A multi-criteria approach for assessment of agricultural systems in context of sustainable agriculture

Constanta Zoie Radulescu, Marius Radulescu, Adrian Turek Rahoveanu,
Magdalena Turek Rahoveanu, Silviu Beciu

Abstract— In this paper, is presented a multi-criteria approach for assessment of agricultural systems in context of sustainable agriculture for different spatial scales. The important step in the assessment is the selection of a set of representative criteria, in order to analyze the potential impacts (environmental, social and economic) on agricultural sustainability. The assessment of sustainability was performed with the TOPSIS multi-criteria decision method. This method supports the structured evaluation of problems with multiple decision criteria. The TOPSIS analysis was performed with the software tool MULTICRIT – Multi-criteria decision support software. The proposed approach for assessment was tested for agricultural systems represented by two development regions of Romania: South Muntenia Region and North East Region. Each region consists of several counties. The spatial scales taken into account were the regional and counties scales. A comparative study of the two development regions is presented.

***Keywords*—**Multi-criteria approach, assessment, TOPSIS method, agricultural systems, development region

I. Introduction

An "agricultural system" should be understood as a geographical unit comprising a set of natural, historical, social, economic, legal and technical phenomena that affect the methods of cultivation that form the homogeneous agricultural landscape. Agricultural sustainability is regarded as an important factor for the long term profitability of agricultural systems. Increasing public interest in the concept of sustainable agriculture has resulted in a considerable resonance in scientific literature driven by the need to operationalize this concept [1]-[3]. But despite some progress, it often remains difficult to link the research on sustainability assessment to practical decisions and actions [4]. The common theme in the literature on agricultural sustainability assessment is that it embodies ecological, economic, and social dimensions [5]-[7].

Sustainability indicators for agriculture have been widely used to understand and measure agricultural systems performance. Such indicators have included environmental quality, economic viability and employment and social performance [8]-[10]. Indicators can be used individually, as part of a set, or in the form of a composite index, whereby individual indicators' scores are combined into a single number.

In order to assess agricultural sustainability, many methodological approaches have been proposed. However, no widely accepted method for the creation of a scientifically substantiated system of indicators and indices has been developed [11].

Multi-criteria Decision Making (MCDM) methods are gaining popularity in sustainable agriculture. MCDM methods have inherent properties that make them practically useful. Some of these properties are cf. [12]: (1) ''they seek to take explicit account of multiple, conflicting criteria (objectives)'', (2) they help to structure the management problem, (3) they provide a model that can serve as a focus for discussion, and (4) they offer a process that leads to rational, justifiable, and explainable decisions.

Multi-criteria approaches examine sustainability in agriculture at different spatial scales (plot, farm, region, nation and global), subject to the decision problem which is handled. At each level, different units of analysis, agro-technical possibilities and constraints have to be taken into account.

In this paper, a multi-criteria approach for assessment of agricultural systems in the context of sustainable agriculture is presented. The assessment is realized for different spatial scales. The important step is the selection of a set of representative criteria, in order to analyze the potential impacts (environmental, social and economic) on agricultural

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C. Z. Radulescu is with the National Institute for R&D in Informatics, Bucharest, ROMANIA (e-mail: radulescucz@yahoo.com).

M. Radulescu, Institute of Mathematical Statistics and Applied Mathematics, Bucharest, ROMANIA, mradulescu.csmro@yahoo.com

A.Turek Rahoveanu, and M. Turek Rahoveanu are with the Research Institute for Agricultural Economics and Rural Development, Bucharest, ROMANIA (e-mail: aditurek@yahoo.com and mturek2003@yahoo.com).

S. Beciu is with Universitatea de Stiinte Agronomice si Medicina Veterinara, Bucharest, ROMANIA (e-mail: beciu_silviu@yahoo.com).

sustainability. The assessment of sustainability was accomplished using the TOPSIS multi-criteria decision method. The TOPSIS method supports the structured evaluation of problems with multiple decision criteria. Based of this method are calculated sustainability assessments for different spatial scales. TOPSIS was performed with the software tool MULTICRIT – Multi-criteria decision support software. The proposed approach for assessment was tested for agricultural systems represented by two development regions of Romania: South Muntenia Region and North East Region. Each region consists of several counties. The spatial scales taken into account are regional and counties scales. A comparative study of the two development regions is presented.

II. THE MULTI-CRITERIA ASSESSMENT APPROACH

A discrete multi-criteria assessment approach can be described in general terms using the following terminology:

- A is a finite set of m feasible alternatives (or actions) $A_1, A_2, ..., A_m$;
- n is the number of assesment criteria $g_j, j = 1,2,...,n$ considered relevant in a decision problem, where $g_j : A \to R, i = 1,2,...,n$ are real valued functions. g_j represents the j-th criterion according to a non-decreasing preference, The alternative A_i is evaluated to be better than alternative A_k according to the j-th criterion if–and–only-if $g_i(A_i) > g_i(A_k)$.

The alternatives in our approach are the agricultural systems. The criteria for assessment of agricultural systems in terms of sustainable agriculture are economic, social and environmental criteria.

Therefore a multi-criteria assessment may be represented in a matrix form. Given the sets A (of alternatives) and G (of evaluation criteria), and assuming the existence of m alternatives and n criteria, it is possible to build an m x n matrix $\mathbf{B} = (b_{ij})$, called an evaluation or impact matrix. The entry b_{ij}, $i = 1,2,...,m,\ j = 1,2,...,n$ represents the evaluation of the i-th alternative by means of the j-th criterion. The evaluation matrix may include quantitative, qualitative, or both types of information. The entries of each column have the same measurement unit. The alternatives are evaluated for the distinct criteria using different measurement units and scales. To bring the elements of the evaluation matrix **B** to compatible units is used a normalization process. Normalization makes all the entries lie between 0 and 1. There are several methods applied for normalization of the evaluation matrix entries. The normalization method proposed to be applied for our approach is the vector normalization. If g_j is a minimum criterion then the entries of the column j in the normalized matrix $\mathbf{R} = (r_{ij})$ are:

$$r_{ij} = 1 - \frac{b_{ij}}{\sqrt{b_{1j}^2 + b_{2j}^2 + ... + b_{mj}^2}} \quad i = 1,2,...m$$

If g_j is a maximum criterion then the entries of the column j in the normalized matrix $\mathbf{R} = (r_{ij})$ are:

$$r_{ij} = \frac{b_{ij}}{\sqrt{b_{1j}^2 + b_{2j}^2 + ... + b_{mj}^2}} \quad i = 1,2,...m.$$

A. Steps in a discrete multi-criteria assessment approach

The steps in a discrete multi-criteria assessment approach are:

1) Identification and selection of representative assessment criteria and sub-criteria
2) Calculate criteria and sub-criteria weights
3) Identification and selection of assessment alternatives
4) Evaluation matrix construction and normalization
5) Multi-criteria aggregation procedure – TOPSIS method
6) Alternatives ranking
7) Sensitivity analysis and comparison

B. Multi-criteria aggregation procedure - TOPSIS method

The evaluation matrix **B** is built by the analyst. Its entries represent the performance values of each alternative with respect to each criterion. Denote by **R** the normalized matrix obtained from matrix **B**.

If the weights are used define $r_{ij}^{'} = r_{ij} \times w_j$ for $i = 1,2,...,m,\ j = 1,2,...n$ Define the matrix: $\mathbf{R}^{'} = (r_{ij}^{'})$.

The alternatives ranking is based on the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method. TOPSIS chooses the best alternative that has the shortest distance to the ideal solution and the farthest distance from the negative-ideal solution. The method TOPSIS was first proposed in 1981 by Hwang and Yoon [13].

The positive and negative ideal solutions are determined:

$s_j = \max_{1 \le i \le m} r_{ij}^{'}$ and $t_j = \min_{1 \le i \le m} r_{ij}^{'}$ for $i = 1,2,...,m,\quad j = 1,2,...,n$

For each alternative $i = 1,2,...,m$ are calculated the Euclidian distances in $\mathbf{R}^n$:

$$S_i = \sqrt{(r_{i1}^{'} - s_1)^2 + ... + (r_{in}^{'} - s_n)^2},$$

$$T_i = \sqrt{(r_{i1}^{'} - t_1)^2 + ... + (r_{in}^{'} - t_n)^2} \text{ and } c_i = \frac{T_i}{T_i + S_i}.$$

In the final the entries of the vector $\mathbf{c} = (c_1, c_2, ..., c_m)$ represent the value of the assessment of agricultural systems in context of sustainable agriculture. The alternatives are ranked according to the entries of the vector **c.**

III. SELECTION OF REPRESENTATIVE ASSESSMENT CRITERIA AND SUB-CRITERIA

The criteria selected for the assessment of agricultural systems in terms of sustainable agriculture are economic, social and environmental criteria (Figure 1).

A. The economic criteria

The **average yield** represents the quantity of products obtained on the unit of cultivated area. The measure unit for

average yield is Kg/ha. The principal crops cultivated in the region are considered in the analysis (wheat, rye, two-row barley, maize, sun-flower).

Agricultural branch production indices are calculated as ratio between production value in current year expressed in the prices of the previous year and production value in the previous year. The production is for *Crop production* and *Animal production.*

Animal density index - Represents the number of animals per unit agricultural area (heads per 100 hectares). It is calculated for cattle, sheep, pigs and goats. Herds of cattle, sheep and goats relates to arable surface area plus pasture and meadow area. Pigs relates only to arable land (surface area).

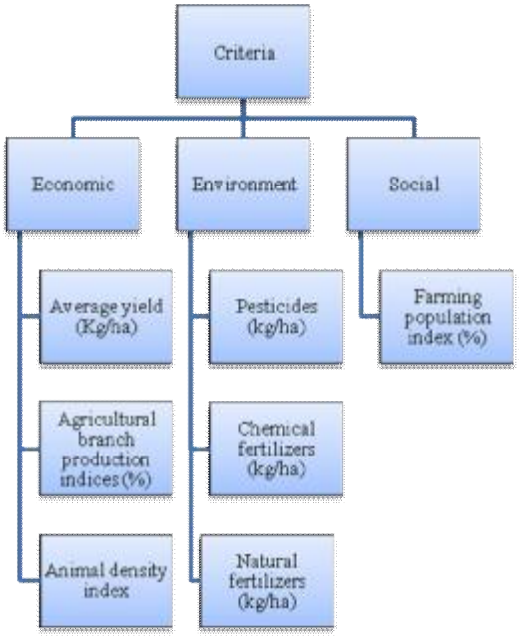

Figure 1. The criteria and subcriteria selected

B. *The environment criteria*

The use of **pesticides** in agriculture is world-wide still the most widespread method for pest control. Environmental and human health problems related to the use of pesticides have created an increasing pressure against their use. The sub-criteria measure unit is consumption of pesticides in kg per ha. The pesticides considered are insecticides, herbicides and fungicides.

Chemical fertilizers are industrial products which by content can be nitrous, phosphatic, potassic or combined, as complex fertilizers. They are expressed in active substance. The sub-criteria measure unit is consumption of fertilizers in kg per ha. The fertilizer considered are nitrous, phosphatic and potassic.

Natural fertilizers include muck from all species of animals and poultry (fresh or fermented) as well as liquid dejections; they are expressed in gross weight. The sub-criteria measure unit is consumption of natural fertilizers in kg per ha.

C. *The social criteria*

Farming population index is equal to the ratio between the farming population and the employed population.

IV. Assessment of South Muntenia and Nord East Regions of Romania in context of sustainable agriculture

Romanian agriculture, which was for a long time considered a traditional, slow moving economic activity strongly dependent on subsidies and public support, is now a sector affected by many political changes and social pressures derived from environmental concerns and trade liberalizations requirements. Romanian agriculture has great potential, which is not properly exploited.

The Eurostat data show that Romania is ranked seventh in Europe in terms of agricultural area and fifth in terms of arable land. The arable land per habitant is 0.42 ha of land, a value higher than most European countries and almost double than the European average (0.236 ha/habitant). In 2008, Romania ranked fourth within the EU in terms of cereal crops (5.2 million ha), behind France (9.6 million ha), Poland (8.9 million ha) and Germany (7 million ha). The average cereal yield in Romania (3400 kg/ha) is almost half of the EU average (5960 kg/ha, EU-25).

Even though Romania has a varied landscape, all the regions of the country have favorable conditions for agriculture. The analysis of the results recorded by Romanian agriculture on regions of development shows important disparities. Therefore, it is required to permanently monitor agricultural performance recorded at regional level.

The agricultural systems considered in the analysis are two development regions of Romania: South Muntenia Region and North East Region. Each region consists of several counties (Figure 2).

The first region chosen for the research is South Muntenia. It is composed of seven counties: Arges, Prahova, Dambovita, Ialomita, Calarasi, Giurgiu, Teleorman.

Agriculture is an important sector in the South Muntenia Region. The agricultural land area in the region is 2,447,192 hectares, that is, about 71% of the total area of the region. This shows the high agricultural potential in the region.

The North-East is the largest region of Romania, with an area of 36,850 square kilometers (15.46% of total land area). In its composition are 6 counties: Bacau, Botosani, Neamt, Iasi, Suceava and Vaslui.

The aim of our analysis is the assessment, from the sustainable agricultural point of view, of the counties of South Muntenia and North – East Regions of Romania. The year considered is 2009.

The data for this analysis is based on “TEMPO online times series” from National Institute of Statistics, Bucharest, Romania [https://statistici.insse.ro/shop/?lang=en].

The analysis was realized with a software tool MULTICRIT – Multi-criteria decision support software.

MULTICRIT is developed in National Institute for Research and Development in Informatics, Bucharest, Romania.

Figure 2. The South Muntenia Region and North East Region

The criteria and sub-criteria weights can be calculated with the AHP method [14]. For this analysis we consider equal weights for all criteria.

The alternatives are counties of the two regions. We consider in the first step the counties of each region: South Muntenia and North East. The ranks of the counties are determined by the TOPSIS method.

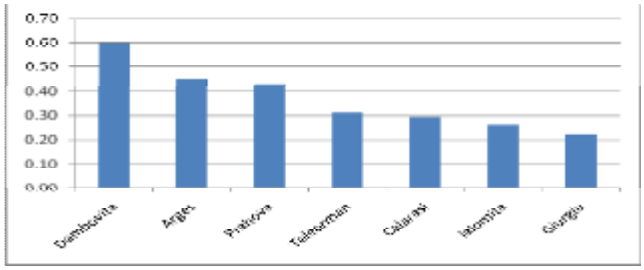

Figure 3. The sustainability assessments of counties in the South Muntenia Region

The results are presented in Figure 3 for the South Muntenia Region and in Figure 4 for the North East Region.

Then the assessment is made for all counties of the two regions (Figure 5).

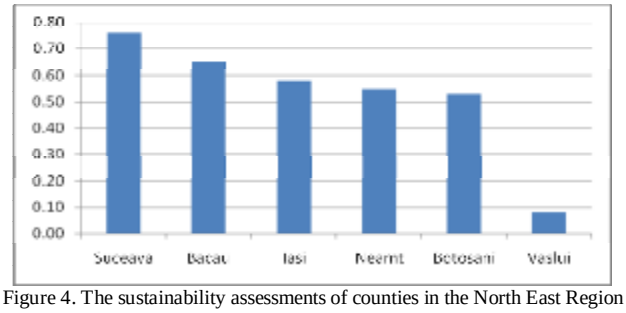

Figure 4. The sustainability assessments of counties in the North East Region

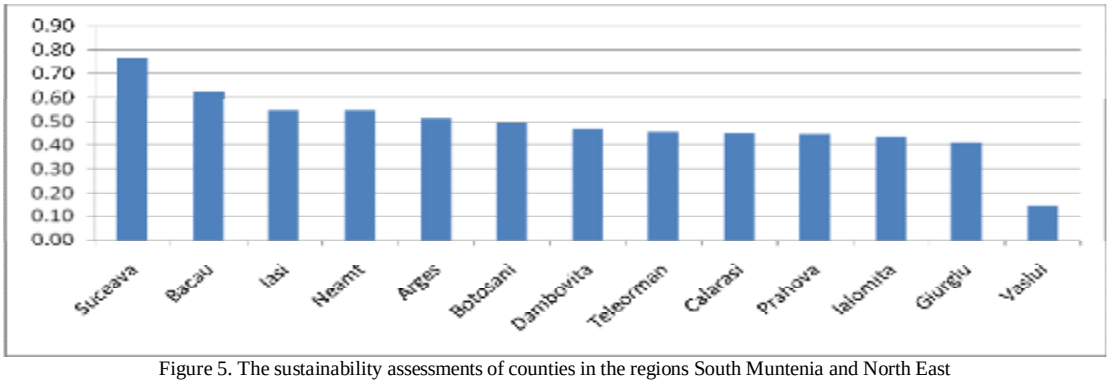

Figure 5. The sustainability assessments of counties in the regions South Muntenia and North East

For each alternative are calculated the Euclidian distances in $\mathbf{R}^n$: S and T. The vector C represents the value of the assessment of the counties in context of sustainable agriculture. The results are presented in table 1.

TABLE I
THE EUCLIDIAN DISTANCES AND THE ASSESSMENT VALUE IN TOPSIS METHOD

Counties	C	T	S
Arges	0.52	0.10	0.09
Calarasi	0.45	0.09	0.10
Dambovita	0.47	0.07	0.08
Giurgiu	0.41	0.07	0.11
Ialomita	0.44	0.08	0.10
Prahova	0.45	0.07	0.09
Teleorman	0.46	0.09	0.10
Bacau	0.63	0.10	0.06
Botosani	0.50	0.10	0.10
Iasi	0.55	0.10	0.08
Neamt	0.55	0.10	0.08
Suceava	0.76	0.12	0.04
Vaslui	0.15	0.02	0.14

A value of the sustainability assessment of the two regions is calculated for each county and for each region. The final result is presented in table 2.

TABLE 2
THE SUSTAINABILITY ASSESSMENT VALUES FOR THE REGIONS

Regions	Sustainability Assesssment Value
North East	3.13
South Muntenia	3.19

V. CONCLUSIONS

Romania is a country recently integrated into the European Union, having a significant agricultural potential.

The assessment of the overall sustainability of various agricultural systems is a complex process involving several steps. An important step is the identification and selection of representative assessment criteria and sub-criteria that could be used to define sustainability.

In the paper we present a multi-criteria approach for assessment of agricultural systems in context of sustainable agriculture. This approach is exemplified for assessment of two regions of Romania, South Muntenia and North East regions. The multi-criteria method used is TOPSIS method. This approach offers to managers a tool that leads to decisions based on rational arguments.

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