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INDICATORS USED FOR ASSESSMENT OF THE ECOLOGICAL DIMENSION OF SUSTAINABLE ARABLE FARMING – REVIEW

S. Valtýniová, J. Křen

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Abstract

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Our study offers:

- A review of basic indicators important for sustainability assessment of arable farming (balance of nutrients, organic matter and energy, pesticide use, biodiversity and soil protection);
- A review and way of expression of the most frequent indicators for assessment of the above characters and impact of farming on the environment including the methods for a complex assessment of agricultural enterprises in which individual indicators have been used;
- A knowledge and practical experience of using of the indicators for assessment in agricultural enterprises.

indicators, agrosystem sustainability

Sustainable management poses on three bases: ecological, economic and social of which the ecological plays a key role. Economy is automatically concerned as a crucial factor as without economy no agricultural business can survive even for a short period. However, man unconditionally needs natural resources for all his activities, development and food production. Degradation or destruction of natural resources cannot be replaced by expending any amount of money – see the concept of strong sustainability (Ščasný *et al.*, 2002; Neumayer, 2002). This does not only mean space and raw materials but also services or functions that the natural ecosystems offer (The Ministry of Environment, 2003). However, this is a long-term issue, observable in the time frame of decades or centuries. Therefore, it is not often taken into account by a farmer, and thus monitoring of the adequate behaviour and motivation from the outside is needed. The manifestation of the increasing negative impacts of human activities, to significant extent particularly of agriculture, gave birth to considerations of sustainability at the beginning of the 20th century, and in a society-wide measure since the 1960s. Therefore, at first the assessment of the ecological aspect of sustainability was developed, and the indicators and methods comprising economic and social matters were gradually added later (Rosnoblet *et al.*, 2006).

Payraudeau and van der Werf (2005) state that from the environmental viewpoint, agricultural activity is sustainable if the produced polluting emissions, and range and way of exploitation of natural resources can be in the long term ensured through the natural environment. Thus, determination of the environmental impact of agriculture represents the first step in the overall assessment of agricultural sustainability.

Agricultural research is aware of the importance of agrosystem sustainability and the need to develop suitable ways of its measurement (Tellarini, Caporali, 2000). For this purpose, different indicators have been developed in order to cover the need for tools in the assessment of impacts on the environment (Bockstaller, Girardin, 2003).

As mentioned by Halberg *et al.* (2005), Green Accounts or Input-Output Accounting systems (IOAs) have been developed in the countries with intensive agricultural production in order to support voluntary relation improvement and activities of farms with regard to the environment. It is typical for IOAs to use a set of indicators for expression of the level of environmental impact. One of the reasons for support and interest of IOAs in individual countries and at EU level seems to be the hypothesis that such voluntary systems for environmental improvement of farms can supplement the obligatory regulations, and that farmers can compare themselves one with the other. Together with the use of indicators, this will enhance their awareness of possible environmental improvements. It might be better to stimulate the farmers to be "managers of their own interaction" between the production and environment rather than to force them to obey current rules and restrictions. According to Halberg *et al.* (2005), the farmer is, from the agrosystem viewpoint, the key to improving interaction management between agricultural enterprises and the environment, and given the right advise, he might be able to find locally adapted improvements.

The objective of our study is the characterisation and review of indicators employed for the environmental (concerned also as bio-physical or agronomic) sphere of the sustainability assessment of management of arable land.

METHODS AND INDICATORS

The methods for sustainability assessment of agricultural enterprises have been developed since the 1990s. The most frequently used means for the assessment are sets of indicators. These enable a comprehensible presentation even of complex phenomena. Rosnoblet *et al.* (2006) identified 150 such methods in their research. They further found that the prevailing assessed aspect of the analyzed methods is impact on the environment. The assessment is most often carried out at the agricultural enterprise level (in about half of the methods) and at higher organizational levels (region and country). The number of indicators range between 4 and 200 per method (median equals to 15) at which the most frequent way of indicator aggregation is their sum or arithmetic mean.

Of this number, 55 so called Input-Output Accounting systems (IOAs) have been identified in Europe (Goodlas *et al.*, 2003; Halberg *et al.*, 2005). These systems take into account inputs into a farm agrosystem, which are related to outputs and thus enable assessment of environmental impact of agro-business management and changes in the management. The basic and most frequently used indicators are balance of nutrients (N, P) and organic matter, and energy balance (Halberg *et al.*, 2005; van der Werf, Petit, 2002; Payraudeau, van der Werf, 2005; Goodlas *et al.*, 2003; Tellarini, Caporali, 2000). The assessment of pesticide use and agrosystem biodiversity is also included (Bockstaller *et al.*, 1997; Eckert *et al.*, 2000; Häni *et al.*, 2003).

According to indicator definitions mentioned e.g. by Bockstaller and Girardin (2003), its major function is to offer:

1. Information (often simplified) about the complex system (e.g. agroecosystem) or an immeasurable criterion (e.g. biodiversity, sustainability etc.);
2. Decision support, which helps to achieve the determined objectives, for example sustainability of a given agrosystem.

Concerning the character of information which the indicators offer, the most frequent is OECD (1999) classification into the indicators of pressure, state and response. The first two types of indicators are in practice used for the assessment of farm management.

Indicators can be the result of a series of measurements, calculated characters or they can be based on expert systems. At least two types of indicators can be distinguished (Girardin *et al.*, 1999):

- Simple indicators based on measurements or estimation (e.g. using a model) of an indicative variable;
- Composite indicators which are obtained by aggregation of several variables or simple indicators (Bockstaller, Girardin, 2003).

Several indicators are not aimed to predict the current impact, but to offer information about the risk or potential impact (Halberg, 1999). Indicators can also inform about the procedure in attaining political goals (Comission of European Communities, 2006). Thus, indicators can signalize both positive and negative trends. Some of the indicators are focused on inducing alarm, in the sense that they should offer information about a negative impact, even before it actually occurs.

Users

The identification of end user and the definition of practical objectives of the indicators have been emphasized as the necessary steps of their development by several authors (Girardin *et al.*, 1999; Bockstaller, Girardin, 2003; Bockstaller *et al.*, 2008).

Two major groups of users, who place different requirements on the indicators, can be differentiated. One group is the administration and politicians, which are increasingly pressured towards the restoration of impacts of agricultural activities on the environment and creation of environmentally fair policy for agriculture. The second group of users is farmers (and also advisors) who have a decisive influence on the quality of agricultural countryside. Here, the indicator methods can be used to find the weak points of management but also the potential for improvement. These results can be further used at farm eco-audits (Meyer-Aurich, 2003).

The form of result

Some methods report the indicator result in the original units and others convert the result to a relative figure, which serves as a grade, points or score. It can be a value which expresses:

1. The risk or impact in the range from 0 to 1 (Hülsbergen, 2003), from 1 to 10 (Eckert *et al.*, 2000) or from 1 to 5;
2. Impact on the environment in the range from 0 to 10 (Bockstaller *et al.*, 1997);
3. The scale between negative and positive values, e.g. –3 to +3 (Rigby *et al.*, 2001) expressing negative and positive effects.

The selection of scale, evaluating conversion functions and the range of values are subjective and eventually depend on individual considerations, and therefore need discussion, which is important for effective communications. In any case, the selection should be explicit and transparent (Bockstaller *et al.*, 2008).

Determination of threshold value

According to Riley (2001), indicators are defined as "observations related to their corresponding reference point". Bockstaller *et al.* (2008) further reported that this reference value helps the user to interpret the raw value of the variable, calculation or measurement, e.g. to evaluate whether a certain action is environment friendly or not. The reference value can be implicit. For example, the reference value for indicators of nitrogen balance is for many users zero as they assume that the system has attained a stable status. But such implicit value is often the object of criticism due to a lack of scientific arguments. The reference value can be a threshold value, e.g. a critical amount of soil pollutant, a standard, e.g. for the indicator of water quality with regard to nitrates and pesticides in the EU, or an objective which is expressed absolutely or relatively. In many instances, the reference value is not determined by scientists but is established by stakeholders. It should be the result of interactions between scientists and politicians, according to Bockstaller *et al.* (2008).

Therefore, determination of optimal target value can differ according to the region, and can also be influenced by political impacts.

Space and time dimension of assessment

The boundary for assessment can be the boundary of a farm, a plot or soil surface. With regard to time, the most usual standard is a year, however, methods based on models also use month step (SALCA) or the main stages of the growth cycle (Indigo) (Bockstaller *et al.*, 2006). But it is necessary to differentiate between the level of input data determination and the level of output data application. Most often, the input data are at plot level and the outputs are aggregated up to farm level. However, this can lead, in the case of large farms, which are frequent in the Czech Republic, to the loss of information about system heterogeneity.

Review of indicators

In agriculture, the ecological aspect of sustainability is often considered as bio-physical or agronomical. Thus, consideration includes both impact on the environment and evaluation of management of system leaning on biological basis.

Basic indicators at a complex assessment of bio-physical management sustainability are nutrient management, organic matter management, and energy balance, basic assessment of the crop protection system as well as agrosystem biodiversity and soil protection. Therefore, further review is focused on these spheres.

Due to a practical feasibility of assessment, input data should only include current agronomical reports and eventually basic characteristics of the locality including information about soil (BPEJ), character of terrain relief etc.

The analysis of nutrients is most frequently oriented to N, and less frequently to P, though agriculture can significantly contribute to eutrophication of water ecosystems. Potassium is mostly ignored. It is not generally a limiting element for water quality but is important for a long-term soil fertility and production quality (Öborn *et al.*, 2005). Moreover, the interest in optimization of P and

I: *List of indicators of N balance*

Indicator	Calculation	Input data	Example of methods
Balance (kg.ha^{-1})	Difference of all N inputs and amount of N going away in products (corrected for change of supply)	● All inputs ● Yields ● N content in production	REPRO, DLG, KUL/USL, KSNL
Efficiency of N use N (%)	(inputs – outputs) /outputs * 100%	● All inputs ● Yields ● N content in production	REPRO, EMA
Risk of emissions	Potential model N loss minus effect of measures on loss reduction	● Fertilizer inputs ● Crop ● Soil type	Indigo, SALCA, REPRO
Risk of leaching	Percentage from N surplus based on balance corrected for inevitable losses and effect of management	● Fertilizer inputs, Crop, soil type ● Soil tillage	EMA

K balance is substantiated by the fact that these nutrients originate from limited, non-renewable resources (Bassanino *et al.*, 2011).

Balance is the basis of indicators which deal with nutrients. In all three nutrients, it is based on the same principle of differences between inputs and outputs (Commission of the European communities, 2000; OECD, 2001; Bassanino *et al.*, 2011). However, in nitrogen, more possible inputs can be considered, as well as more ways of its changes and losses. From this viewpoint, different methods are differently detailed, and indicators from a simple balance, which does not discriminate the ways of losses, up to specialized indicators of a particular type of losses or simple models are used. The basic hypothesis in the case of N is that a positive balance i.e. the surplus enables estimation of potential N losses (Bockstaller *et al.*, 2006).

The list of basic indicators concerning nitrogen is shown in Tab I, these for phosphorus and potassium in Tab. II.

The balance of organic matter is also based on the differences between inputs and loss of soil organic matter by mineralization. The level of mineralization depends on the grown crop, intensity of soil tillage and soil quality (Jurčová, Bielek, 1997), which are taken into account in different extent. The established equivalents with a defined content of carbon and nitrogen are often used for the expression of organic matter level (Humuseinheiten – HE (Hülsbergen, 2003); or t Reproduktionsfähige organische Substanz – t ROS (Eckert *et al.*, 2000)). In the Czech Republic, it is most frequently dry matter of organic substance or the amount of oxidisable carbon. The list of indicators is presented in Tab III.

Energy assessment is a significant objective indicator of efficiency of agricultural production (Neudert, 1998; Pospišil, Vilček, 2000). The advantage of this approach is that different forms of inputs can be reversely conveyed to the same units (Christen, O'Halloran Weitholtz, 2002) and different kinds of production and greatly different ways of production can objectively be compared (Refsgaard *et al.*, 1998; Halberg, 1999; Tellarini and Caporali, 2000). Different methods can be used for the calculation of plant production energy balance depending on the objective of the analysis performed. The methods mentioned in the literature differ in spatial and time limitation of system boundaries, in flows of substances and energy, which are taken into account, and in energetic equivalents established for these flows (Jones, 1989; Kalk and Hülsbergen, 1997).

The list of indicators of energy balance is presented in Tab IV. The base of all indicators is quantification of inputs of fossil energy, especially the direct one, characterized by consumption of fuels. Some of the methods supplement even the energy needed for production of inputs into plant production. Other methods then use the obtained inputs for calculation of balance (diference between inputs and outputs) or efficiency (proportion of inputs and outputs) of energy. Consumption or energy balance can be related to the area or production unit.

The indicator of assessment of the use of pesticides (see Tab. V) is sometimes included into the complex methods but frequently builds an independent

II: *List of indicators of P and K balance*

Indicator	Calculation	Input data	Example of methods
Balance (kg.ha^{-1})	Different between the applied dose of nutrient and dose going away in products	• Fertilization • Content in production	KUL/USL, KSNL, REPRO
	Comparison of applied dose in fertilizers and recommended dose	• Fertilization • Soil characters, crop rotation	Indigo (P only)
Category of soil supply with nutrients	Direct measurement – soil analysis		KUL/USL

III: *List of indicators of organic matter balance*

Indicator	Calculation	Input data	Example of methods
Organic matter balance (HE or t ROS.ha^{-1})	Difference between input of organic matter (in fertilizers and plant residues) and its loss (according to effect of crops)	• Organic fertilization, straw management • Crop	KUL/USL, KSNL, REPRO, DLG
Supply of organic matter (%)	Loss / inputs of organic matter	• Organic fertilization, straw management • Soil type	REPRO
	Average dose of organic matter in the last 4 years / recommended dose of organic matter based on content of clay and CaO in soil	• Organic fertilization, straw management • Soil type, content of clay particles, CaO content	Indigo

IV: *List of indicators of energy balance*

Indicator	Calculation	Input data	Example of methods
Consumption of fossil energy (GJ.ha^{-1})	Consumption of direct and indirect energy (energy for production of machines and pesticides, eventually fertilizers)	• Mechanized work operations and their parameters, inputs of pesticides or fertilizers	Indigo, REPRO
	Consumption of direct energy	• Mechanized work operations and their parameters	KUL/USL
Energy balance (GJ.ha^{-1})	Difference of energy outputs in products and inputs (consumption) of energy	• Mechanized work operations and their parameters, inputs of pesticides or fertilizers • Crop yields	REPRO, DLG, KUL/USL, KSNL
Energy efficiency	Proportion of energy outputs in products and inputs (consumption) of energy	• Mechanized work operations and their parameters • Inputs of pesticides or fertilizers • Crop yields	REPRO
Energy need	Combination of energy consumption in factual form (Driving force) and efficiency of its use and independence of a farm with regard to energy sources (State).	• Consumption of energy, impacts on the environment • Consumption of energy per worker, level of independence with regard to energy	RISE

method. In this case, there is the most expressed variance from simple indicators (of the type of average applied dose of active substance per hectare) to complex models which also include persistence period in the environment, toxicity of substances for particular components of the environment and groups of animals. All indicators for this area use some form of score (Reus *et al.*, 2002). Relatively great number of indicators also includes the component assessing the system of plant protection or non-chemical ways of protection. Indicators which only assess this aspect also exist.

Diversity of an agricultural system (see Tab. VI) can be considered from several points of view. This can be a diversity of groups or plant species grown in a given year, plot size diversity (Eckert *et al.*, 2000) or a proportion of ecologically valuable area within the farm acreage (Eckert *et al.*, 2000; Häni *et al.*, 2003). However, the term can also be comprehend differently as the diversity of farming system concerning the frequency and date of work operations, diversity in soil cultivation, ways of harvest etc. (Zapf *et al.*, 2009). Thenail *et al.* (2009) and Leteinturier *et al.* (2006) assess also crop rotation, which has influence on both the stability of agrosystem, enabling reduction of inputs of plant protection preparations, and on landscape diversity.

Quite often, this area is comprehended from the point of view of diversity of non-production free living organisms. Actually, it is the original point of view. For example Manhoudt *et al.* (2005) differentiate biodiversity in crop stand, in field margin stripes, and in stands of line landscape elements.

In the Czech Republic, information value of indicators which assess spatial and species diversity of the grown crops and proportion of ecologically valuable areas is decreased due to the fact that land tenure of enterprises is not compact but penetrates to plots of other owners.

The most frequent field of soil protection assessment is its erosion and compaction. Some authors are also interested in chemical changes characterized by soil reaction changes (Eckert *et al.*, 2000). However, this requires soil analysis; therefore it is indirectly assessed through soil liming (Lewis, Tzilivakis, 1998). For the estimation of soil erosion risk, several procedures have been developed, independently to sustainability assessment, which are widely used and included in the methodologies for a complex assessment of agricultural enterprises. This is for example the ABAG method (Germany) or USLE (USA). These methods have been adjusted so that they require relatively large amount of input data but these are easily available. The methods assessing the risk of soil compaction require quite detailed information about the mechanization used in each plot (Rücknagel *et al.*, 2007; Lebert *et al.*, 2007). The indicators are listed in Tab VII.

Most of the complex methods use relatively simple procedures of indicator calculation for better feasibility. It appears generally that risk of errors

V: *List of indicators assessing the use of pesticides*

Indicator	Calculation	Input data	Example of methods
Index of treatment	Applied dose / approved dose Treated area / area of farm land in an enterprise	• Pesticide treatment in particular plots including the dose	REPRO
Intensity of pesticide use (€.ha^{-1}.a^{-1})	Proportion of the used pesticides in an enterprise to the average for a given region	• Amount of applied preparations for plant protection	KUL/USL, KSNL
I_{PHY}	Combination of amount and persistence of pesticide, its penetration to and deposition in the soil and water environment, and air, and its toxicity in the above environments using Fuzzy logic	• Date, dose, preparation • Crop	Indigo
Plant protection	Combination of crop rotation, amount of active substance and its danger (Driving force) on one side and the system of plant protection and level of management (State) on the other side	• Crop rotation, amount of active substances, potential risk of the used substance • System of plant protection, education, equipment, existence of waiting periods and buffer zones	RISE
	Amount of active substance * toxicity	• Used preparations and their amounts	SALCA
Proportion of untreated area (%)	Proportion of untreated area to the total area of cultivated soil in an enterprise	• Untreated area	REPRO
Limitation of risks	Assessment of good agricultural practice (e.g. hand weeding, waste management)	• Used non-chemical ways of plant protection	KUL/USL, KSNL

VI: *List of indicators of system diversity*

Indicator	Calculation	Input data	Example of methods
Diversity of cultures	Indirect assessment through diversity of arable crops and plot size	• Crop structure, their distribution in plots, plot size	Indigo
Diversity of crop species	Shannon index	• Total area of individual crops in a given year	KUL/USL, KSNL, REPRO, DLG
Biodiversity	Combination of ecological quality of areas and plot size	• Zones of ecological compensation, plot size (of low diversity) • Area of high diversity	RISE
Mean size of plot (ha)	Median	• Acreage of plots	KUL/USL, REPRO
Proportion of ecologically valuable areas (%)	Proportion of agriculturally unemployed ecologically valuable areas to the enterprise cadastre area	• Acreage of agriculturally unemployed ecologically valuable areas	KUL/USL, KSNL, REPRO
Proportion of soil long term in rest (%)	Proportion of set aside land to the total cultivated soil area within the enterprise	• Acreage of set aside areas	REPRO
Proportion of chemically untreated area (%)	Proportion of untreated area to the total cultivated soil area within the enterprise	• Acreage of untreated areas	REPRO

VII: *List of indicators of soil protection level*

Indicator	Calculation	Input data	Example of methods
Potential of erosion	ABAG method	● Soil type, frequency and intensity of precipitations, length and slope, crop, applied anti-corrosion measures	KUL/USL, KSNL
Risk of compaction	Comparison of soil resistance to soil compaction and pressure generated by the machinery used	● Soil type ● Work operation, used machinery	KUL/USL, KSNL
Soil pH	Direct measurement		KUL/USL, KSNL
Soil management	Combination of intensity of fertilizer and pesticide use and soil load by machinery (Driving force) on one side and soil status (State) on the other side	● Soil contamination with fertilizers and pesticides, effect of mechanization ● Soil state (a) nutrient supply, C content, pH, humidity, salination (b) erosion	RISE

at using a method increases with its complexity. Equally, the demand for input data is increasing (Bockstaller *et al.*, 2006). However, the problem is a non-point (locally specific) determination of limit values of the indicators because these depend on soil heterogeneity within fields, on field conditions, and are also influenced by production orientation of an enterprise. When assessing the use of indicators by agricultural enterprises, van der Werf and Petit (2002) came to the following conclusions:

- Indicators based on assessment of environmental impacts of management are preferred to the indicators based on evaluation of farmer practices, as the link with the objectives is direct and the choice of intervention is left to the farmer;
- Indicators allowing expression of the impact on unit area as well as on production unit are also preferential;
- The result in the form of values is preferred to some form of points;
- If possible, scientifically based threshold values should be defined for indicators.

From our experience we would like to add that it is useful to:

- Keep and analyse data not only on the level of farm, but also of individual plots;
- Evaluate results regarding defined threshold values using some form of points which helps clear interpretation;
- Adjust required input data to standard records available on farms.

SUMMARY

The paper reviews the basic indicators for arable farming sustainability assessment, analyses depth of detail, way of calculation, input data intensity, expression of the result and its evaluation. Focus is on indicators of nutrients, organic matter and energy balance, use of pesticides, soil protection and biodiversity, which we consider as basic issues from environmental and agronomic viewpoint. It is important to find a compromise between exactness of calculation and feasibility of input data. It also appears that risk of errors at using a method increases with its complexity.

According to experience from practice, indicators based on assessment of environmental impacts of management are preferred to the indicators based on evaluation of farmer practices, although the need for input data is higher. The link with the objectives for this kind of indicators is direct and the choice of intervention is left to the farmer. Indicators allowing expression of the impact per unit area as well as per production unit are also preferential. Keeping the result in the form of values is desirable but appraisal regarding defined threshold values using some form of points helps clear interpretation. In conditions of large farms is useful to keep and analyse data also on plot level not to lose information on system diversity.

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Adresa:

Ing. Soňa Valtýniová, prof. Ing. Jan Křen, CSc., Ústav agrosystémů a bioklimatologie, Mendelova univerzita v Brně, 613 00 Brno, Česká republika, e-mail: xvaltyni@mendelu.cz