

BIOPHYSICAL MODELS IN LAND EVALUATION

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Contents

1. Introduction
 2. Classification of biophysical models
 3. Models of expert knowledge
 4. Empirical-statistical models
 5. Dynamic simulation models of crop yield
 - 5.1. The WOFOST Approach
 - 5.1.1. Production Level 1: Radiation and Temperature Limited
 - 5.1.2. Production Level 2: Water Limited
 - 5.1.3. Production Level 3: Nitrogen Limited
 - 5.2. Decision Support System for Agrotechnology (DSSAT)
 - 5.3. APSIM
 - 5.4. Others
 6. Dynamic simulation models of individual land qualities
 7. Critical issues in using dynamic simulation models for land evaluation
 - 7.1. Context
 - 7.2. Calibration vs. Validation
 - 7.3. Calibration
 - 7.4. Data
 - 7.5. Mismatched Conceptual Levels
 8. Selecting a modeling approach
- Glossary
Bibliography
Biographical Sketch

Summary

Biophysical models are simplified representations of land use systems that allow prediction of the success of such systems prior to their actual implementation. They are classified according to their degree of computation (qualitative to quantitative), descriptive complexity, (empirical to mechanistic) and level in the organizational hierarchy (scale).

The simplest models are holistic local knowledge, which is difficult to formalize and can not be extrapolated. Expert models are formalizations of expert judgment about individual Land Qualities, following the FAO Framework for Land Evaluation. Empirical-statistical models are quantitative predictions of crop yield from a set of static

Land Characteristics. Dynamic simulation models attempt to model biophysical mechanisms, based on the laws of nature, to follow a system over time based on a time series of input data. Widely applied models in these various categories are discussed here, including ALES, MicroLEIS, WOFOST, PS123, DSSAT, APSIM, EPIC, GAPS, and LEACHM.

A stepwise approach is recommended, with simpler models being applied to limit the areas in which the more complicated models must be calibrated.

1. Introduction

A *model* is a simplified representation of reality with which we can compute outcomes without having to perform actual experiments. In land evaluation, models are computer programs that predict the performance of a land use on a land area, when given information on that area's land characteristics. *Biophysical* models predict the behavior of the land use system in physical terms such as crop yields, environmental effects, and effect on management. They thus provide a quantified procedure to match land with various actual and proposed land uses, as proposed by the FAO Framework for Land Evaluation.

Models can be used to predict *crop yields* under different management strategies, as well as individual *land qualities* that are important components of yield, such as moisture supply, nutrient supply, and radiation balance. They can also be used to evaluate individual land qualities important for the land use but not directly affecting yield, such as erosion hazard, trafficability, and workability.

2. Classification of Biophysical Models

In 1992, Hoosbeek and Bryant proposed a classification of models of pedogenesis (soil formation), which was adapted by Bouma (1997, 1999) for land evaluation models (Figure 1). In this scheme, models are classified in three dimensions.

The first two dimensions are shown in Figure 1 on a horizontal plane: (1) the *degree of computation*, ranging from qualitative to quantitative; and (2) the *descriptive complexity*, ranging from empirical to mechanistic.

The *degree of computation* refers to the precision of the model's prediction. For example, the simplest qualitative model (at the left of the plane) could predict land suitability as "suitable" or "not suitable", in other words, the use will succeed (to some degree) or fail; this could be adequate for some decisions.

The most quantitative model (at the right of the plane) would give precise numerical predictions of crop yields and environmental effects. The *descriptive complexity* refers to the detail with which processes are made explicit in the model. An *empirical* model (at the back edge of the plane) is a model where processes are not known, but where relations are established based on experience. By contrast, a *mechanistic* model (at the front edge of the plane) is a model where processes, not just relations, are modeled.

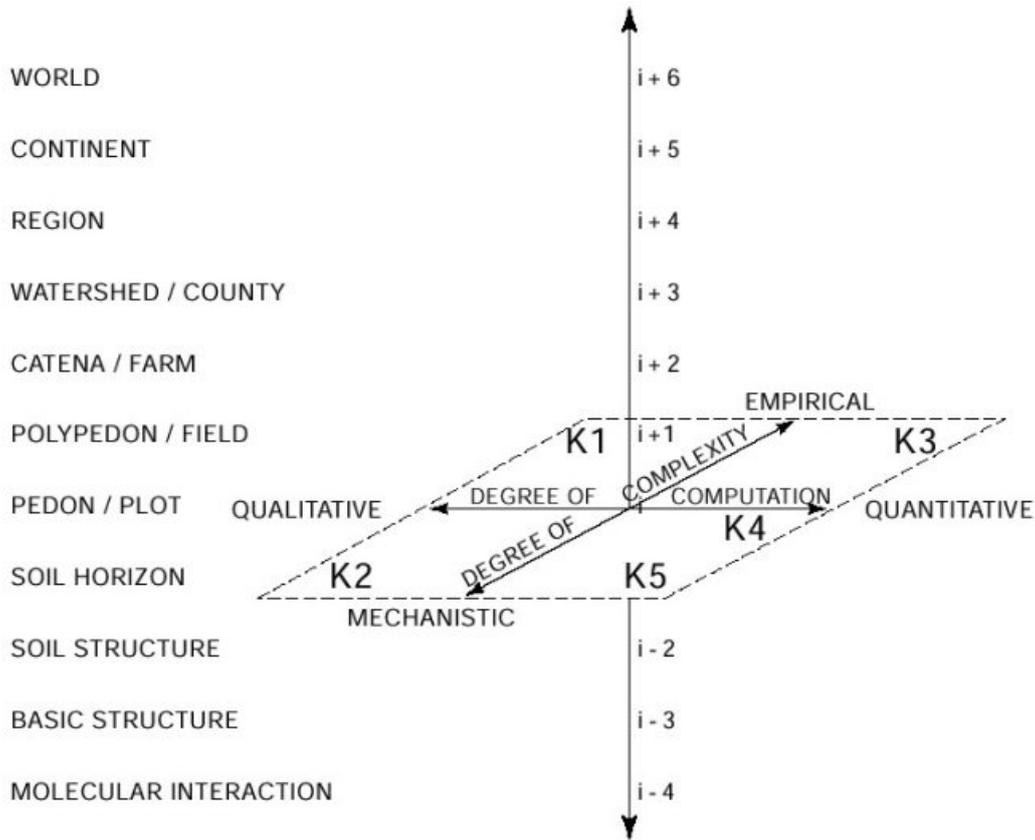


Figure 1. Conceptual framework to classify models, after Bouma (1999)

The third dimension is shown on Figure 1 as the vertical axis passing through the plane formed by the first two dimensions: (3) the *level in the organizational hierarchy* (scale of processes being modeled), which for land evaluation range from region through field and “point” to soil horizons and finally molecular interactions. At any scale level, the first two dimensions are possible; in practice the more quantitative and functional models are generally found at smaller scales.

Along the plane formed by dimensions (1) and (2), Hoosbeek and Bryant distinguished several levels of knowledge, which they termed K1 (user expertise), K2 (expert knowledge), K3 (generalized holistic models), K4 (complex holistic models), and K5 (complex models of system components), which of course grade into each other in any actual model.

K1 models are empirical, qualitative expressions of the land user’s experience. These have low descriptive complexity and require no computation. They are applied intuitively within the geographical and phenomenological area of the user’s experience. K1 models are difficult to formalize, since they draw on the user’s holistic experience, rather than a reductionist problem analysis.

K2 models are also qualitative, but consider mechanisms. In particular, the FAO approach with its analysis of land suitability as a set of Land Qualities has the

reductionist structure required for these models, which are built by specialists who are trained to search for causes.

K3 models are empirical but quantitative. These are statistical relations between output (e.g. yield) and input (e.g. precipitation, heat units, soil fertility), usually established by regression analysis on large datasets. Predictive variables are selected based on a reductionist concept of causative factors. They can not be applied outside their area of calibration. All variables are static, and there is no attempt to simulate system behavior over time. They can only be applied to Land Utilization Types (LUTs) that are widely practiced; so they are not useful for new crops, new technologies, or new management strategies.

K4 and K5 models attempt to be mechanistic rather than empirical. This means that they are based more on scientific principles (laws such as conservation of mass and energy, diffusion, convection and dispersion, chemical kinetics and equilibrium) and less on site-specific empirical relations. It is thus expected that they will be ‘universally’ applicable. However, the line between empirical and mechanistic models is not clear, since all ‘mechanistic’ models have empirical components. These models, when applied to land evaluation, are usually driven by *daily weather data*. This allows the analysis of *dynamic* and *transient* phenomena that may affect land performance, so that these are commonly referred to as *dynamic simulation models*. Such models can be used to model individual *land qualities* such as moisture sufficiency (K5) as well as crop yield (K3). This is appropriate if the *timing* of the quality is important. Water stress is a good example: the yearly moisture deficit often isn’t as important as the deficit in specific parts of the crop growth cycle.

In the following chapters these modeling approaches will be critically reviewed from least to most sophisticated.

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