Methodology for assessing the sustainability of agricultural production, taking into account its economic efficiency

L Sakharova1*, M Stryukov1 and V Zolnikov2

1Department of Fundamental and Applied Mathematics, Rostov State University of Economics, 69 B. Sadovaya Street, Rostov-on-don, 344002, Russian Federation
2Department of Computer Facilities and Information Systems, Voronezh State University of Forestry and Technologies named after G.F. Morozov, 8 Timiryazeva Street, Voronezh, 394087, Russian Federation

*E-mail: L_Sakharova@mail.ru

Abstract. The aim of the study is to develop a methodology for assessing the sustainability of agricultural production in the region based on the consideration of factors of two groups: economic and environmental. The task of the research is to develop mathematical tools that allow, based on standard multi-level fuzzy [0,1] - classifiers, to form a comprehensive assessment of the sustainability of agricultural production in the region using a set of heterogeneous ranked indicators. A method was developed that allows: 1) to form a comprehensive assessment of the intensity of agricultural production in the region based on aggregation of indicators of the level of production intensification in agriculture, as well as significant indicators of the level of economic efficiency of production intensification in agriculture for a period of n years; 2) calculate a comprehensive assessment of the impact of agricultural production on the ecology of the region based on the aggregation of indicators reflecting the dynamics of the chemical load on the ecology of the region, soil fertility, the dynamics of emissions of pollutants into the atmosphere for the relevant periods; 3) aggregate the obtained estimates into a comprehensive assessment of the sustainability of agricultural production in the region.

1. Introduction

At present, the paradigm of sustainable development of agriculture in Russia has been formulated, which is a qualitatively new technical, technological, organizational and economic, socially oriented, environmentally balanced, consistent with the objective requirements of environmental imperatives, system. Its defining links are the ecological balance of its inherent elements, the priority solution to the problems of restoring land fertility and agroforestry, an active state social policy for the development of rural communities and territories, which allows the gradual transfer of the country's agrarian and agro-food sectors to predominantly green technologies [1]. The need for a scientific paradigm for the sustainable development of agriculture has been substantiated over the past three decades in the work of foreign experts, such as: E. Bird, L. Brown, S. Budejovis, G. Bulten, E. Weizsacker, J. Gardner, X. Garrett, R. Dixon-Goach, R. Lal, E. Lovins, L. Lovins, R. Costanza, D.Kh. Meadows D.L. Meadows, J. Oldfield, I. Randers, D. Sitarz, L. Harper, M. Khrabankova, D. Shaw, etc.

The essence of the criterion for the efficiency of agricultural production is the maximum production of agricultural products necessary for society at given costs and the amount of resources per unit of...
output. At the same time, agricultural production should ensure high quality products and rational use of labor, material, monetary and land resources [2]. At present, the task of increasing the efficiency of agricultural production is a priority. At the same time, there is a deterioration in the environmental situation of natural-industrial systems. Therefore, the rationalization of agricultural production must be carried out not only from the position of increasing the efficiency of agricultural production, but also taking into account the reproduction of soil fertility, as well as improving the ecological condition of the environment. The system of indicators of the ecological and economic efficiency of agricultural production in the region should reflect not only economic, but also environmental and social factors. Thus, we are already talking about the sustainability of agricultural production.

Theoretical, methodological and methodological issues of assessing the effectiveness of agricultural production and the possibilities of increasing it are quite fully investigated by such agricultural economists as V.R. Boev, E.P. Bryanskikh, I.N. Buzdalov, V.V. Butyrin, A.B. Golubev, V.A. Dobrynin, A.P. Zinchenko, N.S. Katkov, V.V. Kozlov, G.G. Kotov, I.V. Kurtsev, K.P. Obolensky, N.Ya. Petrenko, A.B. Petrikov, V.A. Svbodin, I.G. Ushachev, A.A. Chernyaev, A.A. Shutkov, and others. Their works and developments are a good basis for analyzing the efficiency of agricultural production, identifying external and internal reserves for its increase. At the same time, the problem of a comparative assessment of the efficiency of enterprises, regardless of their size, specialization, and other conditions, has not yet been resolved; the criteria for evaluating production efficiency taking into account environmental factors are not well defined. With the obvious differentiation of agricultural organizations, both in terms of function and in terms of efficiency, there is currently no clear methodology for differentiated assessment of the effectiveness of agricultural production.

Currently, there are private methods for assessing the intensity of agricultural production by its individual indicators [3-7]. However, they do not allow the assessment and ranking of agricultural enterprises, agribusiness sectors and entire regions on the basis of a comprehensive analysis of many indicators. There are a number of developments devoted to assessing the impact of agricultural production on the ecology of regions [8-12], as well as assessing the sustainability of agricultural production [13-17]. However, the methods proposed in them do not allow a comprehensive study of the agricultural region based on a set of heterogeneous indicators, as well as aggregate estimates of the effectiveness of agricultural production with estimates of its impact on the ecology of the region, in order to obtain a final assessment of the sustainability of agricultural production.

In the aspect of optimizing agricultural production on the basis of environmentally friendly technologies, the development of methods is gaining practical importance, allowing a comprehensive assessment of the intensity of agricultural production based on a combination of ranked indicators objectively reflecting the efficiency of use of material and financial resources by the agricultural sectors, as well as the impact of agricultural production on the region’s ecology. This determines the relevance of this study. In this paper, we propose a new technique based on the methods of the theory of fuzzy sets, which allows us to assess the sustainability of agricultural development in the region based on a combination of indicators of economic efficiency and environmental safety of agricultural production in the region. The relevance of the research topic is due to the need to further specify and update the reform directions of the country’s agrarian economy in the context of the provisions of the basic federal law “On the Development of Agriculture” (December 26, 2006 No. 264-FZ), the State Program for the Development of Agriculture and the Market for Agricultural Products and Raw Materials and food for 2008-2012, as well as the Food Security Doctrine of the Russian Federation.

2. Methodology

General principles authoring techniques estimate the intensity of agricultural production are described in detail in [18] and [19]. Mathematical apparatus, which underlies the method and is a modification of standard 5-point classifiers is disclosed in detail in these papers.

The methodology consists in the fact that for each of the indicators, based on the time series of its values, integrated estimates are calculated using normalizing formulas. Subsequent application of the standard five-level fuzzy [0,1]–classifier to them (used earlier in financial analysis and not used in
methods for assessing production intensity) allows us to calculate normalized complex estimates of the levels of production intensification and economic efficiency of production intensification in agriculture, as well as to obtain a comprehensive assessment of the intensity of its production.

For intensity ratings agricultural production following algorithm is used.

**Step 1.** Creating a list of the most important indicators of the level of intensification of production in the agricultural sector over the period n years (hereinafter: the first group of indicators), as well as significant indicators of economic efficiency of an intensification of production in the agricultural sector over the same period (the second group of indicators).

**Step 2.** Ranking the importance of the studied indicators for assessing agricultural intensity, the calculation of weighting factors based on expert assessments.

**Step 3.** Calculation of normalized (i.e., the interval \([0,1]\)) of numerical values of the test parameters of the first and the second group over the period n based on years of formulas defined meaning problem.

**Step 4.** Setting the linguistic variables. The normalized values of parameters determined at step 3 are numerical values of fuzzy variables with universal set (carrier) in the form of \([0,1]\). They are compared with the linguistic variables term set, consisting of five of the terms “very low level of the indicator”; “low level indicator”; “average index”; “high index”; “very high level of the indicator”. Membership functions of linguistic variables determined by trapezoidal functions and are given in Table 1.

Further, we introduce the linguistic variables: \(\gamma = \) “complex evaluation of the intensity of agricultural production”; \(\gamma_1 = \) “assessment of intensification of production in agriculture”; \(\gamma_2 = \) “evaluation of the economic efficiency of an intensification of production in agriculture”.

Universal set for each linguistic variable is numeric interval \([0,1]\), and the set values of the three variables \(\gamma, \gamma_1, \gamma_2\) is term-set \(G = \{G_1, G_2, G_3, G_4, G_5\}\), where \(G_1 = \) “steady trend a reduction in growth”; \(G_2 = \) “downward trend in growth”; \(G_3 = \) “the tendency to stagnation”; \(G_4 = \) “upward trend”; \(G_5 = \) “stable upward trend”. Accessories functions also have a trapezoidal shape and are listed in Table 1.

| Membership function subsets of linguistic variables | Fuzzy sets membership function |
|----------------------------------------------------|--------------------------------|
| \(B_{ij}, C_{ij}, G_{ij}, i = 1, 2, 3, 4, 5\)     |                                |
| \(B_{ij}, C_{ij}, G_{ij}, i = 1, 2, 3, 4, 5\)     |                                |
| \(B_{ij}, C_{ij}, G_{ij}, i = 1, 2, 3, 4, 5\)     |                                |
| \(B_{ij}, C_{ij}, G_{ij}, i = 1, 2, 3, 4, 5\)     |                                |
| \(B_{ij}, C_{ij}, G_{ij}, i = 1, 2, 3, 4, 5\)     |                                |
| \(B_{ij}, C_{ij}, G_{ij}, i = 1, 2, 3, 4, 5\)     |                                |
| \(B_{ij}, C_{ij}, G_{ij}, i = 1, 2, 3, 4, 5\)     |                                |
| \(B_{ij}, C_{ij}, G_{ij}, i = 1, 2, 3, 4, 5\)     |                                |
| \(B_{ij}, C_{ij}, G_{ij}, i = 1, 2, 3, 4, 5\)     |                                |

**Step 5.** The transition from the numerical values of the indices to numerical values based on estimates.
of the total five-level algorithm of the standard 5-point classifiers.

For example, the transition rule of the values of parameters \( x_i \) \((i = 1,2, ..., m)\). Weights of terms \( \gamma \) linguistic variable is of the form:

\[
p_i = \sum_{i=1}^{m} r_i \cdot \mu_{il}(x_i), \quad l = 1, ..., 5.
\]

The value of the variable itself \( \gamma \) defined by the formula:

\[
\gamma = \sum_{k=1}^{5} P_k \cdot \bar{G}_k.
\]

Where \( \bar{G}_i \) are centers of gravity of terms, \((0.125; 0.3; 0.5; 0.7; 0.885)\).

**Step 6.** Linguistic recognition obtained numerical rating in accordance with the definition of the term-sets \( G = \{G_1, G_2, G_3, G_4, G_5\} \), as well as analysis of the received intensity on the basis of numerical values of the indices ratings and recommendations for correcting the situation.

Assessment of the level of intensity of agricultural production Rostov region made on the basis of statistical data provided by the Ministry of Agriculture of Rostov region, for 18 years, taking into account the positive and negative dynamics of their changes.

Investigated indicators of an intensification of production form four groups: the first group reflects the value of productive assets on one ha of agricultural land, the second group - energy resources; The third group - the characteristics of fixed assets; fourth group - the current production costs. The role of total costs and the cost of basic production assets in the assessment of the level of intensification of production in agriculture is revealed through more detailed indicators: in the second group, through indicators of energy equipment and energy availability; in the third group - through the coefficients of agricultural machinery renewal, the proportion of breed animals in the total population, and the density of cattle per 100 hectares of farmland (heads); in the third group - through indicators of the size of the current production costs of crop and livestock. In general, to assess the level of intensification of production data are available for 14 indicators provided by the Ministry of Agriculture of Rostov region for 1996 – 2013 years.

Indicators of economic efficiency of an intensification of production in agriculture Rostov region to form six groups: the amount of gross income, profitability, capital productivity, productivity, productivity of crops by groups, the performance of farm animals in groups.

Thus, the economic efficiency of an intensification of production in agriculture Rostov region it is necessary to assess the 10 indicators on the basis of statistical data for available 18 years. Required on the basis of these estimates the level of intensification of production in the agricultural sector of the Rostov region and the economic efficiency of an intensification of production in agriculture Rostov region to form a final comprehensive assessment of the intensification of production in the agricultural sector of the Rostov region.

This problem is difficult to realize the classical methods of mathematical modeling, primarily due to the need to incorporate a significant amount of heterogeneous data. The starting material is a random table of 24 rows and 18 columns. The contribution of each of the indicators in the final assessment is not equivalent. The indicators have different economic sense, the scope and dimension (e.g., crop yields, measured in t / ha; capital productivity, profitability; rub, %, etc.). In addition, for the considered indicators are currently no widely accepted standards. “Positive” is considered to be a permanent trend of positive growth indicators; “negative” is zero or negative growth for each of the indicators.

Therefore, the calculation of the normalized values \( x_i \) \((i = 1,2, ..., m)\) studied parameters level of intensification of production in agriculture during the period \( N \) s performed based on the scheme, an integrating time-series data for each of the indicators, and taking into account the importance of the different time periods due to weighting coefficients:

\[
x_i = 0,5\left(1 + \sum_{l=1}^{5} k_l I_l\right), \quad k_l = \frac{2(N-i)}{(N-1)N}.
\]
where $k_i$ - weighting coefficients determined on the basis of rules Fishburne, and the numbering of the time periods in the reverse order (i.e., the first period? the years 2012-2013, and the last, 17th, 1996-1997). I. is integer functions determined so that the value of “-1” corresponds to a negative increase in $i$th parameter; value “1” – to a positive gain for $i$th parameter; and “0” – to stagnation, zero growth.

Analysis of formula (1) shows that the circuit takes into account the temporal importance of each of the periods. If in all periods is a positive gain, the sum in brackets is equal to one, and the final numeric value of the index $x_i$ reaches its maximum and is equal to one. In case of a negative growth in all periods value index $x$ reaches a minimum and is equal to zero. Total weight of time periods 2008 and 2013 is equal to 0.4902; from 2002 to 2007 is 0.3726; from 1996 to 2001 is only 0.1372. Thus, a steady negative period total numerical score of i-th index in the past 5 years not higher 0.5098 (which means “bad”).

Similarly shall be calculated normalized values $y_i$ studied indicators of economic efficiency of an intensification of production in agriculture, $i=1,2, ..., m$. Calculation of complex assessments carried out in accordance with the general scheme. The weights and the values of membership functions for the performance of the first and second groups are shown in Table 1 and 2. For calculations based on the above-described circuits designed software package [20].

3. Results and discussion

3.1. Assessment of the intensity of agricultural production in the Rostov region, taking into account the positive and negative dynamics over available 18 years

On the basis of Table 2 we are calculated and linguistic recognition $g_1$ = “assessing the level of intensification of production in agriculture Rostov region”:

$$g_1 = 0.125 \times 0.0558 + 0.3 \times 0.1082 + 0.5 \times 0.1977 + 0.7 \times 0.1597 + 0.885 \times 0.4788 + 0.6739 = 0.6739 .$$

$$\mu(0.6739) = \mu_1(0.6739) = 1 .$$

Accordingly, $g_1$ = “assessment of intensification of production in agriculture Rostov region” corresponds to the term $G_4$, “upward trend”. Based on the same Table 2 identified critical parameters (those for which the normalized value less than 0.5).

These are: 1) the density of cattle per 100 hectares of farmland (heads), $x_8 = 0.1831$; 2) updating the coefficient of agricultural machinery (%), all kinds of appliances, $x_5 = 0.3297$; 3) the proportion of waste in the general population of animals (%), sheep, $x_7 = 0.3636$; 4) energy equipment, $x_2 = 0.4477$; 5) the proportion of waste in the general population of animals (%), pigs, $x_6 = 0.5076$.

On the basis of the obtained estimates, it can be concluded that in 1996 - 2013 there was a steady downward trend in the agriculture of the Rostov Region of the following significant indicators characterizing the level of intensification of agricultural production: the density of cattle per 100 hectares of farmland, the proportion of breed animals in the total population sheep, pigs), the rate of renewal of agricultural equipment (combines of all kinds), power equipment.

Calculation and language recognition $g_2$ = “evaluating the economic efficiency of intensification of production in agriculture Rostov region” performed based on Table 3.

$$g_2 = 0.125 \times 0 + 0.3 \times 0.0587 + 0.5 \times 0.6408 + 0.7 \times 0.0966 + 0.885 \times 0.2039 = 0.5861 .$$

$$\mu(0.5861) = \mu_1(0.5861) = 0.36 . \quad \mu(0.5861) = \mu_1(0.5861) = 0.64 .$$

Consequently, $g_2$ – “evaluation of the economic efficiency of an intensification of production in agriculture Rostov region” corresponds to two terms: $G_3$ – “tendency to stagnation” and $G_4$ – “upward trend”, the statement “has a tendency to stagnation” is truer than utterance “there is a tendency to increase”.

**Table 2.** The weight and value of the membership function for the indicators of the first group.

| Indicators | Weights | Values | Bath of linguistic variable of the first |
|------------|---------|--------|----------------------------------------|
|            |         |        |                                        |
1. The cost of production funds for 1 ha / agricultural land (rubles / ha.) - $x_1$

2. Energy resources (hp / ha)
   2.1. Energy equipment - $x_2$
   2.2. Installed power - $x_3$

3. Characteristics of the basic production assets
   3.1. The coefficient updating agricultural machinery (%)
   3.1.1. Tractors - $x_4$
   3.1.2. Combines all kinds - $x_5$
   3.2. Weight of breed animals in the general livestock (%)
   3.2.1. Pigs - $x_6$
   3.2.2. Sheep - $x_7$
   3.3. The density of cattle on 100 hectares of farmland (goals) - $x_8$

4. The sum of the current production costs of agriculture per 1 hectare of agricultural land (thousand / ha)
   4.1. The size of the current production costs of crop production per 1 ha of arable land (thousand rubles / ha) - $x_9$
   4.2. The size of the current production costs of livestock per 1 head of agricultural animals (thousand rubles per 1 head)
   4.2.1. Dairy cattle - $x_{10}$
   4.2.2. Meat cattle - $x_{11}$
   4.2.3. Pigs - $x_{12}$

The weights of the terms of the linguistic variable of the first group

| Indicators | Weights | Values | Bathes linguistic variable of the second group |
|------------|---------|--------|-----------------------------------------------|
| 1. Obem net profit (income) per 1 ha of arable land (thousand rubles / ha) - $y_1$ | 1/6 0.5230 | 0 0 one 0 0 |
| 2. Profitability level (%) - $y_2$ | 1/6 0.4576 | 0 0 one 0 0 |
| 3. The amount of output per ruble invested capital (rub) - $y_3$ | 1/6 0.4902 | 0 0 one 0 0 |
| 4. Labor productivity (%) - $y_4$ | 1/6 0.9150 | 0 0 0 0 one |
| 5. Crop yield (c / ha) | 1/18 0.4443 | 0 0.057 0.943 0 0 |
| 5.1. The yield of cereals and legumes without corn - $y_5$ | 1/18 0.5947 | 0 0 0.553 0.447 0 |
| 5.2. Yield of sunflower - $y_6$ | 1/18 0.6144 | 0 0 0.356 0.644 0 |
| 5.3. Yields of open field vegetables - $y_7$ | 1/18 0.6144 | 0 0 0.356 0.644 0 |
| 6. Farm animal productivity | 1/18 0.8170 | 0 0 0.330 0.670 0 |
| 6.1. Average milk yield per cow (kg) - $y_8$ | 1/18 0.2941 | 0 one 0 0 0 |
| 6.2. Yield calves in 100 major cows - $y_9$ | 1/18 0.5818 | 0 0 0.682 0.318 0 |
| 6.3. Yield piglets per 100 sows (heads) - $y_{10}$ | 0.0587 0.6408 0.0966 0.2039 |

On the basis of Table 3 are assigned indices, which lead to a decrease in the final assessment, comprising: 1) to yield 100 calves in the main cows (goal), $y_9 = 0.2941$; 2) the yield of grain legumes and corn, without, $y_5 = 0.4443$; 3) profitability level (%), $y_2 = 0.4576$; 4) the amount of output per ruble...
invested capital (rub.), \( y_3 = 0.4902 \). It can be concluded that in 1996, on the basis of the estimates a steady downward trend following significant parameters that characterize the level of economic efficiency of an intensification of agricultural production in 2013 in agriculture Rostov region observed: number of calves per 100 main cows, yield of grains and leguminous plants without maize, the level of profitability, the amount of output per ruble invested capital.

Implemented calculation \( g = \text{"a comprehensive assessment of the intensification of production in agriculture in the region"} \). Weight terms are defined as arithmetic mean of the weights \( g_1 \) and \( g_2 \) ratings:

\[
g = 0.125 \times 0.0279 + 0.3 \times 0.0835 + 0.5 \times 0.4193 + 0.7 \times 0.1282 + 0.885 \times 0.3414 = 0.6301.
\]

\[
\mu(0.5861) = \mu(0.6301) = 0.8, \quad \mu(0.6301) = \mu(0.6301) = 0.2.
\]

Therefore, \( g = \text{"comprehensive assessment of the intensification of production in agriculture in the region"} \) for 1996 - 2013 is in line with \( G_3 \) two terms: “the tendency to stagnation” and the \( G_4 \) – “upward trend”, and saying “there is a tendency to growth” is more true than saying “there is a tendency to stagnation”. Thus, the proposed method makes it possible to perform a comprehensive analysis of agricultural development of the Rostov region in 1996 - 2013, based on the account of the positive and negative dynamics of heterogeneous indicators of the two groups: 14 indicators characterizing the intensification of production and 10 indicators - economic efficiency of an intensification of production. The analysis performed with the weighting indices significance and contribution rank different time periods in the final evaluation.

It was established that the level of intensification of production in agriculture Rostov region in the period under consideration can be given a rating of “upward trend”, while the level of economic efficiency of an intensification of production in agriculture Rostov region corresponds to a greater extent score “tendency to stagnation” than “upward trend”. Factors leading to the low level of the final assessment of economic efficiency of an intensification of production are, first and foremost, steady downward trend in the level of profitability, as well as the volume of production per ruble invested capital. These factors, in turn, are the result of sustained downward trend in such important indicators characterizing the level of intensification of agricultural production, such as:

Comprehensive assessment of the intensification of production in the agriculture of the region responds more to a “upward trend” than “tendencies to stagnation”, which indicates a relatively steady development of agricultural production in the Rostov region in 1996 - 2013. The analysis pointed out areas of agricultural production in which in the future, investment is required to ensure sustainable growth.

3.2. Evaluation of the impact of agriculture on the environment in the region

Methods of forming integrated assessments described above are used to estimate the degree of impact of agricultural production on the ecological state of the region. Introduced modification is a particular case of the author's technique of estimation of complex systems based on complexes of heterogeneous indices [18] and [19]. As the set of indicators based on which the formed assessment of the impact on the environment of agricultural production region, using data about the application to the soil pesticides, soil fertility, emission of pollutants and agricultural production region using water agriculture. Consider a method of forming an integrated assessment of influence on the environment of agricultural production region in more detail.
Table 4. Pesticide in the open ground of the Rostov region.

| Indicator         | 2012 | 2013 | 2014 | 2015 | 2016 |
|-------------------|------|------|------|------|------|
| The volume of pesticides in the open field of the Rostov region - total, t |       |      |      |      |      |
| Insecticides, t   | 798  | 834  | 573  | 545  | 600  |
| Fungicides, t     | 587  | 736  | 408  | 404  | 650  |
| Herbicides, t     | 1,271| 1,796| 1,071| 1,122| 1,390|

Assessment of chemical load dynamics on the ecological system of the region. Calculations carried out on the basis of time series, reflecting the application of fertilizers in the open field for the available 2012 – 2016 years (table 4, data of [20]).

Calculation of normalized x-values of the studied parameters during the period N years carried out on the basis of the formula:

\[ x_i = 0.5 \left( 1 + \sum_{i=1}^{N} k_i I_i \right), \quad k_i = \frac{2(N-i)}{(N-1)N} \quad (2) \]

where \(k_i\) - weighting coefficients determined on the basis of rules Fishburne, wherein the weighting factor for the period 2015 - 2016 years is 0.4; for 2014 - 2015 years is 0.3; for 2013 - 2014 years is 0.2; for 2012-2013 years is 0.1. \(I_i\) is the integer function, the value of “1” corresponds to an increase of \(i\)-th index (situation worsened); value of “-1” corresponds decrease of \(i\)-th parameter; value “0” corresponds stabilization, no change.

Let us consider the linguistic variable \(g_1 = \text{“evaluation of the dynamics of chemical load on the ecological system of the region”}\), which is a versatile set is a numerical interval \([0,1]\). Term-set consists of five terms of \(G = \{G_1, G_2, G_3, G_4, G_5\}\), provisionally estimating system state: \(G_1 – \text{“steady tendency to decrease load”}\); \(G_2 – \text{“the tendency to reduce the load”}\); \(G_3 – \text{“stabilization of the situation”}\); \(G_4 – \text{“trend to increase the loading”}\); \(G_5 – \text{“steady trend towards an increase in the load”}\).

Membership function - the standard trapezoidal.

Calculations based on Table 4 show that for Rostov region \(g_1 = 0.66\), meaning \(G_4\) term – “tends to increase the load”.

Evaluation of soil fertility. Qualification is based on statistical data reflecting the content of humus in the soil by natural agricultural zones, available 1976 - 2013, five-year periods of [20].

Assessment of the dynamics of humus content in the soil. To assess the dynamics of humus in the soil introduced linguistic variable \(g_2 = \text{“evaluation of the dynamics of humus in soil”}\), which is the universal set numerical interval \([0,1]\). Term-set consists of five terms of \(G = \{G_1, G_2, G_3, G_4, G_5\}\), provisionally estimating system state: \(G_1- \text{“steady trend towards increased humus content”}\); \(G_2 – \text{“tendency to increase humus content”}\); \(G_3 – \text{“stabilization of the situation”}\); \(G_4 – \text{“a tendency to reduce the humus content”}\); \(G_5 – \text{“a steady trend towards a decrease in humus content”}\).

Calculation of normalized x-values of the studied parameters is carried out on the basis of the scheme during the period N years:

\[ x = 0.5 \left( 1 - \sum_{i=1}^{N-1} k_i I_i \right), \quad k_i = \frac{2(N-i)}{(N-1)N} \quad (3) \]

where \(k_i\) - weighting coefficients determined on the basis of rules Fishburne; time slot numbering is carried out in reverse order; for the period 2007-2013, the highest ratio and is 7/8. \(I_i\) - integer function, as described above.

Calculations show that for the Rostov region \(g_2 = 0.63\), which means belonging to two terms \(G_3 – \text{“stabilization”}\) and \(G_4 – \text{“tendency to decrease humus”}\), and the values of membership functions are 0.2 and 0.8. This means: a statement “there is a tendency to a decrease of humus content” is more true than
saying “holds stabilization”, which coincides with the qualitative evaluation of [20].

Assessment of the level of humus in the soil. To assess the humus content in the soil was put into consideration the linguistic variable: \( g_3 = \) “the level of humus in the soil”. Universal set for the linguistic variable is numeric interval \([0,1]\).

Term-set consists of four terms \( G = \{ G_1, G_2, G_3, G_4 \} \): \( G_1 \) – “norm”; \( G_2 \) – “ecological risk”; \( G_3 \) – “zone crisis”; \( G_4 \) – “disaster area” (according to the standard classification [10]).

Normalized values of the input parameters are calculated for each natural and agricultural areas as the ratio of 2013 to the value of the average humus content in the virgin lands (4.2%). Standard 4-point classifiers are used [18], [19].

Calculations show that for the Rostov region \( g_3 = 0.385 \), which means belonging to the term \( G_2 \), “ecological risk”, which coincides with the estimates of [20].

Estimation of the dynamics of emission of pollutants. Analysis of pollutants emission dynamics performed based on data on emissions of pollutants in Rostov region extending from the stationary source of agricultural production tons [9]. Let us consider the linguistic variable: \( g_4 = \) “evaluation of the dynamics of pollutant emissions into the atmosphere”. Term-set consists of five terms of \( G = \{ G_1, G_2, G_3, G_4, G_5 \} \): \( G_1 \) – “steady trend towards a decrease in emissions”; \( G_2 \) – “tendency to reduce emissions”; \( G_3 \) – “stabilization of the situation”; \( G_4 \) – “tendency to increase emissions”; \( G_5 \) – “steady tendency to increase emissions”.

Timing parameters are aggregated rows on the basis of formula (1). To form the final grade, standard 5-point classifiers. Calculations show that for the Rostov region \( g_4 = 0.46 \), which means belonging to the \( G_3 \) to the term – “stabilization”.

Assessment of the dynamics of water use in agriculture. Analysis carried out on the basis of the volume of water used data for 2007 - 2016 years [20]. Grade aggregated based on the formula (4).

Let us consider the linguistic variable: \( g_5 = \) “load estimation of the dynamics on the water system of the region”.

Term - set consists of five terms \( G = \{ G_1, G_2, G_3, G_4, G_5 \} \): \( G_1 \) – “stable tendency to reduce the burden on the water system of the region”; \( G_2 \) – “the tendency to reduce the load on the water system of the region”; \( G_3 \) – “stabilization of the situation”; \( G_4 \) – “the tendency to increase the burden on the water system of the region”; \( G_5 \) – “stable tendency of increase the burden on the water system of the region”.

Calculations show that for the Rostov region \( g_5 = 0.5 \), which means equally belonging to two terms \( G_1 \), “steady tendency to reduce the load on the water system of the region”; \( G_2 \), “the tendency to reduce the burden on the water system of the region”.

3.3. Comprehensive assessment of “the environmental impact of agricultural production in the region”

Based on the standard 5-point classifiers aggregated scores obtained in 3.1 - 3.2: \( g_1 = \) “evaluation of the dynamics of chemical load on the ecological system of the region”; \( g_2 = \) “evaluation of the dynamics of humus content in the soil”; \( g_3 = \) “assessment of the content of humus in soil”; \( g_4 = \) “evaluation of the dynamics of polluting emissions into the atmosphere”; \( g_5 = \) “load estimation of the dynamics on the water system of the region”.

Let us consider the linguistic variable: \( g = \) “estimate the negative impact of agricultural production on the ecological system of the region”.

Term - set consists of five terms \( G = \{ G_1, G_2, G_3, G_4, G_5 \} \): \( G_1 \) – “very limited”; \( G_2 \) – “minor”; \( G_3 \) – “average”; \( G_4 \) – “substantial”; \( G_5 \) – “destructive”. Membership function is the standard trapezoidal.

Calculations based on the results of the preceding paragraphs show that the Rostov region \( g = 0.49 \), which means that equally belongs to the \( G_3 \), “average negative impact of agricultural production on the ecological system of the region”.

Thus, the developed method allows to form a complex evaluation of the effect of agricultural
production on the environment of the region based multi statistics on pesticide, soil fertility, pollutant emissions into the atmosphere from stationary sources of water use in agriculture region. It allows you to aggregate together diverse information on the use of various resources, at the same time take into account the dynamics and the level of intensity of the impacts of agricultural production on the ecological state of the region.

Comprehensive assessment of the sustainability of agricultural production in the region. Qualification α = “integrated evaluation of stability in agricultural production” is formed by aggregation based on five-point standard classifiers two estimates obtained in claim 1 and claim 2: γ = “complex evaluation of the intensity of agricultural production” and β = 1-γ, where γ = “assessment of the negative impact of agricultural production on the ecological system of the region”.

Term-set consists of five terms G = {G1, G2, G3, G4, G5}: G1 – “very bad”; G2 – “bad”; G3 – “satisfactory”; G4 – “good”; G5 – “excellent”.

Calculations based on the results to claim 3.1, 3.2 show that for the Rostov region α = 0.59, which means equally belonging to the term G3 – “satisfactory”.

4. Conclusion
In this paper, we propose a new technique based on the methods of the theory of fuzzy sets, which allows us to assess the sustainability of agricultural development in the region based on a combination of indicators of economic efficiency and environmental safety of agricultural production in the region.

The technique consists of three blocks. The first block is aimed at obtaining an objective comprehensive quantitative assessment of the intensity of agricultural production according to the set of criteria of two groups: the level of intensification of production and the level of economic efficiency of intensification of production in agriculture. The novelty of the proposed method, as well as its difference from similar developments, is that for each of the indicators, based on the time series of its values, integrated estimates are calculated using normalizing formulas. Subsequent application of the standard five-level fuzzy [0,1] –classifier to them (used earlier in financial analysis and not used in methods for assessing production intensity) allows us to calculate normalized complex estimates of the levels of production intensification and economic efficiency of production intensification in agriculture, as well as to obtain a comprehensive assessment of the intensity of its production.

The second block is aimed at forming a comprehensive assessment of the degree of influence of agricultural production on the ecological condition of the region. Mathematical tools are similar to those used in the first block. As a set of parameters, on the basis of which the assessment is formed, time series of data on the application of pesticides into the soil, soil fertility, emissions of pollutants into the atmosphere and water use by agriculture are used.

In the third block, two formed assessments are aggregated into an integrated comprehensive assessment of the sustainability of agricultural production in the region based on standard five-level fuzzy [0,1] –classifiers.

In the future, it is supposed to formulate an assessment of the sustainability of agricultural production and taking into account the socio-economic development of the region.

The novelty of the proposed method lies in the possibility of aggregating an arbitrarily large number of heterogeneous parameters to form an estimate, without significantly complicating the model.

References
[1] Pshikhachev A S 2010 The paradigm of sustainable agricultural development in the context of reforming the Russian economy, PhD thesis, Russian Academy under the President of the Russian Federation
[2] Bondarenko L V 2002 Environmental and economic efficiency and sustainability of grain production, PhD thesis, Kuban State Agrarian University
[3] Garina I S 2010 Evaluation of the effectiveness of intensification of agricultural production Problems and Prospects of Economic Development 5 110
[4] Tsathlanova T T 2011 Methodological aspects of assessing and improving the efficiency of agricultural production. *Economic Systems Management* **33** 71

[5] Gavrilova Z V and Ryzhkova S A 2018 Evaluation of the effectiveness of state support in agricultural organizations of the Voronezh region. *Bulletin of the Voronezh State University* **2**, 76

[6] Anipenko L N and Dorohova AV 2018 The level of intensity and efficiency of grain and sunflower production in the Rostov region. *Bulletin of Agricultural Science of the Don.* 2012. 6 52

[7] Harutyunyan F G, Geshel V P and Toporov V T 2016 Indicators and methods for assessing the effectiveness of agriculture from the standpoint of public interests. *Innovation Science* **6**(10-3) 46

[8] Stepanova L P, Myshkin A I, Korenkova E A and Moiseeva M N 2011 Ecological assessment of the impact of agricultural production on the intensity of environmental pollution. *Bulletin of Orel State Agrarian University* **2,5** 219

[9] Bryukhanov A Yu, Vasilyev E V, Shalavina E V and Oblomkova N S 2019 Indicators of negative environmental impact in the production of agricultural products. *Technologies and Technical Means of Mechanized Production of Crop and Livestock Production* **8** 209

[10] Tilman D 1982 *Resource Competition and Community Structure: Monographs in Population Biology* (Princeton: Princeton Univ. Press)

[11] Howarth R W, et al. 1996 Regional nitrogen budgets and riverine N & P fluxes for the drainages to the North Atlantic Ocean: Natural and human influences. *Biogeochemistry* **35** 181

[12] Vitousek P M, Aber J D, Howarth R W, Likens G E, Matson P A, Schindler D W, Schlesinger W H and Tilman D 1997 Human alteration of the global nitrogen cycle: Sources and consequences. *Ecol. Appl.* **7** 737

[13] Khayrullov D S and Eremeev L M 2012 Problems of the sustainability of the socio-economic development of the region. *Bulletin of Kazan State Agrarian University.* **7** 473

[14] Benton T 1998 ‘Sustainable development and the accumulation of capital: reconciling the irreconcilable?’ *Fairness and futurity*, ed Dobson A (Oxford: Oxford University Press)

[15] Crissman C C, Antle J M and Capalbo S M *Economic, Environmental and Health Tradeoffs in Agriculture: Pesticides and the Sustainability of Andean Potato Production* (Lima: Kluwer Academic)

[16] Chudilin G 2006 On the state and methodology for assessing the sustainability of agricultural production. *Bulletin of the Chuvash University.* **14** 165

[17] Ryabova I V 2016 Assessment of the sustainability of agricultural production in the territorial system of food security. *Bulletin of the NIIE.* **6** 21

[18] Alekseychik T V, Bogachev T V, Karasev D N, Sakharova L V and Stryukov M B 2019 Fuzzy method of assessing the intensity of agricultural production on a set of criteria of the level of intensification and the level of economic efficiency of intensification. *Advances in Intelligent Systems and Computing* **9** 790

[19] Vovchenko N G, Stryukov M B, Sakharova L V and Domokur O V 2019 Fuzzy-logic analysis of the state of the atmosphere in large cities of the industrial region on the example of Rostov region. *Advances in Intelligent Systems and Computing* **7** 709

[20] Albekov A U, Arapova E A, Karasev D N, Stryukov M B and Sakharova L V 2018 A program for assessing the intensity of agricultural production through a fuzzy 5-point classifier. *Federal Service for Intellectual Property*, Computer Registration Certificate No. 2018613875.

[21] On the state of the environment and natural resources of the Rostov region in 2011/2012 / ... / 2017 *Ecological Bulletin of the Don*, available at https://xn--d1ahaoghejbc5k.xn--p1ai/projects/19/