FROM THE LAND USE EVALUATION TO A QUANTITATIVE INDICATOR OF SUSTAINABILITY

VON DER LANDNUTUNGS-EVALUIERUNG ZU EINEM QUANTITATIVEN INDIKATOR DER NACHHALTIGKEIT

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Evaluation of agricultural land for planning purposes has been done traditionally on the basis of its use capability through the application of methodologies based on soil survey and interpretative soil classification. It is now becoming important to evaluate agricultural land also with respect to their environmental performance. In this paper we present a methodology for evaluating the agricultural land use, rather than land capability, based on interpretative soil classification, from which an indicator of sustainability is derived. The evaluation methodology was applied in different sites in Germany and Brazil, and showed good applicability under different site characteristics. The results also confirm the main assumptions adopted by the methodology as well as indicate its potential use in agricultural landscape planning strategies.

Keywords: land use; interpretative soil classification; sustainability; indicator

INTRODUCTION: IDENTIFYING THE QUESTION

Traditionally derived from soil survey and interpretative soil classification, evaluation methodologies of land capability have been generally used to explain and predict the potential use of land. Because of its broad application and the various research fields that it involves, land evaluation grew to become an independent research field. An extensive literature review on this subject is not presented here but it can be found elsewhere (see, for example, van Diepen et al., 1991).

Our interests here are concerned mainly to the basic and central features of these methodologies and how they can be further improved or even how they must be modified in order to be an adequate approach to further evaluate and quantify
sustainability of land use. In short, we are thinking here about the complex subject of ‘sustainability’, in particular in Agriculture, and how one approach to characterize it quantitatively can be derived from land use evaluation methodologies.

The existing evaluation methodologies of land capability are based, to a minor or major extent, strictly on survey and interpretation of natural characteristics of land, such as soil properties and characteristics like texture, fertility, depth, etc, and their significance for farming systems. Frequently, these methodologies only consider to which crops or farming systems the selected site or soil characteristics and properties are more or less suitable. As a result, the physical characteristics of land almost always determine *a priori* which kind of land use should be considered appropriate (the central idea of land capability). These classical evaluation methodologies do not consider the possibility that a suitable land use can also arise through a proper man-landscape interaction, despite the site characteristics. Then, what an evaluation methodology should evaluate is whether the goals of the human actors (e.g. the farmers) were adequate or not with regard to the site characteristics that support them.

But why has this kind of interpretative soil classification and evaluation of land capability predominated? What are the consequences arising from land use evaluation methodologies with these characteristics? From an epistemological viewpoint, these evaluation methodologies are oriented by the long tradition of classical dynamics, one of its main characteristics being the effort to recognize regularities from which natural laws can be derived, becoming the key for knowledge. In the evaluation methodologies of land capability, the natural characteristics of land are the ‘regularities’ which define the ‘laws’ on which the evaluation is based. As a consequence of this epistemological perspective, the success or failure of a specific land use strategy depends (logically) only on the site characteristics. In this way, man is not evaluated, but it is transformed into a privileged observer of the natural world which he describes, models and even evaluates. Man is no longer a part of his own real world and therefore did not need to be evaluated.

However, recent achievements in the understanding of natural phenomena show us that in nature interactions and their effects play an important role in the emergence of macroscopic structures (Prigogine et al., 1991). This understanding has deep implications, meaning that the kind of the relationship man-nature defines the modality of interactions present in human determined macroscopic structures like agricultural landscapes. It means also that man must be reintroduced in the world from which he was isolated by the influence of the classical dynamics. Now, after being reintroduced in nature as a part of it, man must also be evaluated in the evaluation methodologies of land use. In the following two sections we will present an approach on land use evaluation that attempts to take this new epistemology into consideration.

In order to get back to the point addressed earlier we would like to raise some questions: Is it possible to ‘measure’ sustainability? What should be understood as ‘sustainability’? How must evaluation methodologies be constructed and which features they must have in order to assess sustainability of farming systems? What is an ‘indicator of sustainability’? Even though our aim here is not to discuss and present answers for all these questions, some important insights can be taken from the considerations of Hansen (1996) and of Werner and Bork (1998). We consider of fundamental importance to achieve an integrated measure of sustainability of farming systems. We hope that through an aggregated index or indicator of sustainability we
should be able to compare different land use strategies, identifying their constraints, as well as pointing out other utilization possibilities. However, we should keep in mind that some constraints may emerge by summarizing all the information obtained by the application of an evaluation methodology of land use by using a single index. Therefore, our concern is to develop an index allows us to talk about the ‘degree of sustainability’ of a specific land use and by extension, of a selected region. Or, in other words, how to construct an ‘indicator’ of sustainability from such evaluation methodologies of land use.

Therefore, the objective of this paper is to discuss an alternative evaluation methodology of land use, presenting a brief summary of the approach on which this methodology is based, as well as how we can design an indicator of sustainability that tries to attend the questions formulated above.

PRESENTING A NEW APPROACH

In the following two sections we briefly introduce the main features of the evaluation methodology of land use proposed by D’Agostini and Schlindwein (1996), as well as their proposed indicator of sustainability, which was used in the present work. These authors aimed to develop an integrated and quantitative measure of sustainability that can be objectively employed to compare different strategies of agricultural land use. Their intention was not only to overcome some of the constraints of other methodologies, and pointed out by authors such as Hansen (1996), but also to introduce an evaluation methodology based on actual land use rather than on land capability.

The challenge of the approach of D’Agostini and Schlindwein (1996) was to identify a representative indicator of sustainability of the man-agricultural landscape relationship. Despite the fact that until their work we could not identify in the literature other indicators for the sustainability of this relationship, we can cite some important antecedents to some extent developed to evaluate sustainability. Among them we can include the several interpretative soil classification systems. Since these systems aim to evaluate and to orient for proper destination and management of agricultural soil, they surely also look for the sustainability of the adopted use, even though not explicitly.

Therefore D’Agostini and Schlindwein (1996) intended to obtain an indicator of sustainability for the man-agricultural landscape relationship departing from an adequate interpretative soil classification system. In other words, starting from a strict analysis of the exploitation relationship which man establishes with agricultural soils, they intended to achieve an indicator of sustainability valid for the whole environment under evaluation.

It is apparent from the foregoing discussion that from the viewpoint of the approach of D’Agostini and Schlindwein (1996) sustainability must be regarded as an emergent property of the system which can not be accounted by a single parameter measured either in their biotic or abiotic compartments. So sustainability is intended to be related to a specific man-nature relationship and not to a specific unchanged environmental condition. Therefore, in this paper we will refer to the sustainability of farming systems or, to express it in more general terms, to the sustainability of the man-agricultural landscape relationship.
Central to the approach of D’Agostini and Schlindwein (1996) is the recognition that farmers use land on the basis of several different criteria, which may include economic, technical, as well as ecological aspects. Definitely, it is the ‘ranking’ or the hierarchy of these criteria, constructed on the basis of the farmers’ values, that will decide about the characteristics of the farming system (and also on its environmental performance, an evidence that was also commented by Niels et al., 1994). But the evaluation methodologies are developed (more or less intuitively) also on the basis of a criterion ranking that mostly takes in consideration some pre-selected requirements. Often, the most important criterion for evaluation purposes of land use is the one directly related to environmental conservation. However, for the land users, this is not always the most important criterion. They are mainly interested in the economic return of their farming activities, and consequently the economic criterion is generally the most important one for them. As we can perceive from these different perspectives about the relative importance of different criteria, it is not uncommon that some controversies arise between those who recommend and carry out an evaluation methodology and those who are using agricultural land. However, the controversy relies on the hierarchy of the selected criteria and not on the criteria itself.

The significance of the criteria hierarchy in defining the characteristics of farming systems, is that an indicator of suitable land use should not be limited to the inventory of objective parameters and data survey, but it must also allow the man to be assessed in his subjective behaviour in land use (by the influence of a criteria hierarchy) through proper expert judgement. The assumption is that only through a direct comparison in land use, which an indicator can make possible, farmers will change and reorient their behaviour toward a new relationship with agricultural landscapes. Therefore, it is desirable and necessary to develop an evaluation methodology which simultaneously and equitatively takes into consideration the criteria determining a specific agricultural land use as well as the man, who decides the type of land use, as a part of the evaluation process. As a result, the interpretative soil classification system of D’Agostini and Schlindwein (1996), from which they derived the evaluation methodology of land use, is organised on the basis of a hierarchy of criteria.

Frequently, evaluation methodologies of land use based on interpretative classifications are criticized with the argument that interpretations are ephemeral in time, and that reinterpretations are needed as changes in technology or in land use occur (Ramalho Filho et al., 1978; van Diepen et al., 1991). Trying to overcome the restrictions imposed by such changes and considering that situations can be found where different technological levels are coexisting side by side at a given time, D’Agostini and Schlindwein (1996) have introduced the concept of ‘entropic cost’ in their evaluation methodology. By ‘entropic cost’ they understand the fraction of the energetic demand of a productive process in dissipative structures which can not be converted into the desired product. The entropic cost is related to all energy flows involved in the productive process and not only to the direct or apparent flows. The entropic cost expresses therefore a relative and indirect measure of the energy expenditure of an open farming system, including all the energy input necessary to overcome the deleterious effects of the kind of agriculture being practiced. Although the concept of entropic cost results from an analogy with the concept of entropy expressed by the second law of thermodynamics, it should not be considered as equal or similar to entropy which, as a property of the system, has well defined physical unities.
To some extent, the concept of entropic cost embodies all those costs that Schaller (1993) called ‘hidden costs of modern industrialized farming’. It includes not only the costs related to environmental problems associated with conventional agriculture but also the costs related to the social and psychological impacts of this kind of agriculture. The entropic cost is, therefore, an attempt to consider demands that can not be evaluated in monetary or even in direct energy terms. By introducing of this concept, the authors are also considering some of the issues appointed by Addiscott (1995), who proposed the ‘Principle of Minimum Entropy Production’ as a useful framework within which sustainability should be discussed.

The central task of the approach presented above can be described as an attempt to reintroduce man in the process of land use evaluation, forcing him to abandon his condition of ‘privileged observer’ of nature to assume a ‘protagonist’s’ role in a specific land use system. If we are to reintroduce the man in this process, we have to evaluate the characteristics of the man-landscape relationship, which he determines, rather than the characteristics of the natural environment alone, over which he normally has not influence.

THE EVALUATION OF LAND USE

The methodology

The evaluation methodology of land use proposed by D’Agostini and Schlindwein (1996), developed from the approach presented above, is an interpretative classification of land use (based on soil attributes and management characteristics) from which an indicator of sustainability is calculated. The diagram of Figure 1 gives an overview on how this methodology is organized. We present here only a summary of the main characteristics of it.

The methodology is organized in two complementary parts:

(a) Part 1 (left side of Figure 1): the interpretative classification of land use – parcel-referenced
(b) Part 2 (right side of Figure 1): the calculation of the indicator of sustainability – farm- or region-referenced

Part 1: The interpretative classification system

Four steps must be followed in the first part of the method applied to field parcels:

STEP 1 Survey on characteristics of management of the farming system, necessary to estimate the ‘entropic cost’. Obviously, we are not able to quantify the entropic cost of a farming system in absolute terms. However, a relative entropic cost can be estimated by comparing productive processes with very different management characteristics, resulting in different entropic costs. Therefore, in the methodology the entropic cost is estimated in relative terms (and not in absolute physical unities). It takes into consideration the components of management of the productive process in farming systems, especially those related to the management of the environment (mechanization, soil coverage, runoff control) and inputs (seeds and fertilizers, pesticides). General aspects of different
management present in different farming systems are summarized in a table with their respective relative entropic costs, ranging from 1.0 to 5.0.

**STEP 2** Weight of the classification criteria according to the estimated entropic cost. The classification criteria (see step 3 below) assume different relative importance according to the entropic cost of the productive process. The entropic cost can assume values between 1 (one) and 5 (five), and is then classified into three categories: low (from 1.0 to 2.3), mean (from 2.4 to 3.7) and high (greater than 3.8) entropic cost. These groups determine the weight of the classification criteria. At higher entropic costs the conservationist criterion is the most important; at low values of the entropic cost the edaphological-economic is the most important one.

**STEP 3** Survey on soil attributes and classification of land use into classes. Following the assumptions presented earlier, the evaluation methodology of D’Agostini and Schlindwein (1996) is organized on the basis of three classification
criteria: a conservationist criterion, an operational criterion and an edaphological-economic criterion. For each criterion a set of soil (or site) attributes was selected (see below). These criteria, with their attributes, were then arranged into five classes and organized in a table according to preferential agricultural land uses. This classification implies that the site attributes are evaluated in relation to their significance for the preferential land use, and therefore their significance can change from one land use to another. The field parcels are then classified, according to soil or site attributes, into five classes (from 1 to 5), class 1 being the best. The classification criteria with their attributes are:

Conservationist criterion: Parcel slope;
Operational criterion: Parcel slope, presence of stones, soil depth;
Edaphological-Economic criterion: Soil fertility (Ca, Mg, P), surface soil horizon, soil depth, parcel slope and soil drainage.

STEP 4 Classification according to the man-agricultural landscape relationship and according to categories of land use. The first part of this step is the association or aggregation of steps 2 and 3. The results of this association can also assume numerical values between 1.0 and 5.0. In the second part these values are distributed in five categories (A to E) of land use. An extra category (F) is attributed to all the situations where the land use is other than agricultural or where agriculture is not possible. The category A expresses the best suitability of present land use whereas the category E expresses the worst one.

After this part of the methodology has been completed, it is possible to condense the result in a legend that informs about the actual state of a parcel, as well as indicates other possible uses. Based on the category of land use of individual parcels a color map can be draw for the whole area under evaluation.

Part 2: The calculation of the indicator of sustainability

Based on the results for individual parcels, the farm- or region-referenced indicator of sustainability – the so called IQRM (indicator of the quality of land use) can be calculated. This indicator should reflect the quality with which a given agricultural landscape is being used, and by extent expresses the sustainability of this specific land use. The IQRM is calculated as follows:

$$\text{IQRM} = \sum_{i=1}^{n} V_i A_i$$

where \( n \) = number of parcels being evaluated, \( V_i \) = relative value of the class of man-agricultural landscape relationship for parcel \( i \) (obtained after step 4 of part 1), taken from a table and ranging from 1.000 to 0.000 (\( V_i \) values close to 1.000 corresponds to category A of land use, whereas values close do 0.000 corresponds to the category E of land use), and \( A_i \) = relative area of parcel \( i \). The IQRM-Indicator can assume values between 0 (zero) and 1 (one). Values close to one (1) indicate that the man-agricultural landscape relationship of a specific farming system is near to a sustainable state.
Although the application of this method seems to be time consuming and complicated, it is, in fact, extremely simple, as has been verified in the field. With the aid of a computer program the work can be further facilitated.

The selected study sites

The evaluation methodology presented above was applied to two selected study sites. Site 1 is located at Santa Catarina State, Southern Brazil, while site 2 is located at North-Eastern Germany, in Brandenburg State (see Figures 2 and 3, respectively).

Site 1 is a 975 ha catchment denominated ‘Rio Canela Grande’, in the municipality of ‘Pedras Grandes’ (28°28′ S and 49°14′ W). The climate is humid subtropical with mean annual temperature of 22°C and mean annual rainfall of 1471 mm. The soils in this watershed vary from Inceptisols to Ultisols with granite as predominant parent rock. The farms average 12.5 ha in size and are typically run by families. These farms are also characterized by the diversification of activities, which includes crops as well as livestock. Further description of this catchment can be found in Kleveston (1997). In this site, all the data for the application of the method were collected in 1996.

Site 2 comprehends two close farms denominated ‘Trebnitz’ and ‘Jahnsfelde’ (52°21′ N and 54°48′ E). The climate is humid-semicontinental with mean annual temperature of 9°C and mean annual rainfall of 532 mm. The study site is located on a former glacial landscape with very heterogeneous soils depending on the distance to the endmorane of

FIGURE 2 Location of study site 1 at Santa Catarina State, Brazil.
the ‘Frankfurter Stadium’ of the Weichsel-(Wisconsin)-Ice Age. The soils are Inceptisols in the loam areas and Entisols in the sandy areas. The whole area being evaluated at Trebnitz is 842 ha. In this farm we can find crop cultures, dominated by cereal crops (50%) and sunflower (20%), as well as forage and corn (20%) for cattle feeding. This farm practices an ‘integrated farming’ system, in which the farmers adopt practices to reduce the unwanted ecological effects of agricultural production. The Jahnsfelde farm, an ‘ecological farm’, has 689 ha of agricultural farmland as well as animal production (cattle and pigs). The crop cultures, produced without pesticides and synthetic fertilizers, are dominated by cereal crops (about 40%) and 30% of the whole farmland is being used to produce forage and corn for animal feeding.

The size and structure of the farms are typical of the north-east Germany, according to the structures present in the former German Democratic Republic. The data from this site are from 1993, taken from existing files.

RESULTS AND DISCUSSION

The results of the application of Part 2 of the evaluation methodology of D’Agostini and Schlindwein (1996) for both study sites are presented in Table I. The results for site 1 were taken from Kleveston (1997). For this site, 50 representative field parcels with a total sampled area of 129.5 ha were evaluated, and the results were extrapolated to the whole area (the ‘Rio Canela Grande’ catchment). The mean entropic cost of the sampled area was 2.77, ranging from 1.10 to 3.80. The mean extrapolated entropic cost for the whole catchment was 2.71. Whereas the IQRM-Index of the sampled area was 0.65 for the whole catchment the extrapolated IQRM-Index presented a value of 0.635.
For the site 2, the whole area of the two farms were evaluated. For the farm Trebnitz, 34 field parcels were evaluated whereas for the farm Jahnsfelde we evaluated 56 field parcels. Although the entropic costs for these two farms differ (2.99 for Trebnitz, ranging from 1.40 to 3.90, and 2.10 for Jahnsfelde, ranging from 1.40 to 3.10), the IQRM-Indexes were the same (0.71). The fact that IQRM-Index for Trebnitz was the same as for Jahnsfelde, despite the much lower mean entropic cost of the later, can be explained on the basis of the different entropic costs (remember step 2 of part 1 of the methodology). At low entropic costs levels, as is the case for Jahnsfelde, the edaphological-economical criterion assumes the higher relative importance. One of the attributes of this criterion is soil fertility, and since the soil fertility condition of site Jahnsfelde is unfavourable, this condition influenced negatively the IQRM-Index. The IQRM-Index for Trebnitz is better than that of site 1, despite its greater entropic cost, due the influence of the site attribute ‘parcel slope’ of the conservationist criterion. The entropic costs for both sites were grouped as ‘mean’ (step 2 of the methodology), but the hilly landscape of site 1 in combination with the inadequate farming practices lowered its IQRM-Index. This was due to the strong (negative) influence on soil conservation (possibly enhancing the erosion rates) of this site.

Even though the number of farms and field situations that have been evaluated until now is reduced, the results indicate that a direct relationship between entropic cost and the IQRM-Index, of the type the lower the entropic cost the higher the IQRM-Index, should not be expected. However, the entropic cost appears to be a good indicator of the environmental impact of the farming system. This can be seen for the farms in site 2. Trebnitz, a farm that has been managed with conventional agricultural practices, has a mean entropic cost higher than Jahnsfelde, a farm which practices ‘organic agriculture’. Also for site 1, where conventional agriculture predominates, the mean entropic cost is higher than Jahnsfelde and it is lower than Trebnitz only because the adopted technological level (mainly machinery), like in most of farms in southern Brazil is lower than in Germany. These results corresponded to our expectation, since the entropic costs should grow from organic to conventional agriculture and with the adopted technological level.

On the other hand, the good IQRM-Index found for Trebnitz, besides its relatively high mean entropic cost, was unexpected. This is a clear evidence of the importance that interactions between site characteristics and management assume when the sustainability of a specific farming system should be defined. This is also a remarkable evidence of the role of man (and not only of the site characteristics) in defining the suitability of a specific land use system, indicating undoubtedly why man must be incorporated in an evaluation methodology of land use.

If we should elect which of the studied sites present the best situation, we would certainly choose Jahnsfelde (the lower entropic cost and the higher IQRM-Index), although the differences between the results are not expressive. Although the results presented here are based on a few case studies, the IQRM-Methodology indicates that a

<table>
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<tr>
<th>Site</th>
<th>Mean entropic cost (range)</th>
<th>IQRM-Index</th>
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</thead>
<tbody>
<tr>
<td>1 (Catchment-Brazil)</td>
<td>2.71 (1.10 – 3.80)</td>
<td>0.635</td>
</tr>
<tr>
<td>2 (Trebnitz-Germany)</td>
<td>2.99 (1.40 – 3.90)</td>
<td>0.71</td>
</tr>
<tr>
<td>2 (Jahnsfelde-Germany)</td>
<td>2.10 (1.40 – 3.10)</td>
<td>0.71</td>
</tr>
</tbody>
</table>
priori ‘organic farms’ are not necessarily more sustainable than traditional farms, as usually thought. Nevertheless, the lower entropic cost of Jahnsfelde indicates that the management characteristics of organic farming systems are more matter-energy conservative. According to the thoughts of Georgescu-Roegen (1977) such systems would maintain for a longer time the accessibility of matter-energy, surely an essential issue concerning sustainability.

The results of the IQRM-Methodology for site 2 were also compared with those obtained with the evaluation methodology being formulated at ZALF (Center for Agricultural Landscape and Land Use Research). The procedure of the ZALF approach is characterized by an ‘ecological (energy) balance’. It uses all the available quantitative information about the direct and indirect energy flows present in an open farming system as well as the potential for waste production and their deleterious environmental effects, such as those caused by CO₂ emissions (for a detailed description see Eulenstein, 1995). The objective was to confront the two methodologies in their basic assumptions since they were conceived under very different contexts while having both the same goal of evaluating land use systems from the viewpoint of their sustainability. The underlying assumption for this comparison is that sustainability is an intrinsic (and emergent) property of a farming system and therefore, at least at some aspects the two evaluation methodologies must provide the same results or should allow similar statements about the ‘sustainability state’ of the farming system under evaluation.

Some of the parameters of the ZALF approach and their correlation to the D’Agostini and Schlindwein’s entropic cost are presented in Table II.

The coefficients of determination \( (r^2) \) are high for two parameters under comparison (entropic cost × energy input; entropic cost × CO₂ equivalent), and moderate for one (entropic cost × CO₂ emission), showing a good approximation between the two methodologies. Especially interesting is the correlation between entropic cost and energy input, which reveals similarity in some of the basic assumptions made in both methodologies, confirming our expectation that the entropic cost would increase with the energy input.

Despite the small number of available results for the application of the methodology of D’Agostini and Schlindwein (1996) so far obtained, our attempt was to bring this kind of evaluation methodology of land use into discussion, rather than present conclusive results about the application of a specific methodology. At a first look the methodology presented may appear not sufficiently objective, but as Bosshard (1997) pointed out, objectivity must emerge as a result of a ‘dialectic cognition process between different poles’. In the approach proposed by D’Agostini and Schlindwein (1996) this

<table>
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<tr>
<th>Evaluation methodology of D’Agostini and Schlindwein (1996)</th>
<th>Parameters of ZALF approach</th>
<th>Determination coefficients ( (r^2) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entropic cost</td>
<td>Energy input</td>
<td>0.8480</td>
</tr>
<tr>
<td>Entropic cost</td>
<td>CO₂ equivalent*</td>
<td>0.8159</td>
</tr>
<tr>
<td>Entropic cost</td>
<td>CO₂ emission</td>
<td>0.6764</td>
</tr>
</tbody>
</table>

*Corresponds to the equivalence of the N₂O + NOₓ emissions.
dialectic process results from the association between site attributes and management characteristics. Only both aspects considered together can define quality of land use. This is also the reason why this approach is so different from the usual land capability approach. The results obtained by the application of the methodology adopted allows decision makers to rank different catchments or land users in relation to their environmental performance. It is also a tool for planning land use at a landscape scale. Moreover, by using this methodology we can monitor the effectiveness of specific and objective measures developed to improve the quality of man-land relationship, often incorporated in public policies designed to promote sustainable rural development.

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References