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Scaling Methodologies in Ecoregional Approaches for Natural Resources Management

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Scale problems in agroecological studies: tension among aggregation levels

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Ecoregional studies are the fifth phase of international agricultural research. Ecoregional approaches that account for differences in biophysical and socioeconomic conditions in different regions are being adopted more frequently. Problems of scale and aggregation/ disaggregation are major issues in various projects on ecoregional methodologies begun in the 1990s.

Tension among aggregation levels and disciplines occurs frequently. Ecoregional studies deal with systems at a high aggregation level and apply three sets of classification criteria: time, space, and the influence of humans. The biophysical potentials of land units within a system can be investigated using crop growth simulation models. At the farm or regional level, production-ecological concepts and insights into socioeconomic characteristics and policies are used to explore land-use potentials. Aggregating information from a lower to a higher level is risky when homogeneity at the lower level is absent. The credo "first calculate, then average" is valid. An interactive approach between the regional and the farm level seems to be more appropriate.

The presence of various aggregation levels and many disciplines in land-use studies may easily lead to misunderstanding, polarization, and, finally, the absence of communication. Some guidelines are proposed to prevent misunderstandings and lack of communication among disciplines and aggregation levels and as a checklist for evaluating case studies on land use.

The increased interest in ecoregional programs and projects is in line with the evolution of national and international agricultural research agendas. In general, five phases of agricultural research can be distinguished. In the first phase, scientists focused on developing new varieties and international research centers were basically breeding institutes. It became rapidly clear that the new varieties could perform well only when appropriate agrotechnologies were used. Thus, we saw in the second phase more interest in irrigation, soil fertility, crop protection, and other agronomic activities. In the third development phase, in the early 1970s, socioeconomic characteristics of farm households were taken into account to fine-tune technologies and interventions to specific needs. Farming systems and participatory research became the buzzwords. The fourth phase witnessed an expansion of research objectives. Productivity-related objectives alone were no longer considered sufficient and objectives such as efficiency became major issues. Increasingly, natural resources management formed the second pillar of international agricultural research.

Ecoregional studies dominate the fifth phase of international agricultural research. It is now recognized that biophysical and socioeconomic conditions vary among regions and ecoregional approaches that account for such differences have been adopted. Research methodologies, however, have not been adjusted and refined accordingly; for that particular reason, various projects were designed to develop new research methodologies in the 1990s. The SysNet project is an example. In these projects, problems of scale and aggregation and disaggregation are the major issues.

Tension among aggregation levels

Tension among aggregation levels and disciplines occurs frequently, partly because of misunderstandings, improper definitions, and the absence of properly defined objectives. In this introduction, I provide definitions of concepts and discuss different objectives of land-use studies in an analysis of real and apparent conflicts among disciplines and aggregation levels.

All ecoregional studies consider systems at a high aggregation level. Crops, or cropping systems, are building blocks in land-use studies for farming or regional systems. Systems are limited parts of reality with well-defined boundaries that are selected on the basis of research objectives.

In all ecoregional studies, land-use systems have to be well defined and based on three sets of classification criteria: time, space, and anthropogenic influences. We can distinguish three types of studies with different objectives: (1) descriptive and comparative studies, (2) explorative studies, and (3) planning studies.

In descriptive and comparative studies, the functioning of a system (e.g., the farm household, a village, or a region) is investigated to understand and explain the current situation and to gain insights into limiting factors in order to predict immediate-future scenarios. In this type of systems analysis, anthropogenic influences are very important driving variables.

Exploratory studies, on the other hand, investigate possibilities and potentials for a particular farm or area in the long run. In studies designed to investigate biophysical land-use potentials based on soil types, climate, and crop characteristics, contemporary human activities and impacts are neglected. Research results cannot be directly translated into farm management recommendations. If that is the research objective, then socioeconomic factors need to be considered and research needs to be of an interdisciplinary nature.

The question of how the selected land-use options can actually be realized is crucial. This is where studies for planning and management purposes become important. Policy instruments play a crucial role in decision-making and in many ways drive land-use changes. Predictive models at various aggregation levels may be very useful in strategic and tactical planning.

It is vital for any study to identify the appropriate level of aggregation, that is, the level that corresponds with the objectives of the assessment. Production-ecological and socioeconomic aggregation levels can be distinguished and possible reasons for tension and conflicts between aggregation level and disciplines need to be identified. An interface between the farm and regional level and various disciplines is also required. Rules and recommendations to prevent tensions and conflicts should be suggested.

Aggregation levels in production-ecological terms

The basis of all primary and secondary production in agriculture is the photosynthesis of plants. Integration of photosynthesis at the crop level (De Wit 1965) enables the quantification of crop performance under diverse circumstances. At this level, various growth factors can be distinguished: growth-defining, limiting, and reducing factors (Fig. 1).

The biophysical potentials of land units within a system can be investigated using crop-growth simulation models. At the farm or regional level, production-ecological concepts and insights can be used to explore land-use potentials. Such concepts are not appropriate, however, for prediction, explanation, and management support. The latter objectives require rather different approaches and models.

In systems analysis, the degree of detail for each of the underlying levels is dictated by the questions posed at the higher levels. If greater accuracy or more quantitative aspects are required at the higher level, more detail is necessary at the lower levels. In dynamic simulation studies, such as crop-growth simulation studies, this need is addressed by using the concept of aggregation level and taking into consideration spatio-temporal characteristics. Many production-ecological studies, aimed at understanding and explanation, require sophisticated crop-growth simulation models. This is unnecessary, however, for explorative land-use studies. The results of sophisticated crop-growth

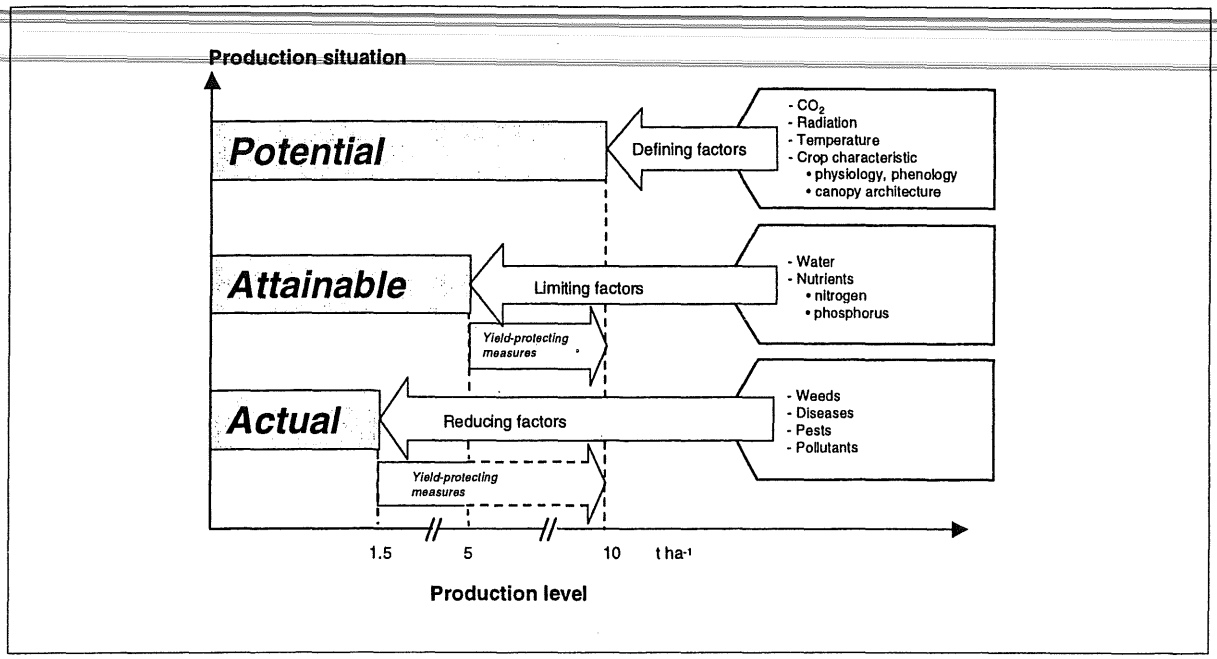

Fig. 1. Schematic overview of different production factors and their corresponding production levels. (Adapted from Rabbinge and van Ittersum 1994.)

simulations are location-specific and cannot be used for quantifying ("guesstimating") yield levels in land units with different characteristics. Land-use studies need relatively simple crop-growth simulations to estimate the potential and attainable crop yields for homogeneous units on the soil and climate map. Time coefficients are usually extensive and the land units for which yields are estimated are of a considerable size. Aggregating information from a lower to a higher level is risky when heterogeneous conditions prevail. I discuss two examples of possible consequences of aggregation in land-use studies below. The first concerns rainfall heterogeneity, which affects quantitative land evaluation (Fig. 2). Because of the curvilinear relation between rainfall and yield, yields are underestimated in the lower rainfall region and overestimated in the higher rainfall region if average rainfall data are used.

The second example shows the possible consequence of aggregating land units in a study based on linear programming (Fig. 3). By aggregating heterogeneous units or subregions and averaging their corresponding input and output data, the extremes in the original data level off. When these aggregated data are used in linear programming (LP), extremes in the optimization model may be less pronounced. Suppose a particular region consists of four land evaluation units of 1,000 ha each. Wheat yields under alternative production practices are 8, 6, 4, and 2 t ha^{-1} for units 1, 2, 3, and 4, respectively. The objective of the optimization in this example is to minimize the area required to produce 10,000 t of wheat. Figure 3 shows the effect of aggregating units 1 and 2 and units 3 and 4. Without aggregation, the minimum area is 1,333 ha (1,000 ha in unit 1 with 8 t ha^{-1} and 333 ha in unit 2 with 6 t ha^{-1}), whereas after aggregation the minimum area is 1,429 ha (1,429 ha in units 1 and 2 with an average yield of 7 t ha^{-1}). In the latter case, the required agricultural area is larger than in the nonaggregated situation.

The examples above clearly indicate that heterogeneity in time and space should be handled with great care. The credo "first calculate, then average" is valid. Heterogeneity and curvilinearity in input relationships should be retained as long as possible and their impacts should be included in evaluation studies.

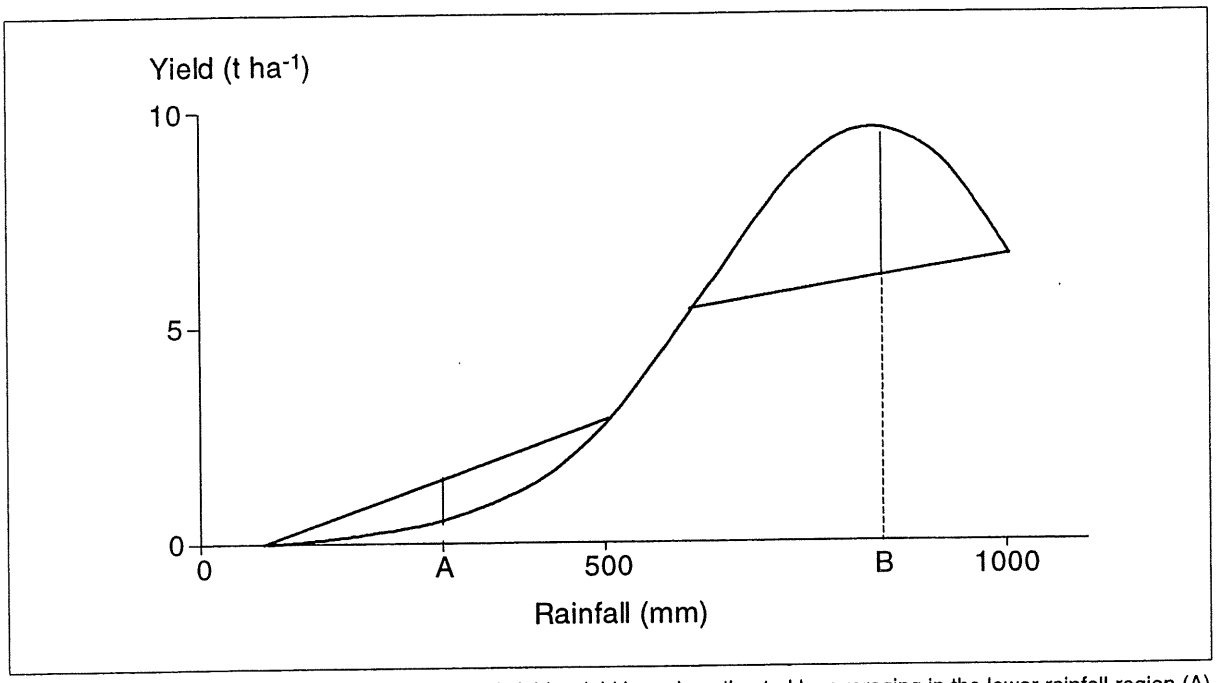

Fig. 2. The influence of averaging rainfall-estimated yields: yield is underestimated by averaging in the lower rainfall region (A) and overestimated in the higher rainfall region (B). Source: De Wit and van Keulen (1987) (Reproduced by permission of Elsevier Science Publishers BV.)

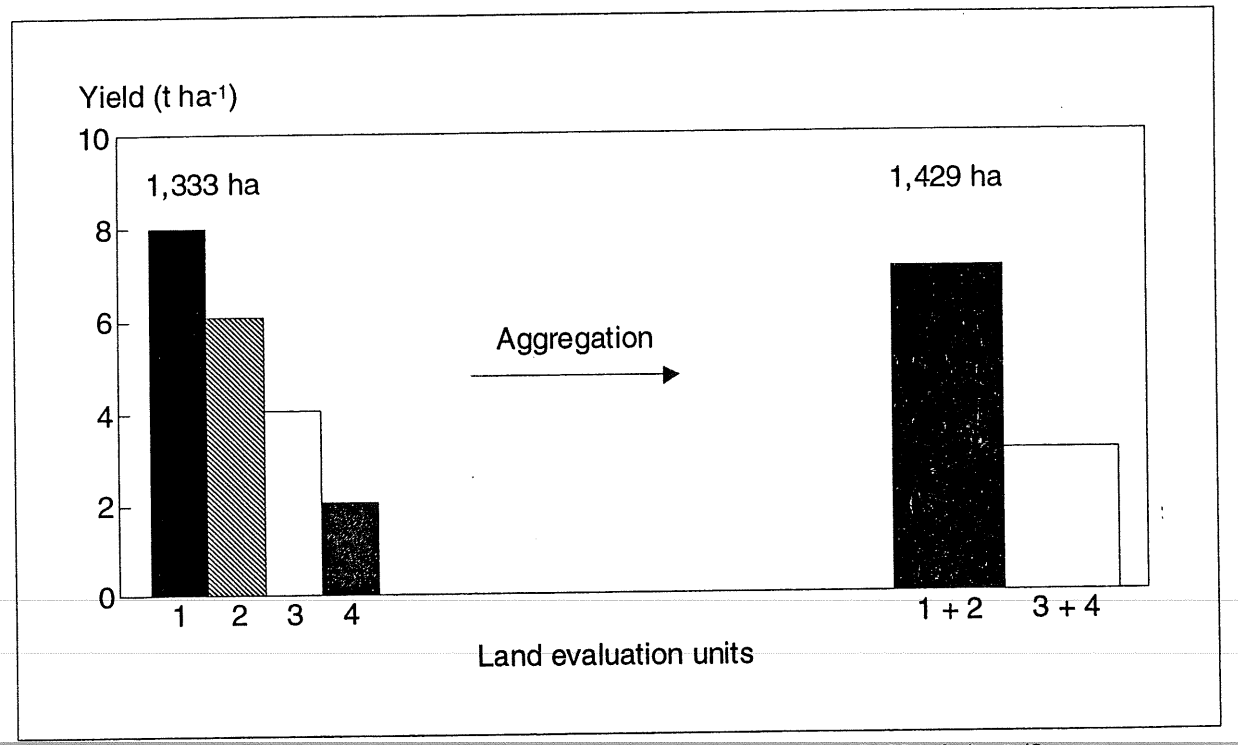

Fig. 3. The effect of aggregation on the minimum agricultural area required to produce 10,000 t of wheat. (Source: unpublished data of R.J. Hijmans and M.K. van Ittersum.)

Aggregation levels in socioeconomic studies

The farm household is usually the lowest aggregation level in socioeconomic studies because it forms the basic decision-making unit in agriculture. By analyzing the characteristics of farm households, it is possible to explore options for change and get a better insight into biophysical as well as economic, socio-cultural, and institutional constraints such as labor shortage, capital scarcity, lack of knowledge, poor infrastructure, or inappropriate policies. Once the functioning of farm households and their farming systems is better understood, recommendations can be outlined to overcome barriers to development.

Regional studies based on aggregated farm household data face some difficulties because the farms are diverse and variations among them can be considerable. In addition, constraints at the regional level may differ from local constraints experienced by individual households. Aggregating farm level data to higher levels can lead to ambiguous results, although they are indispensable to obtaining and maintaining relevance at higher aggregation levels. Therefore, an interactive approach between the regional and farm level appears to be the most appropriate approach. Before substantiating this assertion for explorative studies, I will discuss the tension among the different types of land-use studies and disciplines.

Tension and conflicts among aggregation levels and disciplines

The presence of numerous aggregation levels and disciplines in land-use studies may easily lead to misunderstandings, polarization, and, finally, the absence of communication. Moreover, conflicts and tension often have their origin in unclear research objectives.

Static observations of present land use provide insights into potential future scenarios to a limited extent only. The future is treated as an extrapolation of the past and present, and trend discontinuities are disregarded. Deterministic descriptive studies are sufficient only in short-term socioeconomic studies.

When the future is not treated as the necessary continuation of the past and political or societal objectives are combined with technical possibilities, then explorative instead of predictive studies are required. Such studies rely on plausibility and predictive values as the criteria for measuring quality. Studies describing the present situation are based on the correlation between various variables and characteristics. Causal relationships based on an understanding of basic processes are absent and the actors' behavior is often incorporated and set as an integral part of land use. The actors' behavior should be explicit and choices should be transparent to help in judging assumptions, expectations, and objectives.

Production-ecological studies are usually explorative and deterministic, and based on explanatory models that are integrated in multiple-goal models. In such studies, the relationships are not described but based on a good understanding of the input-output relationships. This may lead to the definition of techniques that are not yet widely used. The feasibility of these techniques is not based on their relationship with the present but on the biophysical and technical limitations and possibilities that determine future potential.

Possible interface between various aggregation levels and disciplines

In explorative land-use studies at the regional level, technical information about land use is confronted with different objective functions in an interactive multiple-goal LP model. Technical information can be derived from crop-growth simulation models, the literature, and expert knowledge, and the objective functions can be distilled from different policy views. These studies, however, do not show the consequences for individual farm households within the region. The relationships with the actual situation and short-term options are absent but may be achieved with a procedure explained in Figure 4.

Regional land-use options set the scene for more detailed studies at the farm level. This can be done in an interactive way and for distinct sets of farming systems. For each set, explor-

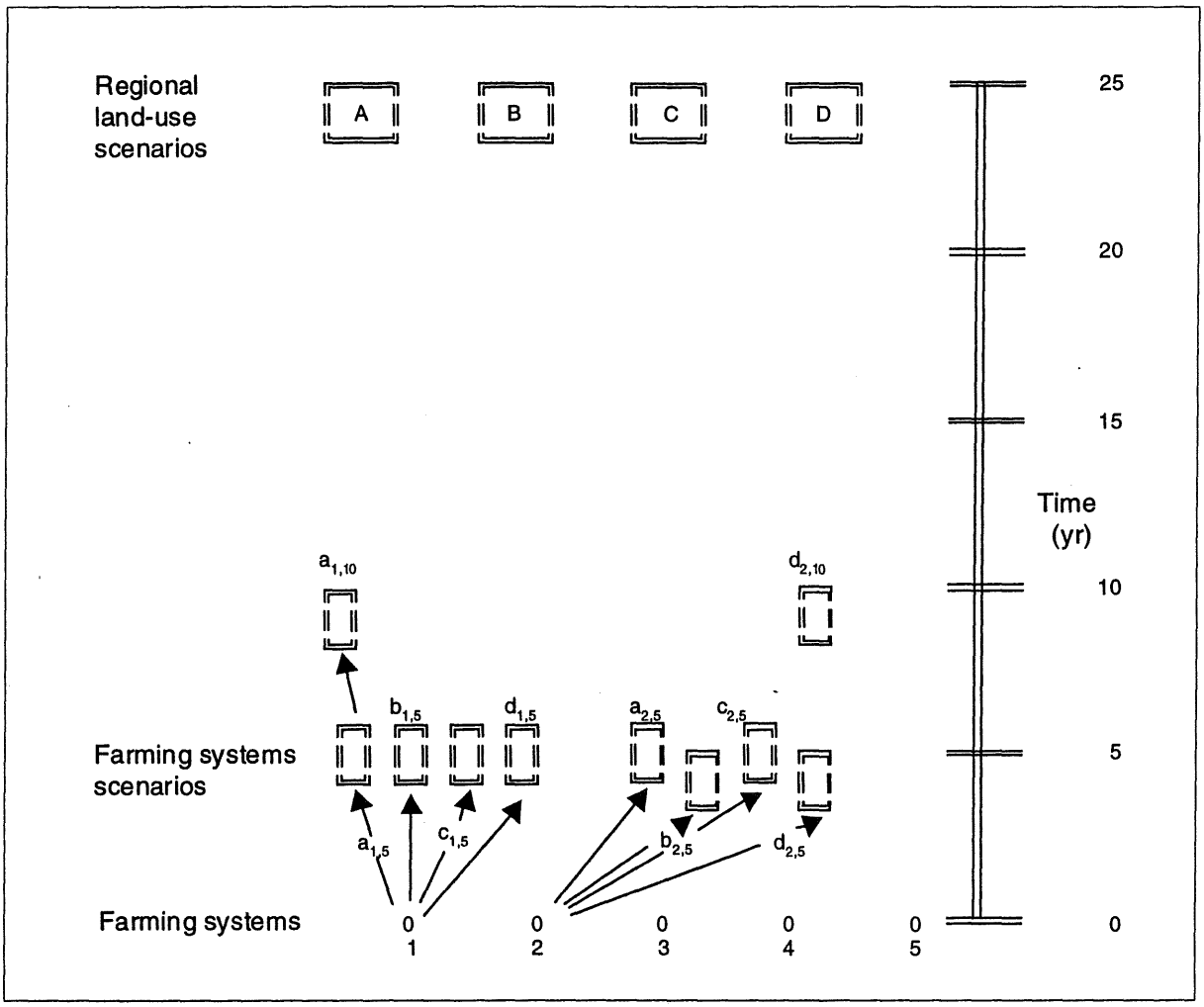

Fig. 4. Interface between an explorative land-use study at the regional level and the farming systems level. A, B, C, and D are regional scenarios representing different policy views; $a_{1,5}$ = scenario a (priority of different objectives similar to those in scenario A for the region) for farming system 1 in year 5; $d_{2,10}$ = scenario d (priority of different objectives similar to those in scenario D for the region) for farming system 2 in year 10.

ative studies can be conducted for shorter time steps (e.g., 5 yr) by confronting technical information about land use on the farm with the objectives of the farm households and those of the region in LP models. Different scenarios for each of the farming systems can be generated by applying a variety of weights to the regional objectives. For the first time interval, the land-use activities that serve as an input into the LP model are more closely related to current land-use activities, whereas for later intervals they are more closely related to possible future land-use activities. From these explorative farm studies, an answer to the question of whether individual farm households (farming systems) have the capacity to reach the desired land-use patterns might be obtained. These studies should demonstrate whether institutional, socioeconomic, or cultural factors restrict the ability to change in the near future. Such studies require a detailed economic and social analysis of the present situation. The link with explorative studies for the long term may take place from both temporal directions, from the present and from the future. If necessary, regional studies may be made more dynamic by introducing alternative time horizons (Spharim et al 1992).

In both regional and farm studies, the definition of the system boundaries, system elements, and environmental influences is very

important. At the farm level, the "farm gate" is the appropriate boundary; however, it should be clear whether off-farm income used for farm investment is taken into account. At the regional level, it is important to be explicit about imports and exports of products, in other words, to distinguish between policies aimed at self-sufficiency for agricultural products and policies supporting market development and trade.

Guidelines for land-use studies

To prevent misunderstandings and to improve communication among disciplines and aggregation levels, the following guidelines should be considered:

1. *Describe the objectives of land-use studies explicitly.* The objectives of the study determine the size of the system, its boundaries, and the environment.
2. *Define the system and its boundaries in time, space, and anthropogenic influence.* Systems as a limited part of reality are not a construct but are quantifiable and identifiable phenomena. Models are simplified representations of a system.
3. *Describe the next lower level and next higher level of aggregation.* The relationship between aggregation levels can be identified. It is impossible to consider at once (e.g., in any model) more than three aggregation levels, as this can easily lead to unreliable results or unjustified conclusions.
4. *Identify the external influences and constraints.* Driving forces and constraints should be defined.
5. *Determine the internal variables (activities) related to land use, their interaction, and their relationships with the environment.* A minimum number of variables is preferable.
6. *Make explicit the necessary technical information and the various policy issues.* In regional studies, an indication of various techniques and their organization is sufficient, whereas studies at the farm-household level require more detail on labor organization, income generation, etc.
7. *If explanation is the aim, distinguish clearly between levels.* System behavior is explained from the underlying process level. Quantification of explicit relationships at a process level forms the backbone of the explanation and understanding of system behavior.
8. *If prediction is the aim, be sure of the reliability of the models.* Models that are used for predictions should be validated and their sensitivity for changes in inputs and input relationships should be tested. Their robustness or fragility should be quantified and considered in the predictions.
9. *If exploration is the aim, do not pretend to predict.* Explorative studies are often interpreted as predictions. If plausibility and not consistency or technical possibility is considered as a criterion for the value of an explorative study, this may lead to the wrong type of discussion.
10. *If decision-making is the aim, determine exactly the appropriate decision variables.* Decision-making, be it strategic, tactical, or operational, requires the proper identification of decision variables. The ultimate decision variable and consequences of change should be quantified.
11. *Aggregate or average as late as possible.* Aggregating or averaging input data may lead to the wrong results. First compute/calculate and then average should be the credo.
12. *Never disaggregate in order to derive guidelines for management decisions at a lower aggregation level.* The relationship between micro, meso, and macro level in socioeconomic studies is critical. The same holds for aggregation levels in production-ecological studies. It is dangerous to draw conclusions from studies at meso or macro levels for individual situations at the micro level, such as the farm household. The study at the meso or macro level shows the ultimate consequences of the choices of policymakers at that level. It does not indicate what decisions have to be made at the micro level.

The guidelines and suggestions described above may be used as a checklist in the evaluation of case studies on land use. Awareness of

these guidelines may increase their quality and indicate what can be expected and for what purpose the studies can be used.

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