat	155.0	306.7	15.8	31.3	31,899.0	63,118.9	31.9	131.9
Millet	400.0	427.3	36.6	39.1	94,720.0	101,184.6	94.7	113.3
Winter rye	302.5	278.2	30.0	27.6	57,142.3	52,552.0	57.1	82.8
Buckwheat	250.0	274.3	18.9	20.7	73,500.0	80,644.2	73.5	151.6
Oats	350.0	257.1	27.6	20.3	45,955.0	33,757.2	46.0	72.5
Peas	370.0	305.2	58.3	48.1	80,512.0	66,411.5	80.5	156.8
Vetch and vetch mixtures for grain	465.0	375.1	57.1	46.0	97,371.0	78,545.9	97.4	112.8
Total	2500	2500	263.8	259.1	509,236.3	513,626.4	509.2	908.2
General (fodder + grain – fodder)			1249.2	1227.9	866,609.8	803,180.4	866.6	1671.8

Figure 2 shows that the calculated structure of the areas of grain-fodder crops, using the systemic comparative economic approach, differs from the actual one. Sowings of barley are reduced by 2.7% (68.4 ha), spring wheat—by 6.1% (151.7 ha), millet—by 2.1% (27.3 ha), buckwheat—by 1% (24.3 ha). However, there is an expansion of leguminous crops by 2.6% (64.8 ha), oats—3.7% (92.9 ha), vetch and vetch mixtures—3.6% (by 89.9 ha). The expansion of the sown area of leguminous crops can help to solve two problems: firstly, the problem of lack of fodder protein is eliminated, and secondly, the flow of biological nitrogen and humus into the soil increases, due to which the soil fertility and the productivity of grain crops cultivated in crop rotation behind them increase (Ershadi et al., 2020).

Let us translate each grain-fodder crop's specific weight into the sown area and reflect the change in the leading indicators with the current and recommended structure of sown areas (Table 5).

Let us assess the application of a systemic comparative economic approach to the efficiency of forage production in terms of gross crop production, costs and protein yield. The change in the structure of the sown areas contributed to an increase in the yield of digestible protein by 21.2 centners (2%), the gross yield of cultivated crops increased by 63,429.4 centners of the equivalent unit (8%). As for the cost indicator—the cost in terms of feed units, there is a decrease by 805.2 thousand rubles (48%). The use of this technique will eliminate the disagreements between specialists in animal husbandry and crop production in terms of giving preference to cultivating crops that nutritionally correspond to the optimal diet of animals and observing the order of their cultivation in crop rotation fields.

Discussion of results

The efficiency of livestock production depends on the stable supply of animals with quality and affordable feed. The most readily available food source is perennial grasses. New varieties of forage grasses with improved characteristics are an essential reserve for forage production (Obraztsov et al., 2020).

In our opinion, the analysis of Chinese and New Zealand dairy farms is interesting from a scientific point of view. In their analysis, the researchers found that Chinese dairy farms can improve environmental efficiency by finding low-efficiency feed, better nitrogen management, and using leftover processed products with feed crops. In contrast, New Zealand farms can improve environmental efficiency through efficient use of legume-based pastures, rather than only forage crops or livestock management systems. However, their studies are limited only to assessing environmental performance without considering cost factors (Ledgard et al., 2019).

Only the ecological characteristics of the most common forage crops in Northern Italy were studied by Zucali et al. (2018). Their analysis of the impact of various scenarios of the farming system on milk production using the life cycle assessment approach is of great interest. The protein scenario was characterized by introducing protein-rich crops (whole vegetable soybean silage and alfalfa hay) into the cultivation system, which was considered optimal from the global perspective. There is a particular connection with the proposed by us methodology to increase the cultivation of high-protein crops (Zucali et al., 2018).

An exciting position is considered by scientists from the North of Italy, who propose to minimize costs without cultivating the soil. They found that nitrogen utilization efficiency and digestible protein production were significantly higher in a permanent meadow without tillage. They propose converting arable soil into a permanent meadow without tillage and see it as a win–win solution. However, in our opinion, this leads to the lowest dry matter yields and a decrease in feed units compared to arable systems. The most productive annual crop rotation for them is silage corn + Italian ryegrass. It is possible to achieve high yields and fodder units from a smaller area of arable land (Castelli et al., 2017).

Australia is considering using dual-use crops, especially wheat and rapeseed, for feed and grain production in sheep systems. Their research focused on developing crop and pasture management strategies for dual-use crops. Aspects, such as the impact of livestock grazing on the growth, recovery and development of crop yields, and

understanding the grazing value of forage for crops, their impact on animal nutrition and grazing management to maximize live weight gain, were considered. Economic efficiency on the farm is achieved by increasing the rate of winter stock provided by pasture crops, which allows to simultaneously increase the production of crops and the development of the livestock industry (Dove & Kirkegaard, 2014).

Conditions in each region and its zones have their natural and economic characteristics, which differ significantly from each other and, accordingly, are heterogeneous in terms of the possibilities of self-sufficiency in livestock products. By this, it is essential to determine, first of all, the economic efficiency of forage crops.

Methodological approaches proposed in the works of agricultural economists can be used to solve this problem. So, the effectiveness of forage crops is proposed to be assessed by the formula:

$$E = \frac{I_y}{I_{pc}} \times 100,$$

where E is the efficiency of fodder crop cultivation; I_y is the yield index, and I_{pc} , the index of the production cost of a feed unit (Khasanov et al., 2019).

At the same time, it is recommended to consider the indices of productivity and production costs of a specific fodder crop as the ratio of indicators on average for a group of crops of the same use (grain fodder, crops of juicy and green fodder, crops for hay, etc.). The degree of efficiency of their use reflects the actual level of labor productivity in producing a specific type of feed since it includes the actual yield of the crop and the costs of its cultivation.

Based on the data obtained and the structure of the adopted feed balance, the most effective forage crops in the given natural and economic conditions are determined in the future. It is also possible to make calculations in energy costs.

According to this formula, the calculation of the economic efficiency of forage crops does not consider another essential indicator—the yield of digestible protein. As known, high-protein crops are of particular value, which is not considered in the above method for assessing the effectiveness of forage crops.

Another method for determining the effectiveness of forage crops is based on determining the integral results of assessing the effectiveness of forages based on the calculation of particular indicators by using the method of multivariate average. Private indicators include:

1. the output of feed units from 1 hectare, c;
2. the yield of protein per hectare, c;
3. the output of feed units for one head, c;
4. the yield of digestible protein per 1 fodder unit, kg.

The above methodology does not take into account the indicator of the cost of fodder crops. The method for determining the comparative efficiency of forage crops, which considers the costs, is considered more reliable and plausible—the cost of production.

The following methodology for determining the economic efficiency of feed production is based on indicators of the energy nutritional value of feed not in feed units

but metabolizable energy. The essence of this technique is that feed is energy, which is carried out through the sale of livestock products. Thus, knowing the cost of the produced energy and its sale, it is possible to determine the profit. It is more expedient to use this technique in meat and dairy cattle breeding and wool and meat sheep breeding, i.e., it is not suitable for all livestock breeding, including poultry farming. Also, the methodology based on energy nutrition indicators does not consider the indicator of net fodder productivity of a hectare of sowing fodder crops (Kovshov et al., 2019).

In recent years, more and more emphasis has been placed on the method of ecological and economic assessment of the efficiency of feed production, the criterion of which is the maximum yield of nutrients, taking into account the energy value of feed. This method is based on the following indicators:

1. energy yield of forage crops;
2. labor intensity;
3. the content of radioactive caesium.

This technique is not applicable in our case because the indicators are not considered in feed units but the exchange energy. The methodology for the ecological and economic assessment of feed production efficiency does not reflect such indicators as the content of digestible protein and the cost of a unit of production. In many scientific studies on this problem, attention is focused only on environmental problems, mainly associated with land resources depletion. Insufficient attention is paid to the economic efficiency of production and use of forage crops.

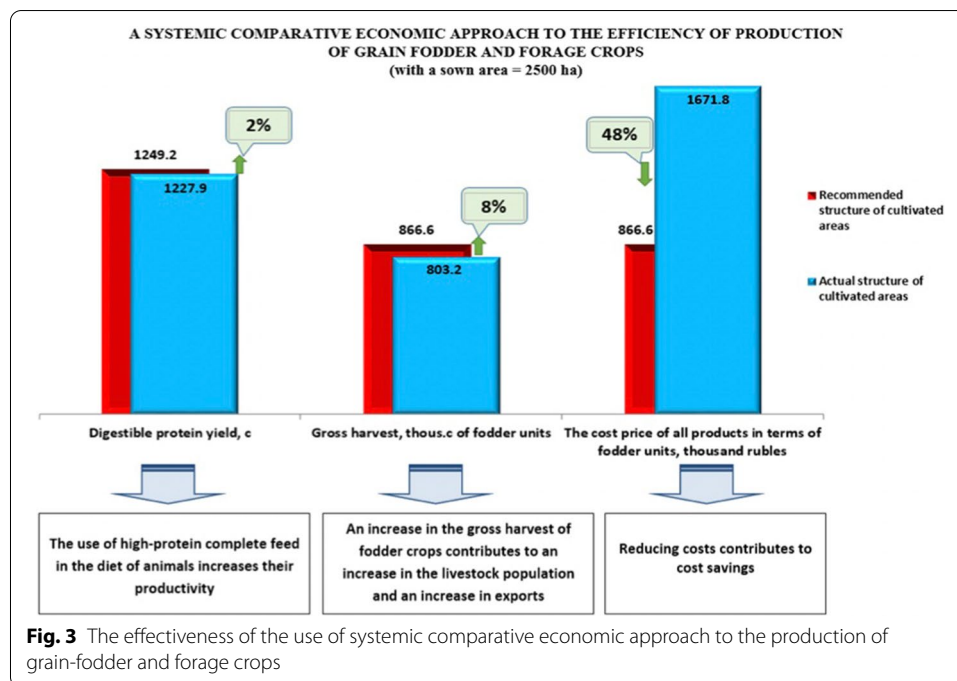
The use of a systemic comparative economic approach contributes to the intensification of feed production. The return on the more efficient use of forage lands increases and highly productive animals' feed needs are met.

Conclusions

The primary purpose of the systemic comparative economic approach is to determine, taking into account the costs incurred, the optimal amount of feed. Simultaneously, special attention is paid to their qualitative composition for the further compilation of a full-fledged diet for agricultural animals. The proposed structure of sown areas for grain and fodder crops is focused on cultivating high-protein crops. As a result, there is an increase in the gross yield by 8%, digestible protein by 2%, and a decrease in production cost in terms of feed units by 48%. It is important to emphasize that the developed and tested methodology of the systemic comparative economic approach applies to other enterprises located in the non-black soil zone with similar production conditions. Thus, the scientifically grounded results obtained using the systemic comparative economic approach are primarily focused on improving agricultural production's crop production direction.

Figure 3 shows the effect of applying a systemic comparative economic approach to grain-fodder and fodder crops.

The vector of further research on the issues under consideration is aimed at developing the animal husbandry industry in the Northern forest-steppe zone of the



Republic of Bashkortostan, which largely depends on the availability of the required quantity and full-value feed in the required quality.

It should be noted that this study has several limitations:

Firstly, the values of indicators characterizing the effectiveness of the proposed structure of sown areas were determined based on actual data for 2011–2020. However, their correction is also possible. These indicators can significantly increase due to the intensification of production, which will lead to a significant increase in both production and financial indicators of the economy.

Secondly, in the proposed variant of the structure of sown areas, the cereal crop's specific weight, which is significant for the region, is somewhat reduced, which leads, accordingly, to a decrease in the gross harvest. The task of achieving the same values of the gross yield of wheat after applying the method can be achieved in the following ways: (1) by expanding the sown areas under wheat, by introducing a part of the arable land previously withdrawn from circulation; (2) increasing productivity; (3) by the simultaneous application of both previous methods.

Abbreviations

Mt: Million tons; *I*: Index; fea: Forage economic assessment; fp: Fodder productivity; dp: Digestible protein; ep: Expenses paid; cea: Comparative economic approach; np: Net production.

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Authors' contributions

ML conceived and designed the analysis; VK collected the data; ZZ contributed data or analysis tools; VL performed the analysis; IA and ML wrote the paper. All authors read and approved the final manuscript.

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Availability of data and materials

Data will be available on request.

Declarations

Competing interests

The authors declare that they have no competing interests.

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