GENERAL METHOD FOR LAND USE SUSTAINABILITY EVALUATION AND BASIC INDICATORS FOR AGRICULTURAL LAND USE DURABILITY[1]

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Abstract

Land use sustainability evaluation is a complex problem. In order to solve it, a nested hierarchy of the main subdomains/types of land evaluation is presented and, according to this systemic approach, a general hierarchical multilevel evaluation method is proposed. A specific component of sustainability is durability, defined as a measure of changes having constant trend over time determined by land use.

The second part of the paper focuses on basic time-related indicators for evaluating the agricultural land use durability. The main requirements that these indicators should meet are outlined and six of such indicators are defined: soil surface water erosion risk, soil humus content change risk, soil available phosphorus content change risk, soil available potassium content change risk, soil acidification risk and risk of soil and groundwater pollution with nitrates. The procedure to implement these indicators in the "DexTer" decision support system for agricultural land management is outlined and an overall index (measure) of the agricultural land use durability is also defined.

Key words: land evaluation, land use sustainability, evaluation methods, land quality, agricultural land use durability indicators.

Introduction

At present, land management should face the new pressures on land resources. The new approaches in land management should focus not only on productivity and profitability, as in the past, but also on evaluating the impacts of human interventions (during the land use) on specific landscapes. Growth has often been achieved by degrading the natural resources, but this is no longer acceptable. Increasingly it is being realised that land is a major factor in global life support and that it has intrinsic value beyond agricultural production. Land provides global environmental benefits, such as its role in global geochemical cycles, nutrient recycling, source and sink functions for greenhouse gases, filtering/buffering the pollutants and transmission/purification of water in the hydrologic cycle. There is increasing evidence that indicators of land quality and sustainable land management should guide our actions. Land use should be sustainable, and "land evaluation" today means "land use sustainability evaluation".

The main objective of the sustainable land management is to harmonise the two complementary goals: providing environmental, economic and social benefits both for present and future generations - that is maintaining and enhancing the performance/quality of the land resources (soil, water and air). Sustainable land management determines the land use according to the changing human needs while ensuring the long-term socio-economic and ecological functions of the land. Sustainable land management is a knowledge-based procedure that guides the decisions on land management toward the most feasible and cost effective options in achieving land use intensification, particularly agricultural production, and improved environmental management.

[1] Canarache A., Enache R. (eds). Proceedings of the International Conference on "***Soil under Global Change – A Challenge for the 21-st Century***" (Constanta, sept.2002), vol.I, Ed.Estfalia, Bucuresti, 2005, p.43-54.

This paper presents a systemic approach for evaluating the land use sustainability, defines time-related basic indicators for evaluating the durability of the agricultural use of land and presents possibilities to implement these indicators in decision support systems and a way to define an overall index (measure) of the agricultural land use durability.

1. Land use sustainability evaluation

Sustainable land use should simultaneously ensure (Smith & Dumanski, 1993; Dumanski et.al.,1998):

- Productivity: maintaining and enhancing production/services;
- Stability-Resilience: reducing the level of production risk (security) and enhancing the soil capacity to buffer the degradation processes;
- Protection: protecting the potential of natural resources and preventing the soil and water quality degradation;
- Viability: economic viability;
- Acceptability-Equity: ensuring social acceptability and the access to the benefits from improved land management.

Land use sustainability (LUS) is a measure of the extent to which the main objectives as above defined can be met by a defined *land use* in a specific *land unit* (area of land assumed relatively homogenous) over a stated period of time (Smith & Dumanski,1993). In fact, the object of evaluation is the *"Land-Use System"*: the binom of the *land unit* and the *land use* as a whole (FAO, 1983; Vlad, 1997a, 2000, 2001). To evaluate the land use sustainability, all the above mentioned factors should be taken into account, quantified and their influences assessed (Smith & Dumanski, 1993; Vlad, 1997ab, 2000, 2001, 2002; WCSS, 1998; Dumanski et.al., 1998; Motoc & Carstea, 1999). It is a wide sense/acceptance of the term of sustainability - the overall sustainability.

In order to establish methods for LUS evaluation, it is useful to see the main subdomains or types of land evaluation as the nested systemic hierarchy structure presented in *Figure 1*. Land performance and quality are statically assessed, based on the present land status, taking into consideration different factors and having in mind different aims: physical (technical) evaluation, economic evaluation, social evaluation and environmental evaluation. It is to note that the economic evaluation should use the physical evaluation results and the social evaluation should use the economic evaluation results. Land use sustainability refers to the present levels of the land physical, economic and social performance and environmental quality and also their lasting in the future (*durability*). Of course, environmental and durability aspects may be included in the economic and social evaluation, especially when some land uses are defined to meet a requested level of environmental quality and land performance durability (so that, for example, the costs to maintain in time the performance and quality are taken into account in economic/social evaluation).

Environmental evaluation refers to the influence of the land use on the evaluated land unit (on-site effects), but also refers to the neighbourhood: it is necessary to estimate the influence of the evaluated Land-Use System on the neighbouring (adjacent) Land-Use Systems (off-site effects) and also it is necessary to estimate the influence of the neighbouring Land-Use Systems on the evaluated Land-Use System.

The new dimension introduced in LUS evaluation, the time, brings new problems: the need to estimate the future changes of the land characteristics/qualities and also the need to establish the confidence time limits or the time extent/level that the evaluation refers to. The changes of land characteristics/qualities may be continuous, having a constant trend over time, or may have a probabilistic (accidental) variability. The last type of characteristic changes is usually taken into consideration in physical and economic evaluation (e.g. climatic variability, price/cost variability, etc.) and *durability* refers only to the changes determined by land use. Consequently, *durability* is a component of sustainability, defined as a measure of changes having constant trend over time determined by land use.

<table>
<tr><th></th><th>Categories of Factors/Criteria</th><th colspan="7">Subdomains / types of Land Evaluation</th></tr>
<tr><td rowspan="7">Static Evaluation
(land performance and quality)</td><td>Soil fertility factors</td><td>Soil Fertility Evaluation</td><td rowspan="2">Soil Evaluation</td><td rowspan="3">Intrinsic Physical Land Evaluation</td><td rowspan="4">Physical
(Technical)
Land Evaluation</td><td rowspan="5">Economic Land Evaluation</td><td rowspan="6">Social Land Evaluation</td><td rowspan="8">Land Evaluation

(Land use Sustainability Evaluation)</td></tr>
<tr><td>Other soil factors</td><td></td></tr>
<tr><td>Other land factors
(climate, relief, hydrology)</td><td colspan="2"></td></tr>
<tr><td>Site factors
(access roads, parcel size/shape, other infrastructure, etc.)</td><td colspan="3">Site Assessment</td></tr>
<tr><td>Economic factors
(prices, costs, subsidies, etc.)</td><td colspan="4"></td></tr>
<tr><td>Social factors</td><td colspan="5"></td></tr>
<tr><td>Environmental factors
(level of pollution/degradation, biodiversity, etc.)</td><td colspan="3">Environmental Evaluation</td><td colspan="3" rowspan="2">Land Evaluation
Specific to Sustainabilty</td></tr>
<tr><td>Dynamic Evaluation</td><td>Time-related aspects
(Durability)</td><td colspan="3">Durability Evaluation</td></tr>
</table>

Figure 1. *Nested hierarchy of the main subdomains/types of Land Evaluation*

2. General hierarchical method for land use sustainability evaluation

The land use sustainability (LUS), as above presented, is a measure that depends - in a very complex way - on a large variety of factors. Generally, it synthesises the factor influence based on an evaluation model *(Figure 2).*

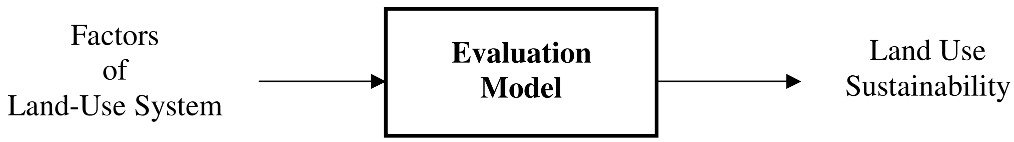

Figure 2. General scheme of land use sustainability evaluation

Usually, it is difficult to develop an evaluation model, because of the number of factors and the complexity of their inter-relational influences on the sustainability. *Figure 3* presents a general hierarchical/multilevel method for evaluating the land use sustainability - a systemic approach based on the nested hierarchical structure of land evaluation *(Figure 1).*

Different factors that determine the LUS are represented by characteristics - measures/attributes that can be directly measured or estimated. There are characteristics of land units (LC_i) and land uses (UC_i). As well as the economic and social factors should be described by appropriate characteristics (EC_i, SC_i). For LUS evaluation, the evaluation criteria (Kx_i) should be defined. They are obtained from the characteristics using a procedure based on appropriate sub-models. The criteria may be physical and environmental (Kp_i and $Kenv_i$, inferred from land unit and land use characteristics), economic (Kec_i - from economic characteristics), social (Ks_i - from social characteristics) and durability criteria (Kd_i - from all characteristics, concerning time-related aspects). The land use sustainability (S) is a measure that synthesises, based on an aggregation sub-model, the influences of all the evaluation criteria.

In order to simplify the sub-models determining the criteria and avoid errors in their development, FAO recommends to use *"land qualities"* (LQ_i) - complex/compound land characteristics acting as an intermediate aggregation level of the primary land characteristics to obtain evaluation criteria (FAO, 1976, 1983). For obtaining the land qualities, (pedo-)transfer functions or rules or more complex sub-models may be used. It is useful to generalise the concept of "qualities" to land use, economic and social factors (UQ_i, EQ_i, SQ_i) too. Many levels of qualities may be established, as needed. The evaluation criteria (Kx_i) may be seen as a higher level of qualities.

The definition of economic criteria is based on economic characteristics/qualities, physical characteristics/qualities/criteria and environmental criteria; the definition of social criteria is based on social characteristics/qualities, physical and economic characteristics/qualities/criteria and environmental criteria; durability criteria are based on all other characteristics/qualities/criteria.

All the evaluation criteria of the same type may be aggregated in partial sustainability indices - physical (Sp), economic (Sec), social (Ss), environmental (Senv) and durability (Sd). Finally, all the partial sustainability indices may be aggregated in an overall index of sustainability (S).

The structure is not necessarily strict-hierarchical, that is in order to obtain an aggregated element, an element in a certain level may be combined with elements in other levels.

The sub-models of aggregation may be implemented as a set of qualitative rules (expert-type), a simple or complex mathematical function or a more complex deterministic (mathematical-heuristic) model, which appropriately integrates the influences of the input elements, irrespectively an unitary area of inter-related dependencies.

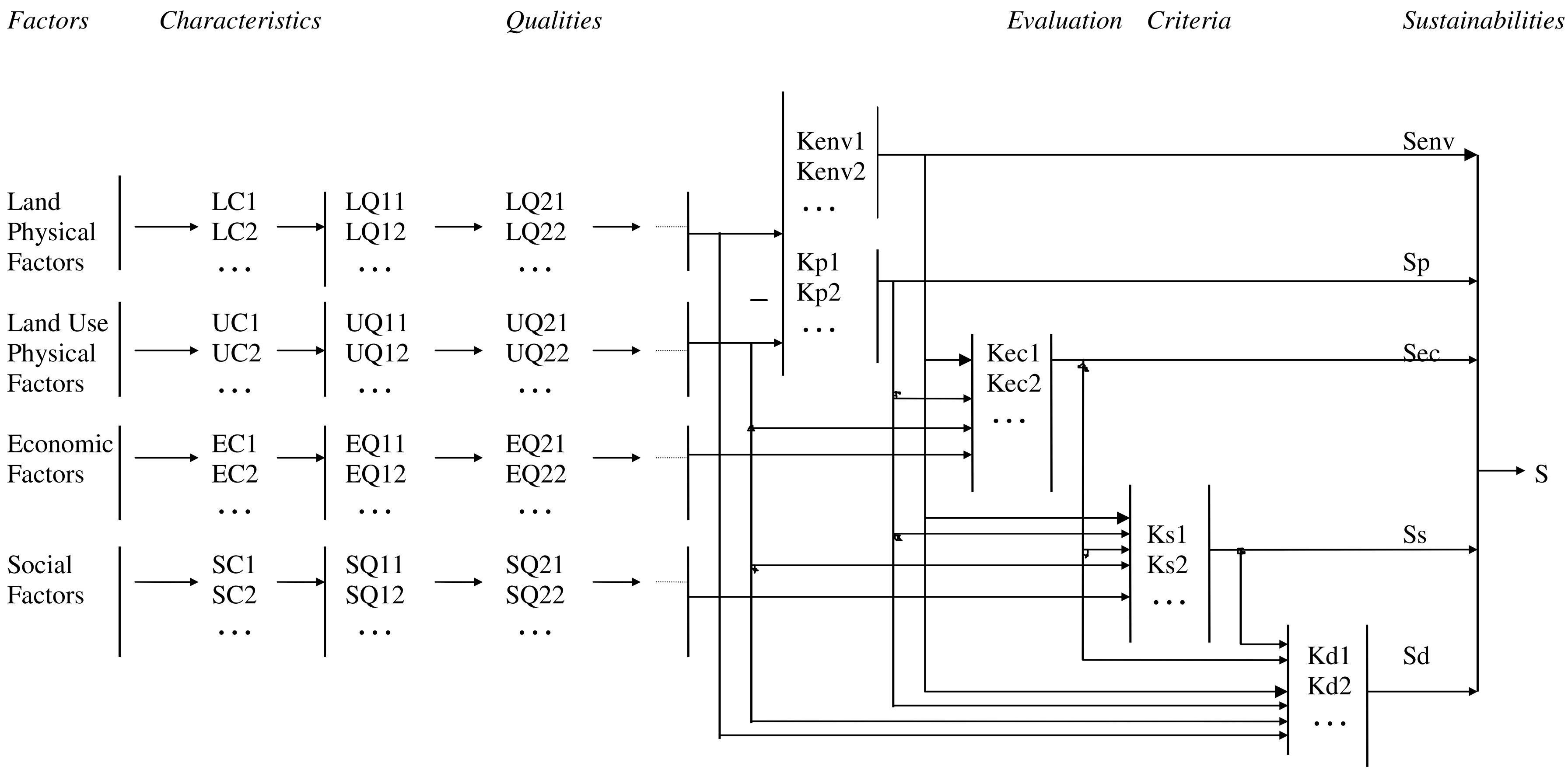

Figure 3. General hierarchical/multilevel method for land use sustainability evaluation
(For meaning of symbols, see the text of the chapter 2)

3. Basic indicators for agricultural land use durability evaluation

For applying the above-developed concepts, the paper aims at defining some indicators (qualities/criteria) to evaluate the agricultural land use durability. The following targets and requirements for these indicators are in view:

- the indicators refer to the agricultural use of land and time dimension of sustainability (durability); they quantify the degree of the main changes of land properties determined by a defined agricultural land use;
- only the on-site effects and the changes having constant trends are taken into consideration;
- the indicators are to be basic indicators (qualities or evaluation criteria): those that characterise the basic processes, whose changes determine the main changes of the other evaluation criteria (qualities, performances), and that take into consideration the main effects of the main common land uses;
- the indicators are to be measured in a unitary way, in order to be easily compared between them and integrated into aggregating algorithms;
- the indicators are aimed at being used in decision making, irrespective in decision support systems, so they should be practical in use, that is they should be simple and clear, acceptable from the viewpoint of accuracy and application cost and complexity, and should be defined on the base of the available data or easily-obtained data.

In this respect, for the time being, the following indicators were defined in order to be implemented into the DexTer system - a decision support system for sustainable management of agricultural use of land (Vlad, 1998, 2001). Other durability indicators concerning other factors, such as soil compaction, soil salinization, pesticide pollution (soil and groundwater), off-site effects, biodiversity changes etc. are to be considered in the future.

3.1. Soil Surface Water Erosion Risk (R_{SE})

$$\boldsymbol{R_{SE}} = (SL_{SE} \ / \ ESM) * 100 \qquad [\ (t/t)\ \% \ / \ year\ ] \qquad (1)$$

where:

SL_{SE} : Soil Loss by Surface Water Erosion [t / ha / year]
ESM : Reference Edaphical Soil Mass [t / ha]

In Romanian Soil Survey Methodology (ICPA,1987), the Edaphical Soil Volume (ESV) is used instead of the ESM characteristic, and the reference soil depth is 100 cm. ESV is a percent value reported to 100 cm depth, so:

$$ESM = ESV * SBD * 100 \qquad [\ t / ha\ ] \qquad (2)$$

where:

ESV : Edaphical Soil Volume [(cm^3/cm^3) % / 100 cm depth]
SBD : Soil Bulk Density [g / cm^3]

and:

$$\boldsymbol{R_{SE}} = SL_{SE} \ / \ (ESV*SBD) \qquad [\ (t/t)\ \% \ / \ year\ ] \qquad (3)$$

where ESV and SBD are soil characteristics given in the usual soil survey works and SL_{SE} is computed using a formula of USLE type. In the DexTer system, the SL_{SE} is determined using an expert rule (ICPA,1987) and a modified/adapted USLA formula (Motoc & Mircea, 2002).

3.2. Soil Humus Content Change Risk (R_{HC})

$$\boldsymbol{R_{HC}} = (\ (\ Hu_f \ - \ Hu_i\ ) \ / \ Hu_i\ ) * 100 \qquad [\ \% \ / \ year\ ] \qquad (4)$$

where:

Hu_i : soil humus content at the beginning of the crop growing season [% / 0-25 cm]
Hu_f : soil humus content at the end of the crop growing season [% / 0-25 cm]

$\boldsymbol{R_{HC}}$ is a negative value when the soil humus content decreases and is a positive value when it increases at the end of the crop growing season.

In the DexTer system, Hu_i is assumed as known (from usual agro-chemical soil tests) and for determining the Hu_f a statistical/empirical model calibrated for the Romanian conditions (Borlan et.al.,2000) is used.

3.3. Soil Available Phosphorus Content Change Risk (R_{PC})

$$\boldsymbol{R_{PC}} = ((P_f - P_i) / P_i) * 100 \qquad [\ \% / \text{year}\ ] \qquad (5)$$

where:

P_i : Available phosphorus content at the beginning of the crop growing season [ppm / 100 g soil / 0-25 cm]
P_f : Available phosphorus content at the end of the crop growing season [ppm / 100 g soil / 0-25 cm]

$\boldsymbol{R_{PC}}$ is a negative value when the soil available phosphorus content decreases and is a positive value when it increases at the end of the crop growing season.

In the DexTer system, P_i is assumed as known (from usual agro-chemical soil tests) and for determining the P_f a statistical/empirical model calibrated for the Romanian conditions (Borlan et.al.,1996) is used.

3.4. Soil Available Potassium Content Change Risk (R_{KC})

$$\boldsymbol{R_{KC}} = ((K_f - K_i) / K_i) * 100 \qquad [\ \% / \text{year}\ ] \qquad (6)$$

where:

K_i : Available potassium content at the beginning of the crop growing season [ppm / 100 g soil / 0-25 cm]
K_f : Available potassium content at the end of the crop growing season [ppm / 100 g soil / 0-25 cm]

$\boldsymbol{R_{KC}}$ is a negative value when the soil available Potassium content decreases and is a positive value when it increases at the end of the crop growing season.

In the DexTer system, K_i is assumed as known (from usual agro-chemical soil tests) and for determining the K_f a statistical/empirical model calibrated for the Romanian conditions (Borlan et.al.,1999) is used.

3.5. Soil Acidification Risk (R_A)

$$\boldsymbol{R_A} = ((pH_i - pH_f) / pH_i) * 100 \qquad [\ \% / \text{year}\ ] \qquad (7)$$

where:

pH_i : Soil pH at the beginning of the crop growing season [/ 0-25 cm]
pH_f : Soil pH at the end of the crop growing season [/ 0-25 cm]

$\boldsymbol{R_A}$ is a positive value when at the end of the crop growing season a soil acidification process occurs and it is a negative value when a soil alkalisation process occurs.

In the DexTer system, pH_i is assumed as known (from usual agro-chemical soil tests) and for determining the pH_f a statistical/empirical model calibrated for the Romanian conditions (Gavriluta et.al.,1997) is used.

3.6. Risk of Soil and Groundwater Pollution with Nitrates (R_{NP})

$$R_{NP} = (N_L / N_{Max}) * 100 \qquad [\% / year] \qquad (8)$$

where:

N_L : Amount of nitrates leached under root zone during the crop growing season [kg / ha / year]

N_{Max} : Amount of maximum acceptable Nitrates in Soil & Groundwater [kg / ha]

N_L can be determined using an appropriate crop simulation model. In the DexTer system, the IMPEL model (Rounsevell et.al.,1998) and STICS model (Brisson et.al.,1998) are planned to be used.

3.7. Overall Index of Agricultural Land Use Durability (Sda)

$$Sda = f (R_{SE}, \gamma_{SE}, R_{HC}, \gamma_{HC}, R_{PC}, \gamma_{PC}, R_{KC}, \gamma_{KC}, R_A, \gamma_A, R_{NP}, \gamma_{NP}, ...) \qquad [\%] \qquad (9)$$

where:

R_{XX} : Risk Indicators [% / year]

f : Algorithm implementing a Multiattribute Multicriterial Decision Method (methods developed in the operational research mathematics, e.g. the Wald, Laplace, Hurwitz, Savage, ELECTRE methods, etc.)

γ_{XX} : Weighting Coefficients appropriate to the decision method.

In the DexTer system, more multiattribute multicriterial decision methods are planned to be implemented, so as the decision makers have the possibility to choose the appropriate method and coefficients according to the aim of the analysis/evaluation/decision, irrespective according to the problem to be solved (Vlad, 2001).

For example, considering the simpliest decision method (weighting average) and defining durability as the annual probability to maintain the six land qualities at the end of the crop growing season with the same level as at the beginning of the crop growing season:

$$Sda = 100 - (R_{SE}* \gamma_{SE} - R_{HC}* \gamma_{HC} - R_{PC}* \gamma_{PC} - R_{KC}* \gamma_{KC} + R_A* \gamma_A + R_{NP}* \gamma_{NP}) \qquad [\% / year] \qquad (10)$$

where:

$$\Sigma \ \gamma_{XX} = 1 \qquad (11)$$

Conclusions

- For evaluating the land use sustainability (LUS), a great number and a great complexity of factors should be taken into consideration. The object of evaluation should be the Land-Use System - the binom of the land unit and the land use as a whole. In order to establish methods for LUS evaluation, it is useful to see the land evaluation as a nested hierarchical structure (*Figure 1*): soil fertility evaluation - soil evaluation - intrinsic physical land evaluation - physical land evaluation - economic evaluation - social evaluation - land (LUS) evaluation.
- For LUS evaluation, it is needed an evaluation model which is difficult to be developed due to the number of factors and the complexity of their inter-relational influences on the sustainability. A practical way to determine the LUS is the hierarchical/multilevel method (*Figure 3*) - a systemic approach based on the nested hierarchical structure of land evaluation: evaluation factors - characteristics - qualities - criteria - partial sustainability - sustainability.
- For decision making in the agricultural practice, many indicators are necessary for evaluating the time-related aspects of sustainability of a land use (agricultural land use durability). They

should be defined appropriately (specifically) to the aim of evaluation. However, some basic indicators may be used in more evaluations. These indicators should be defined to quantify the main changes of the land characteristics and to be practical in use (simple, clear and acceptable from the viewpoint of accuracy, complexity and data used in application).

- In many cases, for estimating/determining the LUS indicators, it is feasible to use more accurate available algorithms or models instead of a direct simple formula.
- Sometimes an overall index for LUS is necessary. It should be specific to the aim of evaluation. The Multi-Attribute Multi-Criteria Decision Method is a practical and acceptable way for estimating such index. This is a general method that can be also used for aggregating different heterogeneous indicators into a higher-level evaluation indicator in the evaluation hierarchy. For that, it is advantageous that the heterogeneous indicators have a unitary measuring way (such as normalisation as percentage indices).
- To evaluate the LUS, appropriate computer software is necessary, which has to implement different algorithms and models for estimating/determining various compound characteristics of Land-Use Systems and different sustainability indicators, and aggregate indices for different aims. The integration of such software into a Decision Support System for Sustainable Land Management is advantageous.
- Besides the indicators defined in this paper for the agricultural land use durability, other important factors should be included into a decision support system for sustainable land management: soil compaction, soil salinization, pesticide pollution (soil and groundwater), off-site effects, biodiversity changes, etc.
- More research is needed in order to establish/define different important indicators, algorithms, models, thresholds, weighting coefficients, etc. for different purposes of LUS evaluation.

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