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THE AUTOMATED LAND EVALUATION SYSTEM APPLIED TO SOTER

with an example from West Kenya

S. Mantel

March 1995

ISRIC
INTERNATIONAL SOIL REFERENCE AND INFORMATION CENTRE

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ABSTRACT

For the development of a World Soils and Terrain Digital Database (SOTER) at scale 1:1,000,000 a methodology for the compilation, coding and storing of data has been made (Van Engelen and Wen, 1993). The SOTER methodology provides a comprehensive framework for the storage and retrieval of uniform soil and terrain data that can be used for a wide range of applications at different scales. The data readily available in the database facilitate land use systems analysis on the basis of which decisions in land use planning can be made, e.g. with the aim of increasing the efficiency of land use and decreasing land degradation.

A SOTER-based, automated procedure for qualitative land evaluation was developed. This procedure, abbreviated to SOTAL, was created in ALES; the Automated Land Evaluation System (Rossiter and Van Wambeke, 1993). The objective was to design a procedure that allows for a quick separation of potentially suitable from non-suitable SOTER-units for the intended land use, indicating constraints to different kinds of land use.

Different kinds of land are unequally suited to various uses (Rossiter, 1990). Land evaluation is the assessment of the suitability of a tract of land for a specified kind of land use. In practice this implicates the comparison ("matching") between the requirements of a specified land use and the properties of the land. Land evaluation concepts and definitions are treated in chapter 2.

The ALES is a computer program that allows land evaluators to build their own knowledge-based system with which they can compute the physical and economical suitability of map units in accordance with FAO's Framework for Land Evaluation (FAO, 1976; Rossiter, 1990). The ALES program works with so called *decision trees*, being hierarchical multiway keys in which the leaves are results (e.g. severity levels of land qualities), and the interior nodes of the tree are decision criteria (e.g. land characteristic values). These trees are traversed by the program to compute an evaluation using actual land data for each map unit (Rossiter, 1990). The working of ALES is explained in chapter 3.

SOTAL is a SOTER-based, qualitative model developed in ALES for physical land evaluation in which presently two land utilization types (LUTs) are distinguished, viz rainfed cultivated maize and sorghum both under low input and low technology. These LUTs are characterized by 11 land use requirements and evaluated by 'matching' the land use requirements with the corresponding land qualities. Chapter 4 elaborates on the criteria used in SOTAL for land quality assessment and how a final suitability rating is achieved on the basis of the rated land qualities.

For determination of the sufficiency of the land quality 'water availability during the growing season' for the ALES-land evaluation procedure, a simple water balance model, WATSAT, was developed. The advantages of using a water balance analysis is that it is land use system (crop) specific and that it is dynamic. The model was kept simple in order to have a low (soil) data input requirement. In chapter 5 the theory and principles of the water balance model are explained and structure of input files and output screens are examined.

A case study is presented (chapter 6) in which SOTAL is applied on KENSOTER data for evaluation of suitability of SOTER units in West Kenya for rainfed maize and sorghum, both under low technology and low input. Results are visualized through GIS-generated maps.

ACKNOWLEDGEMENTS

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1 INTRODUCTION

SOTER methodology and land use planning

For the development of a World Soils and Terrain Digital Database (SOTER) at scale of 1:1,000,000 a methodology for the compilation, coding and storing of data has been made (Van Engelen and Wen, 1993). The SOTER methodology provides a comprehensive framework for the storage and retrieval of uniform soil and terrain data that can be used for a wide range of applications at different scales. The SOTER methodology has however primarily been developed for applications at a scale of 1:1 million (Batjes, 1990b). At that scale land evaluation will permit identification of the suitability of terrain units for broadly defined land uses as put forward by planners (Batjes, 1990a). SOTER contributes to improving knowledge about natural resources on a global, national and regional scale. The data readily available in the database facilitate land use systems analysis on the basis of which decisions in land use planning can be taken with the aim of increasing the efficiency of land use and decreasing land degradation.

SOTAL: a SOTER-based, qualitative land evaluation procedure

A SOTER-based, automated procedure for qualitative land evaluation was developed. This procedure, abbreviated to SOTAL, was created in ALES; the Automated Land Evaluation System (Rossiter and Van Wambeke, 1993). The objective was to design a procedure that allows for a quick separation of the potentially suitable SOTER-units from the non-suitable units for the intended land use, indicating constraints to different kinds of land use. ALES was used for this purpose, because it can easily be adjusted to local experience and data availability. If quantified land evaluation is to be applied, SOTAL can be used as a first and quick assessment to indicate the physically non-suitable areas. In this approach, which is called a 'mixed qualitative/quantitative land evaluation approach' (Van Lanen *et al.*, 1992), the quantitative land evaluation focuses on the areas that are indicated as 'potentially suitable' in the (SOTAL) qualitative land evaluation.

This Working Paper deals with concepts and principles of SOTAL, the SOTER-based qualitative land evaluation model using ALES. For more detailed information on the working and use of ALES reference is made to the ALES Version 4 User's Manual (Rossiter and Van Wambeke, 1993); a well written document, with a clear and completely self-explanatory text.

This Working Paper supersedes the one published under the same title as Working Paper and Preprint 94/10 in November 1994.

2 LAND EVALUATION

2.1 Concepts and definitions in land evaluation

Different kinds of land are unequally suited to various uses (Rossiter, 1990). Land evaluation is the assessment of the suitability of a tract of land for a specified kind of land use; it provides objective sets of data on potentials and constraints, which can contribute to decisions on a sustainable land use (van Lanen, 1991). In practice this implicates the comparison ("matching") between the requirements of a specified land use and the properties of the land.

Land

The entities that are evaluated are land units (LU); internally homogeneous areas of land. It is irrelevant whether a tract of land is uniform in all aspects or not. The question is rather whether the variation that occurs affects the functioning of the land under the intended use; therefore the concept of 'land unit' is used for areas that can be considered uniform in view of the requirements of the defined (actual) or intended land use (Driessen and Konijn, 1992). Soil is but one aspect of land, alongside of terrain, climate, vegetation, hydrology, infrastructure, etc. and the socio-economic context within which a land unit is used.

Land Characteristics

A land unit is described by its major land characteristics (LCs). Land characteristics can be either single or compound. Single land characteristics are properties of the land that can be measured or estimated, e.g. annual rainfall, dominant slope, soil drainage class and soil depth. Compound land characteristics are composed of associated single characteristics. 'Available water capacity' (AWC) is an example of a compound land characteristic as its a function of depth and matrix geometry.

Land Qualities

A land quality (LQ) is a set of interacting land characteristics which acts in a distinct manner in its influence on the suitability of land for a specied use. Examples of land qualities are the 'water availability to a crop' (a.o. influenced by AWC, rainfall, soil depth, hydraulic conductivity), 'availability of nutrients' and 'resistance to erosion'.

Land use

The Framework for Land Evaluation (FAO, 1976) uses the concept of 'major kinds of land use' (e.g. 'deciduous forest', 'annual crops') and the more specific **land utilization type (LUT)**, which is characterized by its **'key attributes'**; the biological, socio-economic and technical aspects of land use that are relevant to the productive capacity of a land unit (LU). Crop selection, labour intensity and management level are examples of key attributes.

Land use requirements

Land utilization types are characterized by a set of land use requirements (LURs), which are 'the conditions of land necessary for the successful and sustained practice of (a given LUT)', (FAO, 1984). Where a land utilization type concerns the growth of a crop/variety, land use requirements are mainly crop requirements. Land use requirements express the demand of a land use, whereas land qualities express the supply, i.e., properties of a particular tract of land.

Matching

Matching is the comparison of land use requirements with land qualities of specified land units. The sufficiency of a land quality, which is the degree to which a requirement of land use is satisfied by a corresponding land quality, is expressed in a rating. In a broader sense, matching refers to the process of mutual adaption and adjustment of (descriptions of) land utilization types and land units, in order to find the best combination of (improved) land use and (improved) land qualities (FAO, 1983; Batjes, 1990).

Final suitability rating

In a final suitability rating in qualitative land evaluation, the ratings of the various land qualities are translated into a (comparative) suitability of a land unit for the land use under study, using a conversion table.
Often a simple limitation method is used in which the suitability class is determined by the highest severity level of one or more land qualities (Law of Liebig). No distinction is made between situations where a suitablity class is determined by the severity level of one land quality (f.i. oxygen availability is limiting) or by several land qualities in the same severity level class (oxygen availability, availability of nutrients **and** conditions for germination are limiting).

In SOTAL, final suitability is assessed with the help of a constructed physical suitability subclass decision tree, which is the conversion table in conventional qualitative land evaluation. Through the physical suitability subclass decision tree, the ratings of the various land qualities are translated into a (comparative) suitability of a SOTER unit for the land use under study.

2.2 Scales and land evaluation

The degree of detail of conclusions which can be derived from a land evaluation study is strongly determined by the level of spatial aggregation of the climate, terrain and soil maps/data, as well as the possible level of integration of the bio-physical and socio-economic information. At a scale of 1:1M "micro-variations" in the environmental features are de-emphasized so as to highlight regional trends (Batjes, 1990). The level of detail used for defining land qualities often depends on the amount, accuracy and availability of input data. Furthermore, the technical level of detail when defining land qualities is determined by the types of questions being asked (Bouma, 1989).

In SOTER each soil component is characterized by a 'representative profile', which is described in detail. This 'representative profile' is selected from a number of reference profiles. These reference profiles have also contributed to the determination of maximum and minimum values for a number of chemical and physical parameters of the soil (Van Engelen and Wen, 1993). When interpreting the soil component data for macro-scale land evaluation (1:1 M), the scale should be considered in the level of detail. Some attributes may be representative or indicative, if however the variability of this attribute in the soil component is high (of which an indication is given by the maximum and minimum value), care should be taken to use this attribute (without probability statement) as diagnostic criterion in qualitative interpretations as well as in quantitative studies.

3 THE AUTOMATED LAND EVALUATION SYSTEM (ALES)

3.1 Concepts of ALES

The Automated Land Evaluation System (ALES) is a computer program that allows land evaluators to build their own knowledge-based system with which they can compute the physical and economical suitability of map units in accordance with FAO's Framework for Land Evaluation (FAO, 1976; Rossiter, 1990). ALES is not by itself an expert system; it does not include any knowledge about land and land use. ALES is merely a framework within which it is possible to build an evaluation model suited to the prevailing local conditions. In terminology of knowledge-based systems it is a *shell*, which provides a reasoning mechanism and constrains the evaluator to express inferences using this mechanism (Rossiter, 1990).

The ALES program has the following main components:

- a framework for a *knowledge base* describing proposed land uses, in both physical and economic terms;
- a framework for a *database* describing the land areas being evaluated;
- an *inference mechanism* to relate these two, thereby computing the physical and economic suitability of a set of map units for a set of proposed land uses;
- an *explanatory facility* that enables model builders to understand and fine-tune their models;
- a *consultation mode* that enables a casual user to query the system about one land use at a time, and
- a *report generator*.

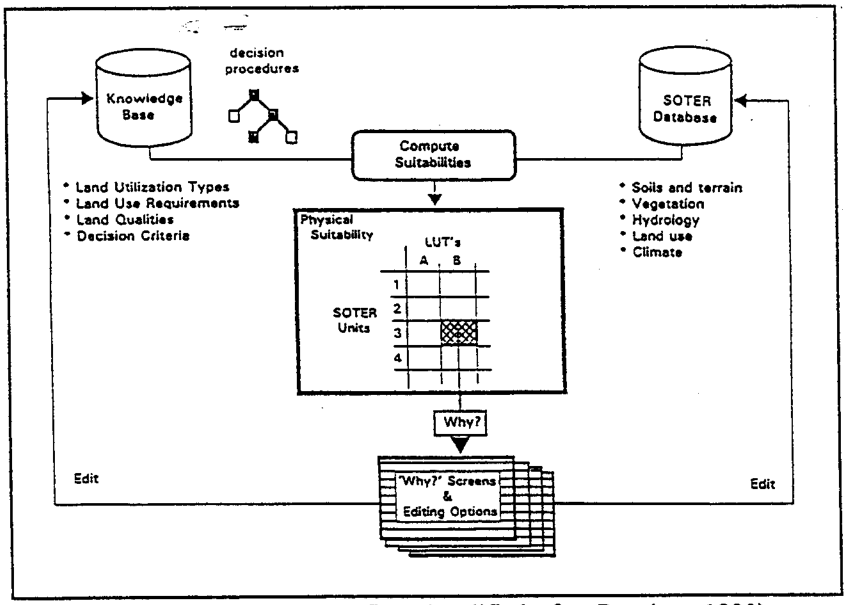
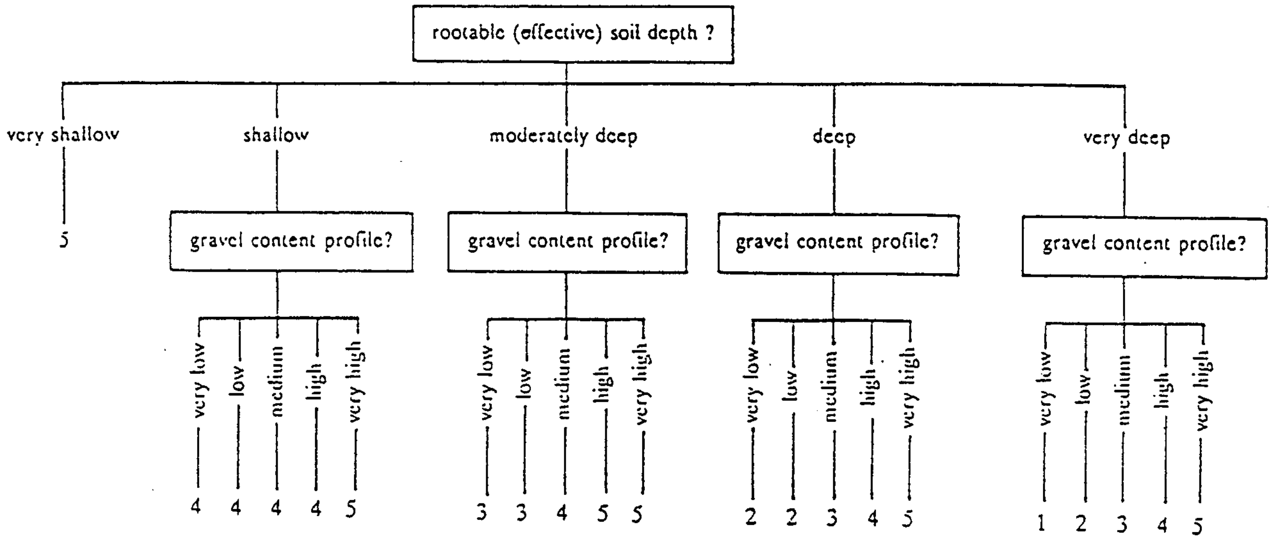


Figure 1: The ALES program flow (modified after Rossiter, 1990)

The ALES program works with so called *decision trees*, being hierarchical multiway keys in which the leaves are results (e.g. severity levels of land qualities), and the interior nodes of the tree are decision criteria (e.g. land characteristic values). These trees are traversed by the program to compute an evaluation using actual land data for each map unit (Rossiter, 1990).
Figure 2 shows a decision tree from SOTAL (SOTER application using ALES) which allows the program to determine the severity level for the land quality 'available foothold for roots':



severity level rating (degree of limitation):

1 = no
2 = slight
3 = moderate
4 = severe
5 = very severe

Figure 2: Decision tree of the land quality 'available foothold for roots'.

Van Lanen (1991) distinguishes five steps to be followed when ALES is used for assessing the physical suitability of land (fig. 3):

(1) **defining land utilization types (LUTs)**. The LUTs chosen in the SOTAL model are (up until now) rainfed cultivated maize and sorghum, both under low technology and input.

(2) **formulating land use requirements (LURs)** for each LUT. They describe the conditions of land which are necessary for successful and sustainable application of the LUT.

(3) **selecting relevant land characteristics (LCs)**. They describe the natural resources relevant for the LUT being considered.

(4) **defining land qualities (LQs)** and deducing these from LCs using decision trees. Ratings or severity levels of LQs are determined for each mapping unit, i.e. no, moderate, extreme limitations etc. They express the degree to which a LUR is met by what the land offers. A land mapping unit (LMU) comprises a number of delineations on a map which are relatively homogeneous in terms of soil, climate, topography, hydrology.

(5) **combining** LQs using a decision tree to infer relative physical suitability for each LMU. Relative physical suitability, expressed in terms of highly, moderately, marginally suited or non suitable serves to rank LMUs on an agro-physical or agro-ecological scale.

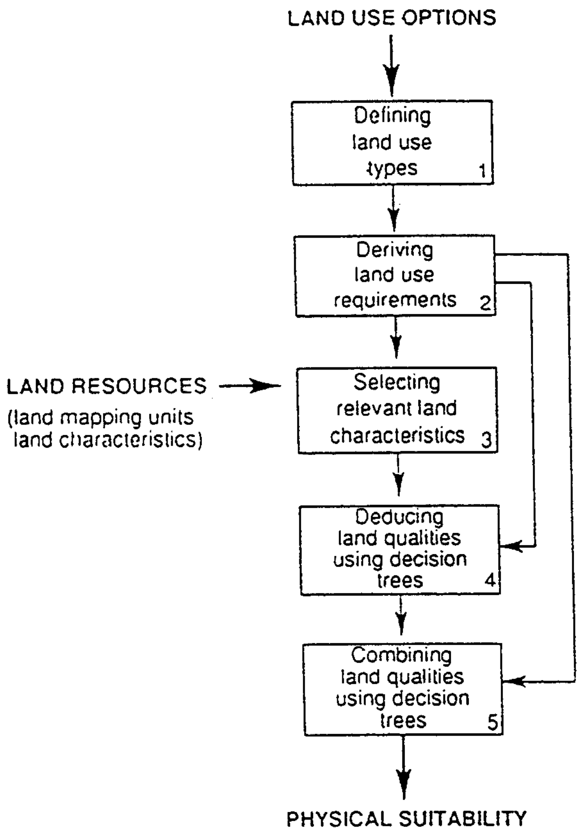


Figure 3: Relational diagram for assessing the physical suitability in ALES. (From: Van Lanen, 1991).

3.2 Using ALES

A summary on how to import data and land mapping unit definitions from a database into ALES can be found in Appendix 1.

3.3 Running ALES

ALES can be started in several modes for different purposes. For building an evaluation model ALES should be entered in the *model building mode*. This is done by entering the command **ales** on the DOS prompt (c:\dtm\ales ↵). The model user, who will start using ALES when the model is completed, will enter ALES in the *evaluation mode* with the DOS command **evaluate** (c:\dtm\evaluate ↵). Another option to enter ALES is in the *consultation mode*. This is an interesting option, as the decision trees can be traversed from the first to the last branch, where the user has to enter values for all land characteristics relevant for an evaluation, on the basis of which the suitability of a land unit for a land utilization type is determined. The consult mode is an easy way to consult an ALES model for the *occasional model user*.

Several help screens are available to the ALES user. With the **F9**-key notes can be read, items that have notes are indicated in ALES with small 'degree' signs: °. The **F1**-key displays information about the mechanics of the interaction (e.g. what keys are active) and the **F2**-key, displays information about what is being requested. In the 'Why?'-screens, the F2-key is the 'Why'-key and shows f.i., when viewing evaluation results, the pathway along which the final rating was reached.

4 SOTAL - SOTER APPLICATION AUTOMATED LAND EVALUATION

4.1 About SOTAL

SOTAL is a SOTER-based, qualitative model developed in ALES for physical land evaluation. In SOTAL presently two land utilization types are distinguished: rainfed cultivated maize and sorghum, both under low input and low technology. These LUTs are characterized by 11 land use requirements and evaluated by 'matching' the land use requirements with the corresponding land qualities (see Appendix 3 for list of land qualities/land characteristics).

4.2 Land qualities and their assessment

4.2.1 Introduction

The sufficiency of each land quality is assessed from one to (mostly) several land characteristics with the help of (severity level) decision trees, before the final suitability rating can be performed. The following sections explain which criteria were used for determining the sufficiency of the land qualities. The ratings of land characteristics used in SOTAL are given in Appendix 6.

4.2.2 Moisture availability

The land quality 'moisture availability' is often of key importance in land evaluation and therefore an approach was chosen using a dynamic water balance analysis. The advantage of using such an approach, over f.i. determining a fixed 'Length of Growing Period', is that it is land use system (crop) specific and that it is dynamic. See chapter 5 that elaborates on the water balance method.

4.2.3 Availability of nutrients

The assessment of the land quality 'availability of nutrients' proves to be very difficult, not least because it is often extremely variable in both time and space. Measurements of relevant indicators of the nutrient capacity of soils is problematic, as will be discussed in the following sections.
For rating the sufficiency of this land quality in SOTAL the following criteria are used: soil reaction (pH), organic carbon content, sum of bases, cation exchange capacity.

'Available' nutrient elements

The availability of nutrient elements to a crop depends on many factors. Nutrient elements in soil may occur in many forms, and are, depending on the conditions, more or less 'available' to the plant. Not only does the 'availability' often depend on soil factors such as soil temperature, pH and moisture conditions, but also on environmental factors such as weather. Moreover, crops differ in their demand on nutrients and some crops are more efficient in extracting elements than others. The concentration of 'available' elements is normally estimated by exposing a pre-treated (drying, grinding, sieving) soil sample to a 'mild' extraction agent.

Driessen (1994), in discussing 'available nutrient elements in soil', states that: "... in *field* situations uptake of nutrient elements is co-determined by non-soil factors such as weather conditions and farm management. Therefore uptake of nutrient elements by a crop cannot be mimicked using a (passive) chemical extractant because the crop's physiological response to particular nutrient element is an active one, influenced by the presence and content(s) of other elements, i.e. by the balance or imbalance of total nutrient supply". Consequently: "'Available element' figures have a limited predictive value. They reflect the likelihood of nutrient stress under field conditions, but since no one can guarantee that actual system parameters will be the same as during the experiment in which the correlation was established, they appear to promise more than they can deliver", (Driessen, 1986).

Furthermore, considering spatial variability, the use of single element figures as diagnostic factor in macro-scale land evaluation (1:1M) would, at the least, be questionable.

Cation Exchange Capacity

The cation exchange capacity (CEC) of many soils consists of both a permanent and a variable component. In "red" soils this is because of the presence of pH-dependent minerals such as iron and aluminum hydroxides as well as organic matter (Sanchez, 1976). Standard methods for determining CEC (buffered at pH 7.0 or 8.2) grossly overestimate the *actual* CEC for soils with a strong variable charge component. Typical red and yellow tropical soils have a cation exchange capacity that is strongly pH-dependent and their field pH is well below 7.0 (often around 4.5), the *actual* CEC of such soils may well be 20 times less than the reference CEC-value at pH 7.0 (Driessen, 1994). An alternative to the use of the 'standard' CEC, is the effective CEC (ECEC), which is the sum of the exchangeable cations, extracted with KCl at the unbuffered pH of the soil, and the exchangeable acidity. For most acid soils the ECEC will be a more representative measure, although the accuracy is limited because of the cumulative errors in the individual methods (Landon, 1991).

In SOTAL both CEC's are used, the standard CEC (SOTER-item 99) for neutral to basic soils and the ECEC (if available) for slightly acid to acid soils.

Exchangeable bases

The proportion of (reference) CEC accounted for by exchangeable bases (Ca, Mg, K and Na) is frequently used as an indicator for soil fertility. For obvious reasons mentioned before concerning the value of the standard CEC, it is preferable to express base saturation as a percentage of the **effective** CEC. However in SOTAL the problem was avoided altogether using sum of bases instead of base saturation. The remaining disadvantage of this is that the sum of bases does not distinguish between different bases as an imbalance in their relative proportions can have considerable effect on plant growth or can even cause severe nutritional problems.

Soil reaction (pH)

The soil pH is used in SOTAL as a general indicator of soil fertility. Soil pH is, more indirect than direct, an indicator for soil fertility, as many processes take place within a specific pH-range and influence exchange capacity and element concentration. Landon (1991), summarizes:

Effects of low pH (< 5.5): phosphate immobilization (reaction with Fe and Al), micro-nutrient release (except for molybdenum), increasing exchangeability of aluminum with decreasing pH, nitrification is retarded.

Effects of high pH (> 8.0): phosphate immobilization (formation of calcium phosphate), release of boron (in sodic and saline soils often to toxic levels), nitrification is decreased, decreased availability of micro nutrients (except for molybdenum).

Soil organic matter

In many (highly weathered) tropical soils, organic matter contributes the bulk of the exchange sites and therefore has a significant contribution to the retention of cations in the surface horizon(s). Moreover organic matter is, together with soil micro-organisms, the main nitrogen source in natural (unfertilized) lands.

4.2.4 Erosion hazard

The erosion hazard is determined in SOTAL using soil data only. Climate data are equally important, however as data on rainfall intensity f.i. are rare, emphasize is put on the soil and terrain factors that make a land area more or less susceptible to erosion (soil erodibility).
As diagnostic factors for rating the sufficiency of this land quality in SOTAL were chosen: dominant slope, slope length, basic infiltration rate (however, often unavailable), and sensitivity to capping/sealing. The qualitative indication sensitivity to capping/sealing comprises the effects of e.g. organic matter content, texture and structure.

4.2.5 *Flooding hazard*

The LQ 'flooding hazard' is rated in SOTAL using two SOTER-items (no's 30 & 31), viz. flooding frequency and flooding duration.

4.2.6 *Available foothold for roots*

The 'available foothold for roots' is evaluated and rated in SOTAL according to the following two criteria; rootable (effective) soil depth and gravel content/stoniness of the profile.

4.2.7 *Conditions for germination*

For germinating conditions only the conditions in the topsoil matter. This land quality is therefore rated on the basis of the following criteria: size of structure elements, topsoil structure type, sensitivity to capping/sealing and surface stoniness.

4.2.8 *Potential for mechanisation*

The potential for mechanisation is assessed and rated in SOTAL on the basis of four land characteristics; surface rockiness, surface stoniness, gravel content/stoniness of the profile and the dominant slope. For the two LUT's now defined in SOTAL, both under low input/technology (no mechanisation), this LQ may not seem very relevant. The weight given to this land quality in determining the final suitability rating is low, but it has to be considered, for in no other LQ the surface rockiness is considered and if land is covered with rocks for, say, 50% the production potential is reduced by (at least) 50%, even if 'hoe-farming' is practised.

4.2.9 *Availability of oxygen for root growth*

The availability of oxygen for root growth is another land quality that is difficult to evaluate qualitatively. The conditions under which the growth of crops are affected by prolonged conditions of water saturation (= lack of oxygen) vary considerably. For rating this land quality, the qualitative description for 'drainage class' is used, that relates to the frequency and duration of periods when the soil is free of saturation, as is described in the "Guidelines for Soil Description", (FAO, 1990).
The soil drainage classes reflect the combined effects of climate, landscape, and soil. Rainfall, seepage, soil permeability, surface infiltration rate, internal and lateral movement of water, and external surface run-off and run-on, may all affect drainage class, of which the experienced surveyor can give a reliable estimate.

Often soil colour and mottling are used as indicators of (impeded) soil drainage. However, the interpretation of mottling patterns is difficult (how many times does this soil get saturated for how long?). Moreover, mottling may be a 'relict' or 'paleo'-feature that is not indicative of actual hydrological conditions. And not all soils that are saturated during part of the year show mottling, as reducing conditions are dependent on several factors such as pH, organic matter content (the energy source for reducing microorganisms), soil temperature and iron content. Therefore: although quite attractive as a diagnostic tool, mottling is not indicative of saturation with water in *all* soils (Driessen, 1994).

4.2.10 *Excess of salts*

Nature and effects

The excess of salts refers to two potential problems that may occur in (semi-)arid regions: salinity and sodicity. Salinity is the excess of free salts and sodicity is the saturation of the exchange complex with sodium ions. Excessive salt levels may affect crop growth in several ways: by toxicity effects, by reducing the water availability to plants through increased osmotic pressure and by causing nutritional disorders.
Sodicity may effect plant growth in a direct way through toxicity effects or in an indirect way through soil structure decline (causing permeability and drainage problems). The effect of sodicity on soil structure is larger when high sodium levels are combined with low soluble salt levels.

Assessment

Most (annual) crops have their highest rooting density in the top 30 cm of the soil. Therefore in rating the LQ 'excess of salts', more weight is given to surface soil than to the subsoil. For evaluating salinity the electrical conductivity (ECe) and for evaluating the sodicity, the Exchangeable Sodium Percentage (ESP) is used.

Where : ESP = exchangeable Na / CEC x 100

and : exchangeable Na = extracted Na - soluble Na.

4.2.11 Climatic hazard

Nature and effect

Examples of climatic hazards that can constrain crop production are frost and storm. In SOTAL only frost is considered. Temperature has a strong influence on the rate of development of a crop. Crops cannot grow below their *threshold temperature for development (Tbase)*; development accelerates as temperature rises (Driessen and Konijn, 1992). Tbase for maize and sorghum is around 10 °C. Prolonged periods (> 10 days) below Tbase and/or temperatures below 0 °C are lethal to most crops.

Assessment

Two severity levels are defined for rating this LQ:

1) crop can complete growing cycle (no limitation) (severity level rating 1 = no constraints).

2) crop dies, either as a consequence of temperatures below 0 °C or of temperatures above 0°C, but with average temperatures being too low (around Tbase) during growing period to ensure complete crop development (severity level rating 5 = not suitable; too cold).

The sufficiency of this LQ is assessed by running the water balance program WATSAT, that incorporates a module for assessment of the length of growing cycle. On a daily basis, temperatures are evaluated, not only for determination of the length of growing cycle, but also for checking temperature extremes. When running WATSAT a possible output is: 'class N - crop dies as a consequence of too low temperatures' (Tmin < 0 °C) or 'class N - crop is too long on the field' (> 730 days), which can be the case at higher altitudes, when the small differences between average daily temperatures (T_{24h}) and the threshold temperature for development (Tbase) of the specified crop cause the rate of development to be too slow. If a WATSAT-run with the same data but another sowing date leads to the completion of the growing cycle (and thus does not give output N - too long on the field/too cold) or leads to failure as a consequence of drought, then the temperature is considered not to be limiting (temp = S1). So only when all runs (with varying sowing dates) with WATSAT, give the output 'too low temperatures' or 'too long on the field' then the rating for temperature should be N.

4.2.12 Soil toxicities

Nature and effects

That are several element toxicities, under widely differing situations, that can affect crop growth. In SOTAL for the LUTs defined only one element is considered in rating this LQ; aluminium. Aluminium toxicity refers to the harmful effects of (high) concentration of Al^{3+} ions in the exchange complex. Concentrations of soil solution aluminium above 1 ppm often cause direct yield reduction (Sanchez, 1976). Aluminium toxicity is strictly a problem of acid soils (mostly Acrisols and Ferralsols), as aluminium becomes exchangeable below pH values of around 5.5. Above pH 5.5 - 6.0 aluminium is precipitated. Below pH 5.5 the exchangeable aluminium concentration increases often sharply with the decrease of the pH. Sanchez (1976, p.225) found a relationship between pH and % Al saturation for eight Ultisols and Oxisols, where aluminium first enters the exchange complex at a pH of approximately 5.4, rising to some 20% Al saturation at about pH 4.9 and 50% or more below pH 4.3.

There is a great difference between crops in their tolerance to high exchangeable aluminium levels in the soil solution. For instance pineapple is a well known example of a Al-tolerant crop. Also tea, coffee, rubber are tolerant. Sanchez (1976) reports of pot studies indicating that root growth of sorghum was affected at much lower Al levels than that of maize. Landon (1991), distinguishes three critical levels of exchangeable aluminium, viz. 30% (sensitive crops may be affected), 60% (generally toxic) and 85% (may be tolerated by some crops).

Assessment

The aluminium saturation percentage (ASP) is calculated as follows:

ASP = (exchangeable Al / effective CEC) x 100

4.3 Final suitability rating

The final suitability for the proposed land use is assessed with the help of a constructed physical suitability subclass decision tree, which is the conversion table in conventional qualitative land evaluation. Through the physical suitability subclass decision tree, the ratings of the various land qualities are translated into a (comparative) suitability of a SOTER unit for the land use under study. In SOTAL the ratings of the land characteristics and the land qualities are not crop specific. The requirements of maize and sorghum are in the same range and are taken into account in the final step, during the conversion of the collective land quality ratings to land suitability classes, when a weight is given to particular land qualities. This avoids the necessity of making separate rating tables for each single land utilization type. This will, however, be inevitable when land use requirements of different LUTs deviate strongly, for example different rating tables for excess of salts would have to be constructed for barley (*Hordeum vulgare*; high salt tolerance) and field bean (*Phaseolus vulgaris*; low salt tolerance).

A qualitative, physical land evaluation results in *relative* suitabilities of each land area for the set of defined land utilization types, based on the evaluator's judgement. This is useful within a single land utilization type. For determining the *best use* of a tract of land, i.e. comparison of land utilization types, more information should be included in the evaluation. Social factors are to be considered, for example the availability of labour and knowledge of farmers. Considerations on sustainability (possibly in economic terms) and quantification of in- and outputs in economic terms have to be made as well. It is possible for instance, that a land unit is rated as 'highly suitable' for a specific land utilization type, and only 'marginally' suitable for another, but that the second LUT is preferred by farmers, because of economic considerations. On the other hand, farmers do not only make market oriented, economic considerations. Often considerations of risk avoidance (food security) have a higher priority than increasing yields/economic return.

5 WATSAT: A SIMPLE WATER BALANCE MODEL

5.1 Introduction

For determination of the sufficiency of the land quality 'water availability during the growing season' for the ALES-land evaluation procedure, a simple water balance model, WATSAT, was developed. WATSAT was originally based on a waterbalance program for educative purposes, WATSUF (Driessen, 1993). However, major changes were made to WATSUF and program performance (and possible errors in) WATSAT are the responsibility of the author of WATSAT.
The advantages of using a water balance analysis is that it is land use system (crop) specific and that it is dynamic. The model was kept simple in order to have a low (soil) data input requirement.

Large parts of paragraph 5.2 to 5.6 are based on chapters 5 and 6 of 'Land-use systems analysis' by Driessen and Konijn (1992).

5.2 Water balance

For WATSAT the soil was considered a 'sponge' that has inflow of water (rainfall) and outflow of water (evapotranspiration and percolation). Not considered are: lateral flow of water, ground water and capillary rise. Hydraulic conductivity as a function of matric suction is not used in WATSAT nor is moisture content as a function of matric suction; the water content is calculated by 'budgeting' water gains and losses. Infiltration capacity is calculated per time step (1 day); see Appendix 4 for formula. The momentary infiltration capacity determines the maximum amount of rainfall that can enter the rooting zone. The amount of excess rainfall that can be stored on top of the land depends on the surface storage capacity of the soil (SSC), which is a function of the slope and surface properties of the land. The surface roughness is some 10 cm for contour-ploughed land, 4 to 6 cm for land tilled with light equipment, and 1 to 2 cm for untilled land. The surface roughness usually decreases during the growing season (time after cultivation). The amount of rainfall in excess of the surface storage capacity is considered lost through runoff.

Field capacity of deeply drained soils is the equivalent soil moisture fraction of moisture which remains if a water-saturated soil is allowed to drain and is assumed equal to the volumetric moisture content at 333 cm suction or pF 2.52 (Θ_{333}):

$$SMFC = SM0 * 333^{-GAM*\ln(333)}$$

In which SMFC is the volumetric moisture content at 'field capacity' ($cm^3.cm^{-3}$), SM0 is the total pore fraction ($cm^3.cm^{-3}$) and GAM is a texture specific constant (cm^{-2}).
The soil moisture content at 'permanent wilting point' is found by substituting the 333 cm suction value by crop variety specific PSI_{leaf} value. In appendix 4, table 4, a list of critical leaf water heads (PSI_{leaf}, in cm) for some common crops is given.

$$SMPWP = SM0 * PSI_{leaf}^{(-GAM * \ln(PSIleaf))}$$

The maximum amount of 'available' moisture that can be stored in the rooting zone is defined as the total pore fraction (SM0) corrected for the gravel content. From SM0 the volumetric moisture content at permanent wilting point and the (supposed) minimum content of air needed for uninhibited root activity is subtracted:

$$SMTOT = (SM0 - 0.06 - SMPWP) * (1 - GRAV).$$

In which SMPWP is the volume fraction of water at permanent wilting point ($cm^3.cm^{-3}$) and (1-GRAV) is the correction for the soil volume ($cm^3.cm^{-3}$) occupied by gravel and stones.

The model aborts the calculations (crop dies) and gives as output class N (not suitable) under the following conditions: temperatures too low (temperature below zero or too long below threshold temperature for development), too long on field (> 2 years) or too dry (soil moisture content is too long below permanent wilting point). The model has to be run with several sowing dates to know the optimum growing period.

Percolation

When wet conditions prevail (precipitation > potential evapotranspiration) and the soil moisture content exceeds field capacity, the assumption of 'adequate internal drainage' implies that all water in excess of the water held at field capacity is discharged to deeper layers under the rooting zone:

If SMAA (initial) > SMFC then INTPERC = (SMAA - SMFC) * RD / DT
and SMAA (resulting) = SMFC
else INTPERC = 0

In which INTPERC is the rate of percolation from the rooting zone ($cm.d^{-1}$), SMAA is the actual soil moisture fraction ($cm^3.cm^{-3}$), RD is the equivalent depth of rooting zone (cm) and DT is the time step (1 day).

5.3 Length of growing cycle

For assessing the length of growing cycle, crop development under the prevailing temperatures of the evaluated site has to be determined.
Crop development is determined by physiological properties of the crop (variety) and temperatures at the site. Crops cannot develop below their **threshold temperature for development**; development accelerates as temperature rises. The positive difference between the average daily temperature (T_{24h}) and the threshold temperature (Tbase) is the **effective temperature sum.** If all effective daily temperature sums in a growing cycle i.e. from emergence to maturity, are summed, the result is a variety-specific **heat requirement for development**.

Maize:	Tbase = 10.5	Tsum = 1588.
Sorghum:	Tbase = 10	Tsum = 1600.

The relative development stage (RDS) of a crop is determined at any moment in the crop cycle by simply dividing the cumulative effective daily temperature until that moment by the variety-specific Tsum-values.

$$DRDS = (T_{24h} - Tbase) * DT / Tsum$$

where:
DRDS is increase in relative development over the time interval (d).
T_{24h} is average daily temperature during the time interval (°C).
Tbase is threshold temperature for development (°C).
Tsum is heat requirement for full development (°C d).
DT is length of interval (d).

A crop is fully mature (and the growing cycle ends) when RDS = 1.0. The relative development stage at the end of a time interval is calculated with:

(new)RDS = (old)RDS + DRDS

5.4 Consumptive water use by plants

Maximum evapotranspiration

There is a strong correlation between the rate of transpiration and the rate of assimilation of CO_2 from the atmosphere. When plants are exposed to drought they close their stomata, in order to avoid more water loss, which at the same time reduces the CO_2 intake. Assimilation, i.e. the reduction of CO_2 to carbohydrates $(CH_2O)_n$, and thus plant growth is then hampered.

Maximum rate of evapotranspiration (ETM) is a function of both the evaporative demand of the atmosphere, expressed by the potential rate of evapotranspiration (ET0), and crop properties, expressed by a crop coefficient (kc).

Maximum evapotranspiration is calculated with the formula of Doorenbos and Pruit (1977):

$$ETM = kc * ET0$$

where:
kc is the crop coefficient.
ET0 is the potential evapotranspiration ($cm.d^{-1}$).

Total consumptive water use by a cropped field is composed of transpiration from the crop canopy and evaporation from the soil surface:

$$ETM = TRM + EM$$

where:
TRM is the maximum rate of transpiration ($cm.d^{-1}$)
EM is the maximum rate of evaporation ($cm.d^{-1}$)

The relevant land-use requirement maximum rate of transpiration (TRM) can be quantified if:
- the crop coefficient (kc) is established
- total consumptive water use (ETM) can be divided into its transpiration and evaporation components

Calculating the crop coefficient

The crop coefficient varies with crop, development stage and morphology of the crop and to some extent with windspeed and humidity (Doorenbos *et al*, 1979). Actual kc increases from a low value at the time of crop emergence to a maximum when the crop reaches full development. When the crop matures the kc value declines. The kc value dependent of the relative development stage (RDS) of a hypothetical, short, 'reference' field crop, adequately supplied with water and not exposed to turbulent air, is described with the following formula:

$$kc_{ref} = 0.33 + 0.73 * RDS + 1.93 * (RDS)^2 - 2.33 * (RDS)^3$$

where:
kc_{ref} is crop coefficient for a short green reference crop.
RDS is relative development stage (d).

A field crop differs from the reference crop because its canopy is less smooth and (can be) exposed to turbulent air. The turbulence coefficient is calculated with the following formula:

$$TC = 1 + (kc_{ref} - 0.33) * (TCM - 1) / 0.67$$

where:
TC is momentary turbulence coefficient.
TCM is (tabulated) maximum turbulence coefficient (given in crop.dat).

Finally the field crop coefficient is calculated, which is approximated by multiplying the reference crop coefficient by the turbulence coefficient:

$$kc = kc_{ref} * TC.$$

where:
kc is momentary crop coefficient of a field crop.

Maximum transpiration and evaporation

Transpiration at time of sowing is negligible (no canopy) and kc is close to 0.33. In the mid-season stage, the transpiration rate is close to TCM * ET0, when kc has its highest value. Interpolation between the two values results in:

$$TRM = ET0 * TC * (kc_{ref} - 0.33) / 0.67$$

where:
TRM is the maximum rate of transpiration of a field crop ($cm.d^{-1}$).

The maximum rate of evaporation is now found simply by:

$$EM = ETM - TRM$$

Actual (evapo)transpiration

When uptake of water by roots cannot fully replenish transpiration losses, plants actively curb their water consumption (i.e. the rate of transpiration). Doorenbos *et al.* (1979) express the moisture content of the soil at which stomata start to close (the critical volume fraction of moisture in soil, SMCR) as a function of the total available soil moisture (SMTOT). A depletion fraction (p, between 0 and 1) indicates the relative depletion of SMTOT, which corresponds with a critically low volume fraction of soil moisture. The depletion fraction is a function of the physiological tolerance to drought of the crop and the maximum rate of water loss from the rooted soil to the atmosphere (TRM). A decrease in soil moisture content below SMCR goes with a drop in actual transpiration (TR), which is assumed to be linear. Plants are not able to take up any more water when the volume fraction of water is lower than the moisture content at permanent wilting point (SMPWP).
The upper limit of soil moisture range for maximum transpiration is set by the occurrence of stress due to lack of oxygen. The minimum content of air needed to maintain root activity is tentatively set to 2% of oxygen and the air content to maintain full root activity is set at 6% or more.
After the depletion fraction is determined (see Appendix 4 - tables 2 & 3), the critical soil moisture content is calculated (SMCR).

$$SMCR = (1 - p) * (SM0 - 0.06 - SMPWP) + SMPWP$$

In figure 4 the approximate relation of TR to SMAA is given.

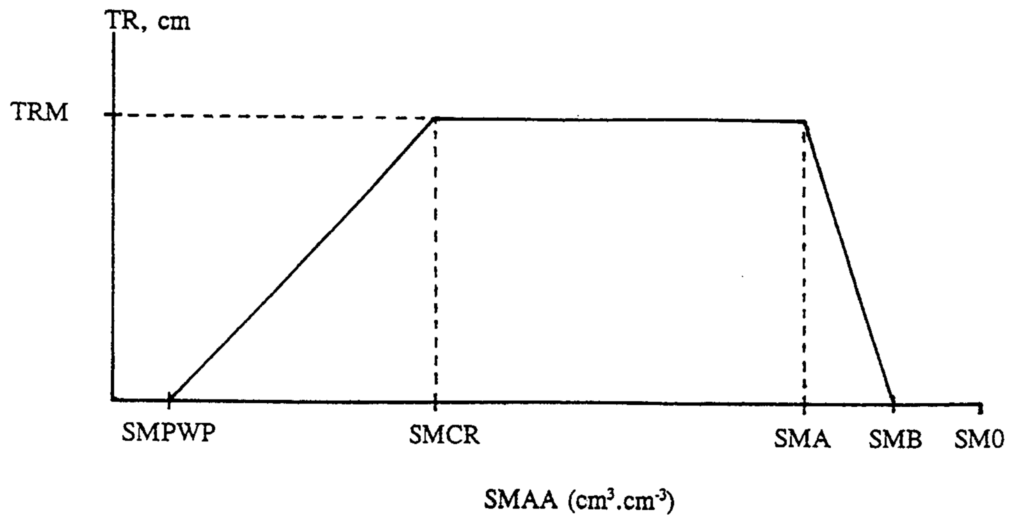


Figure 4: Approximate relation between soil moisture content (SMAA) and transpiration rate (TR). (Note that SMA = SM0 - 0.06 and SMB = SM0 - 0.02). Source: Danalatos (1992).

The compounded losses of water vapour from the rooted surface soil can now be described for five ranges of soil moisture between SM0 and $SMPSI_{leaf}$ (=SMPWP), (Danalatos, 1992):

If SMAA >= (SM0 - 0.02) then TR = 0 and EA = EM

If SMAA <= (SM0 - 0.02) and SMAA >= (SM0 - 0.06) then
TR = TRM * (SM0 - 0.02 - SMAA) / .04

If SMAA < (SM0 - 0.06) and SMAA >= SMCR then TR = TRM

If SMAA < SMCR AND SMAA > SMPWP then
TR = TRM * (SMAA - SMPWP) / (SMCR - SMPWP)

If SMAA <= SMPWP then TR = 0

The actual evaporation rate (EA) varies with the moisture content of the topsoil from zero to its maximum value (EA=EM). Assuming a linear decline of actual evaporation between the two extremes, i.e. SM0 for unhindered evaporation and the air-dry soil moisture content (SMAD) for minimum evaporation, Danalatos (1992) proposed the following relation:

EA = EM * (SMAA - SMAD) / (SM0 - SMAD), in $cm.d^{-1}$

The actual available soil moisture (SMAA) is calculated anew for each daily interval. The lower boundary is set to SMPWP and the upper boundary to SMTOT.

Sufficiency

The sufficiency of the land quality 'water availability' can be evaluated by matching the actual volume fraction of soil moisture (SMAA) against SMCR, SMAD and SMPWP (see figure 4).

- if SMAA remains greater than SMCR throughout the crop cycle, there is no water stress at all (no limitations; avm severity level rating 1).
- if SMAA becomes less than SMPWP, the land is unsuitable for rainfed cultivation of the selected crop (too dry; crop dies; severity level rating avm 3).
- in the intermediate situation (TR < TRM but the crop survives) land suitability for the defined use is marginal (some to severe stress; severity level rating avm 2).

5.5 Equivalent depth of rooting zone (RD)

The amount of available moisture is assessed for the rooted zone. Therefore the rooting depth has to be determined for each interval (from germination to maturity). Plants grow roots until a plant-specific relative development stage at which root growth stops (RDSroot). The equivalent depth of rooting zone (RD) can be found by interpolation between the rooting depth at germination (RDint) and the maximum rooting depth (RDm), as a function of RDS/ RDSroot. It is assumed that the root density decreases linearly from a maximum density at the soil surface to nil at the maximum rooting depth.

If RDS =< RDSroot then
RD = RDint + RDS * (0.5 * RDm - RDint) / RDSroot
else RD = 0.5 * RDm

RDSroot: maize = 0.7, sorghum = 0.61.

5.6 Dynamic simulation

The values of PREC (precipitation), ET0, SMAA and RD are considered invariant for the duration of one interval. The values of PREC and ET0 are fixed for the duration of one time interval, WATSAT works with time steps of one day, after which new values of PREC and ET0 are called from the climate file for calculations for the next time interval. The value of SMAA is used to calculate TR and then the value of SMAA is updated by adding the water influx over the rooting zone (RD) and subtracting the (calculated) water losses in the interval. This updated value of SMAA is considered invariant over the next interval, and so on. SMAA is a 'state variable'; it is calculated anew for each interval in the crop cycle and signifies the state of the system during one interval.

5.7 Data files and file structure

The files accompanying WATSAT are:

- climate file (Kisumu.dat; weather data of Kisumu)
- crop file (crop.dat; crop data of selected cultivar)
- soil file (soil.dat; soil data)

The data files are ASCII-files that can be edited with most editors. f.i. the MDOS-editor, Program Editor or the Norton Editor.

Content of the files:

CLIMATE.DAT:

The climate file (Kisumu.dat, or any other climate file) has the following structure:

line # 1:	"SITELABEL$", LAT(degree), LON(degree), ELEVATION(m)
line # 2-366:	Julian daynr., Tmax(°C), Tmin(°C), PREC($cm.d^{-1}$), RHA(0-1), E0($cm.d^{-1}$), SUNH($h.d^{-1}$), ET0($cm.d^{-1}$).

Where:
SUNH = number of sun hours
RHA = relative humidity of atmosphere

CROP.DAT:

The crop file contains several crop (variety) specific data necessary for simulation of crop development, development of above ground mass (for calculating TR) and development of roots (for calculating the equivalent rooting depth). A listing of the crop data in crop.dat is given in Appendix 5. Full explanation of the theory on crop growth simulation is given in 'Land use systems analysis' by Driessen and Konijn (1992).

SOIL.DAT:

The soil file (soil.dat), has the following structure:

line #1:	"SOILLABEL$"
line #2:	SM0 ($cm^3.cm^{-3}$), ERD (cm)
line #3:	GRAV($cm^3.cm^{-3}$), GAM(cm^{-2})
line #4:	S0 ($cm.d^{-0.5}$), Ktr ($cm.d^{-1}$)
line #5:	dummy value

Where:

ERD	=	effective rooting depth
GRAV	=	volumetric gravel content of the profile ($cm^3.cm^{-3}$)
GAM	=	texture specific constant ($cm^3.cm^{-3}$)
S0	=	reference sorptivity ($cm.d^{-0.5}$)
Ktr	=	permeability of the transmission zone ($cm.d^{-1}$)

In table 5 in Appendix 4 indicative values for soil constants SM0, GAM, S0, Ktr for reference soil texture classes are given.

5.8 Output results

When running WATSAT, the user is asked to give the name of the climate file and the path for file allocation (only in case the file is in another directory than from where the program is run). After the climate data are read, the user is asked to give the name of the soil file (soil.dat) and to select a soil. Finally the user has to give the name of the crop file (crop.dat) and to select a crop. When the data from these three files have been read, the calculations are started. The successive number of the time intervals that is processed is indicated in the centre of the screen, until the final interval in the growing cycle, when a SUMMARY CHART of the calculated values appears (see table 1).

The SUMMARY CHART presents key indicators of the status of the system for every 10th day in the growing cycle. CUM.USE gives the consumptive water needs of the cropped field, composed of cumulative maximum evapotranspiration needs (ETM). The sufficiency of water availability, averaged over the 10-days report periods, is given in the column SUFF, and present the ratio of TR over TRM. Alternative scenarios should be run, with varying sowing dates, with data from the sample files or from files made by the user. The programme asks whether another scenario is to be examined and whether you wish to use the same files.

Table 1: Example of output results obtained with WATSAT run using linear interpolated monthly to daily climate values of Kisumu on a clayey soil from day 90 on.

SUMMARY CHART

MAIZE (cv. PIONEER 3183) grown on soil KE115/4-47(C)
(SMAAint = 0.32) at KISUMU from DAY 90 onwards to DAY 223
could complete growing cycle, however with slight to severe
moisture stress(Class - S2);

DAY	CUM. USE	TRM	TR	EM	EA	PERCOLATION	SUFF.
100	1.71	0.02	0.02	0.15	0.11	0.47	1.00
110	3.74	0.08	0.08	0.12	0.09	0.46	1.00
120	6.20	0.14	0.14	0.10	0.08	0.40	1.00
130	9.08	0.21	0.21	0.08	0.06	0.33	1.00
140	12.37	0.27	0.27	0.06	0.04	0.25	1.00
150	16.06	0.33	0.33	0.04	0.03	0.13	1.00
160	20.10	0.38	0.38	0.02	0.02	0.02	1.00
170	24.34	0.41	0.41	0.01	0.01	0.00	1.00
180	28.72	0.43	0.43	0.00	0.00	0.00	1.00
190	33.12	0.44	0.42	0.00	0.00	0.00	0.96
200	37.35	0.41	0.30	0.01	0.01	0.00	0.73
210	41.28	0.37	0.24	0.03	0.01	0.00	0.65
220	44.70	0.29	0.22	0.05	0.03	0.00	0.77
223	45.59	0.24	0.22	0.07	0.04	0.00	0.93
SUM:	45.59	38.56	35.27	7.03	4.96	20.61	0.91

A program listing of WATSAT in QuickBASIC 4.5 is given in Appendix 7.

6 CASE STUDY: SOTAL APPLIED ON DATA OF WEST KENYA

6.1 Introduction

The Kenya Soil Survey has compiled a SOTER database (KENSOTER). SOTAL was applied to 100 SOTER units of West Kenya.

Rainfall in West Kenya is more or less continuous with little distinction between the first and the second rains. In this part of Kenya relatively wet agro-ecological zones dominate except near the lake, where drier conditions prevail. Average annual rainfall varies from 800 - 900 mm near lake Victoria (Karungu) to > 2000 mm (near Kisii). Due to the more or less continuous rainfall, it is possible to plant two successive early maturing crops instead of one late maturing (Jaetzold **et al.**, 1982). The pressure on agricultural land in West Kenya is high. An increasing amount of people has to be fed. As a result agriculture in this region is rather intensive. In general, low input and technology farming is practised. Often a part of the agricultural land is used for cattle keeping. Sometimes seed of improved varieties is used, fertilizer application is low. The overall farm size in this region is between 1 to 4 ha.

6.2 Material and methods

The SOTER units were evaluated for their potential suitability for supporting two land utilization types; viz. rainfed maize and sorghum, both under low technology and input.

The severity level rating of the land quality 'availability of water during the growing season' was assessed using the water balance model WATSAT. Monthly weather data were obtained from FAO agroclimatic databases, AMDASS (FAO, 1992). The monthly data were converted to daily data by linear interpolation. In addition to the stations from AMDASS, some weather stations (monthly data) were made available by the Kenya Soil Survey.

The required soil data for evaluation were taken from the soil component file and the profile file. For each terrain component the data of dominant soil type were taken as a basis for evaluation. Data on soil physical properties (total pore fraction, bulk density and pF data) were scarce for the area and pedotransfer functions were used to estimate the required soil physical data. Attributes relevant for the most densely rooted part of the profile (f.i. organic matter content) were averaged over 'topsoil depth' (0-30cm). Some attributes were averaged over a fixed depth (120 cm like f.i. pH and CEC), except for the case that the effective rootable depth was less than 120 cm (then the effective rootable depth was taken).

6.3 Results and discussion

Limiting factors

In figure 5, major limiting factors for the cultivation of maize and sorghum are shown. The severity level rating of medium or higher for the land qualities availability of nutrients, availability of oxygen and erosion hazard are visualised on the SOTER unit map. One map is presented for both land utilization types, as the severity level rating of the land qualities is the same for both LUT's; the difference in evaluation is expressed in the final rating in the conversion table (in ALES that is the physical suitability subclass decision tree).
Figure 5 shows that the most limiting factors for the evaluated land utilization types (rainfed maize and sorghum) are availability of nutrients and erosion hazard. In some parts oxygen availability can be limiting to the growth of maize and sorghum.

Suitability assessment

Figures 6 and 7 show the results of the SOTAL evaluation. The major part of West Kenya is potentially suitable for cultivation of both maize and sorghum. Suitabilities vary mainly between marginally to moderately suitable. Some units that are evaluated as moderately suitable for maize are evaluated as highly suitable for sorghum. This is due to the fact that sorghum is more resistant to adverse drainage conditions than maize. When another

technology/input level is assumed (moderate or high), different results will be obtained. For example, the major limiting factor, availability of nutrients, will be counteracted by application of fertilizer.
The evaluation results are reasonably similar for maize and sorghum. This is explained by the fact that the main difference between maize and sorghum is their resistance to drought. Sorghum is more drought resistant than maize and in addition to that, sorghum is more resistant to poorly drained conditions. However, availability of moisture was not a limiting quality. Hence in the drier parts of Kenya the differences in evaluation would be more pronounced.

6.4 Conclusions

When running WATSAT it became clear that the resolution of monthly climatic data was in fact too low to obtain accurate results. Although daily or decadal data are to be preferred, for a regional, simple water balance approach monthly data can be used.

The developed SOTER-based physical land evaluation model SOTAL is not considered to be a ready-to-use end-product. It should be adapted to local experience, extended with more land utilization types and more technology levels. SOTAL can be a useful tool in land use planning, because constraints for different kinds of land use can quickly be determined. The model can quickly be adjusted to local conditions and data availability.
The areas indicated as **potentially** suitable after a SOTAL-evaluation have no major physical limitations for the proposed land use. For more specific statements, like f.i. the potentially attainable yield, a quantified land evaluation is necessary, using dynamic crop growth simulation models. The attractive feature of the procedure following the pathway of a qualitative land evaluation in SOTAL, preceding a quantified land evaluation, is that the non-suitable areas can be neglected in the quantified land evaluation. This is called a 'mixed qualitative/ quantitative land evaluation approach' (Van Lanen *et al*, 1992).
As indicated earlier, for land use planning the biophysical suitability of a land unit for a specific land use is but one aspect; socio-economic evaluation should be taken into account as well.

ALES is a model of expert judgement. The formalization of the land evaluation procedure in ALES diminishes the subjectivity intrinsic to qualitative procedures. However, the procedure is flexible and should be adjusted by the expert-user who's local knowledge of land and land use is crucial to the success of the approach. Validation of the procedure is regarded to be a necessity.

An automated data transfer facility (from SOTER to SOTAL) has been developed.

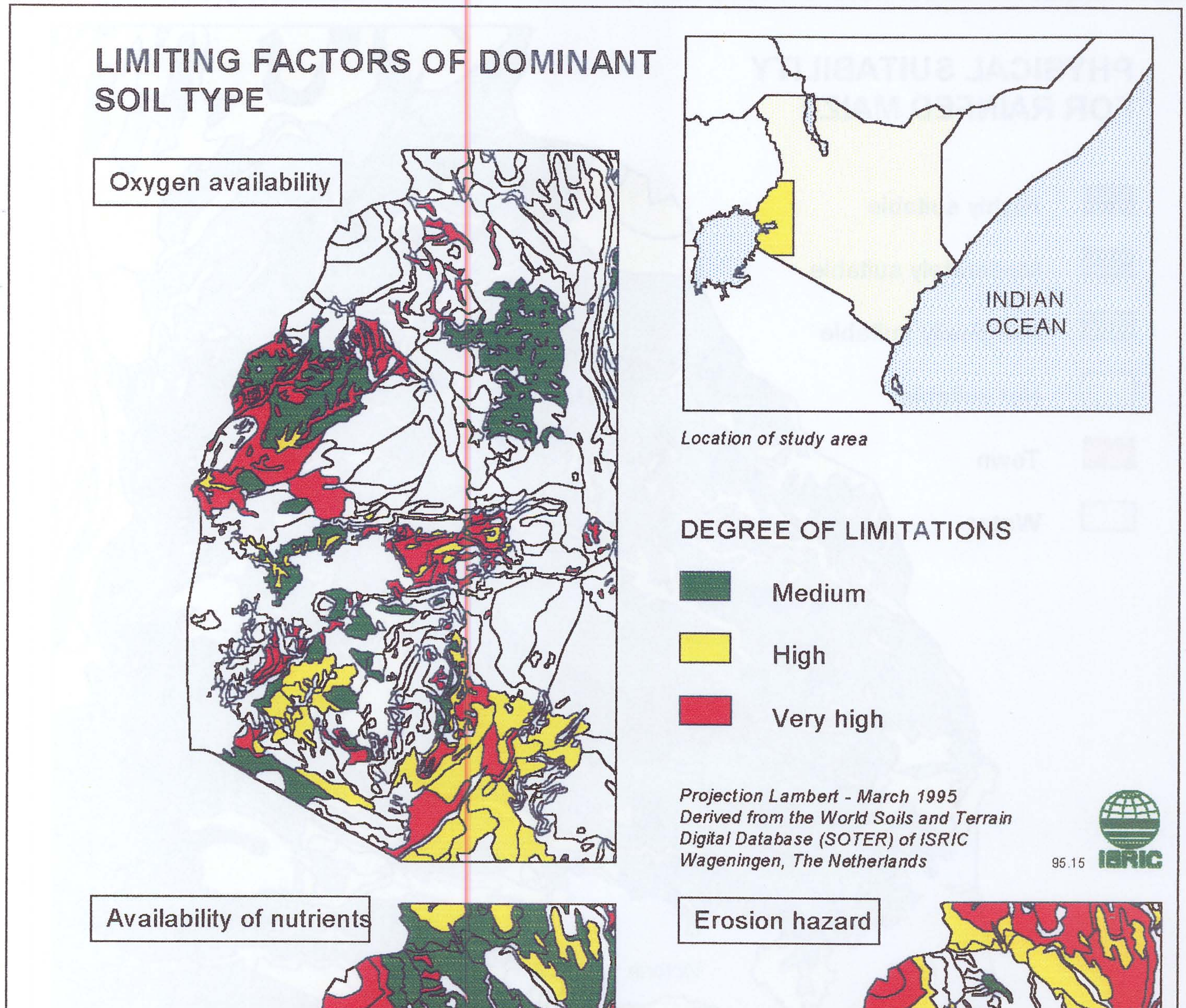


Figure 5: Major limiting factors for cultivation of maize and sorghum in West Kenya

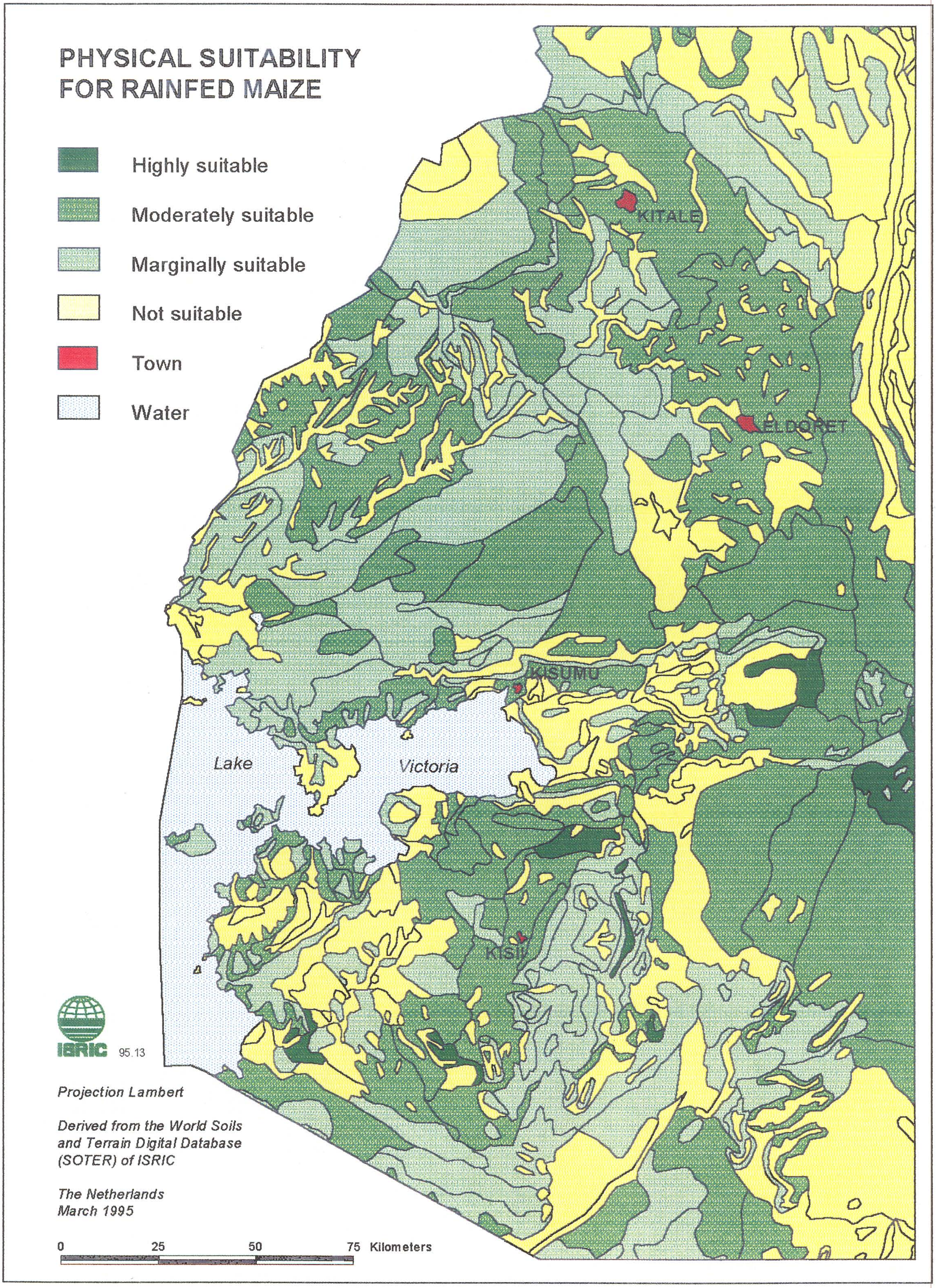


Figure 6: Physical suitability for rainfed maize in West Kenya based on SOTER data

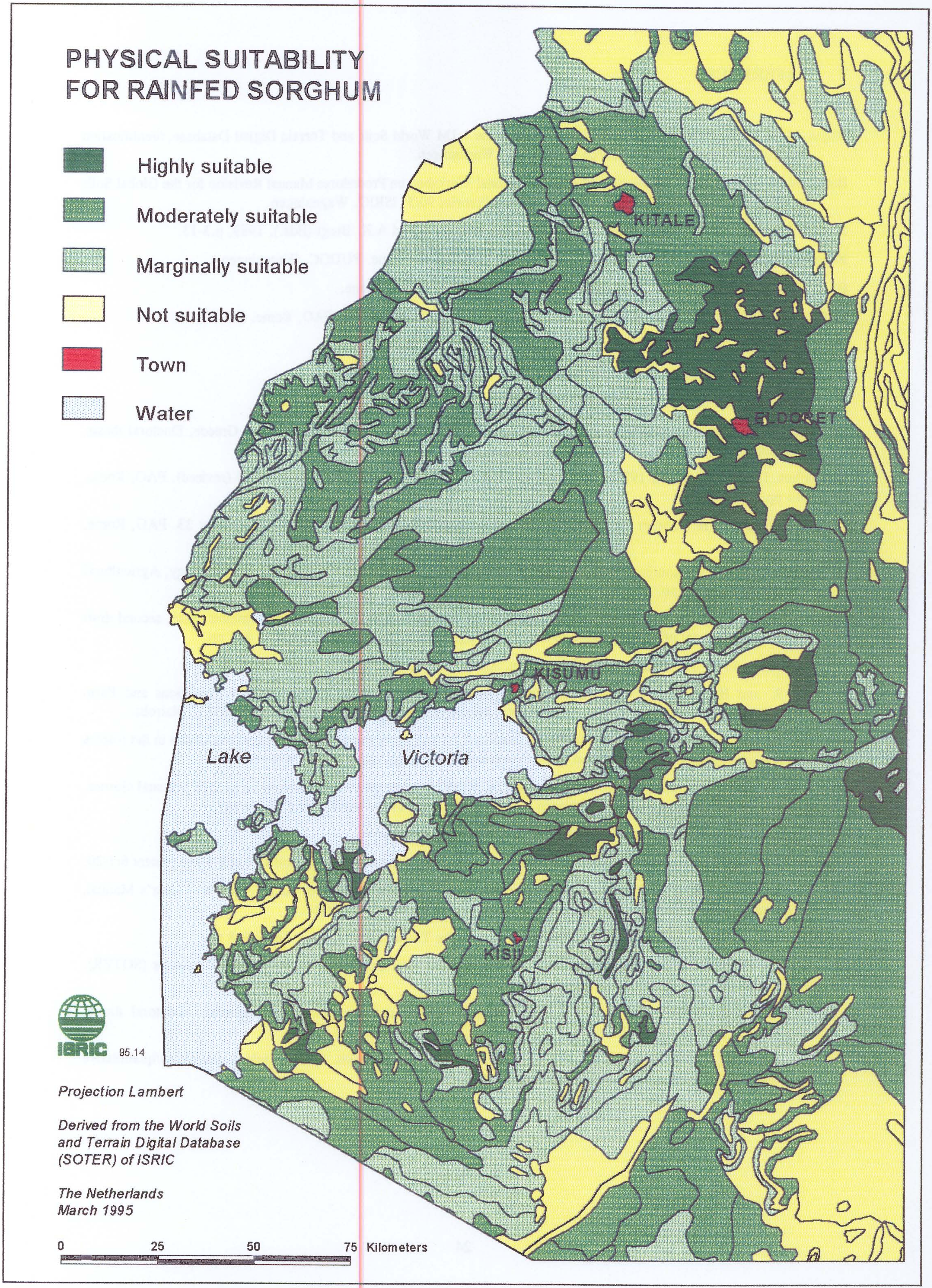


Figure 7: Physical suitability for rainfed sorghum in West Kenya based on SOTER data

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8 INDEX

APPENDIX 1 HOW TO IMPORT DATA FROM A DATABASE INTO ALES

Two files have to be made: one file with land mapping unit definitions (soter unit id's) and another with land unit data.

The land mapping unit file contains the following information: Land Mapping Unit ID (Soter unit ID), Name (can be Soter Unit ID or soil classification name or another name), Type (homogeneous or compound) and Extent (hectares or acres). An example of the format of the ASCII-file:

"SUID";"SUID";"h";100

The land unit data file contains information on the values (either continuous or discrete) of defined land characteristics in the data entry templates of Land Mapping Units. The ASCII-input file should be build up in such a way that every line (record) contains information on one LMU. Each line then reads: Land Mapping Unit ID (SUID), value, value, etc. An example of the format of the ASCII-file of a soter unit, with erosion hazard, nutrient availability, availability of moisture and pH (only the last item is continuous in this example):

"SUID";"1";"m";"h";6.5

The format of a LMU-file can also easily be checked, by exporting existing LMU-data in ALES to an ASCII-file (option 1.3.6).

An automated data transfer facility (from SOTER to SOTAL) facility is currently being developed.

APPENDIX 2 FROM DISCRETE TO CONTINUOUS

For data entry not in classes (discrete) but in numerical values (continuous) it is assumed that the discrete land characteristic has already been defined in the ALES-model, so that the class boundaries have been defined. For example monthly precipitation (PRE) was entered in classes.
The steps then to take are: define the continuous land characteristic --> option 1.1 (reference list) --> then select 4 (land characteristics). Press F3 to define a new LC. ALES then asks you for a code, which normally will be the same as for the discrete LC, but with a c added (f.i.: PRE-c). Fill in zero for the number of classes! Then, in window 1.1.4.c-2, fill in the class limit. Confirm the choice: option 9 and go back to the choice box. Now the two defined LC's (discrete/continuous) have to be linked, so that the class-value can be inferred from the continuous value. This is only possible for LC's with the same unit of measurement (commensurate). Now we have PRE (discrete) and PRE-c (cont.). Go to PRE in the choice box and press F5 (editor). Menu 1.1.4.a appears of which you should choose option 6 (infer...). Choose the related LC (PREC-c) press F10 three times to go back to the main menu. When no value was entered for the discrete LC, but only for the continuous LC, ALES will infer the value (this can also be done by pressing 9 (infer...). An explanation of this procedure is given in the ALES-4 manual on page 108 (par. 7.4.5.1.).

APPENDIX 3 LAND QUALITIES/LAND CHARACTERISTICS DEFINED IN SOTAL

Land qualities defined in SOTAL:

LQ-avm	availability of moisture (avm)
LQ-avn	availability of nutrients (avn)
LQ-er	erosion hazard (er)
LQ-flo	flooding hazard (flo)
LQ-foo	available foothold for roots (foo)
LQ-ger	conditions for germination (ger)
LQ-mech	potential for mechanisation (mech)
LQ-ox	availability of oxygen for root growth (ox)
LQ-sal	excess of salts (sal)
LQ-tox	soil toxicities (tox)
LQ-temp	temperature (temp)

Land characteristics used in SOTAL for land quality assessment:

LQavm	climatic, soil physical and crop characteristics as required by the water balance model WATSAT.
LQavn	organic carbon content, sum of bases, pH.
LQer	dominant slope, length of slope, infiltration rate, sensitivity for capping/sealing.
LQflo	flooding frequency, flooding duration.
LQfoo	rootable depth, gravel content.
LQger	topsoil structure, size of structure elements, sensitivity to capping/sealing, surface stoniness.
LQmech	surface rockiness, surface stoniness, gravel content of the profile, dominant slope.
LQox	soil drainage class.
LQsal	electrical conductivity (ECe) of the topsoil and of the subsoil, Exchangeable sodium percentage (ESP) of the topsoil and of the subsoil.
LQtox	aluminium saturation percentage (ASP).
LQtemp	check for too low temperatures during the growing season as evaluated by WATSAT.

APPENDIX 4 ADDITIONAL INFORMATION ON WATSAT

Table 2: Crop groups with similar drought tolerance. Source: Driessen and Konijn (1992).

Crop group	Representative crops
1	onion, peppers, potato
2	cabbage, pea, tomato
3	phaseolus bean, groundnut, rice, sunflower, water-melon, wheat
4	cotton, maize, sorghum, soya, sugar-beet, sugar-cane, tobacco

Table 3: Depletion fraction (p) as a function of crop group and maximum rate of transpiration (TRM). Source: Doorenbos et al. (1979).

Crop group	TRM ($cm.d^{-1}$)								
	<0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	>=1.0
1	0.500	0.425	0.350	0.300	0.250	0.225	0.200	0.200	0.175
2	0.675	0.575	0.475	0.400	0.350	0.325	0.275	0.250	0.225
3	0.800	0.700	0.600	0.500	0.450	0.425	0.375	0.350	0.300
4	0.875	0.800	0.700	0.600	0.550	0.500	0.450	0.425	0.400

Table 4: Critical leaf water heads (PSI_{leaf}, in cm) of some common crops#. Source: Reinds (1988).

Crop	PSI_{leaf}	Crop	PSI_{leaf}
green pepper	3 500	soya	15 000
potato	7 000	maize	17 000
tobacco	13 000	sorghum	20 000
sunflower	14 000	cotton	25 000
wheat	14 000		

all values are determined on field grown plants

Formula to calculate the maximum rate of infiltration (IM):

First the actual sorptivity is calculated, that changes with soil moisture content:

SPSI = S0 * (1 - SMAA / SMTOT)

where:

SPSI	=	the actual sorptivity ($cm.d^{-0.5}$).
S0	=	reference sorptivity ($cm.d^{-0.5}$); deduce from standard table of reference soil textures (table 5).
SMAA	=	volume fraction of moisture in the rooting zone ($cm^3.cm^{-3}$).
SMTOT	=	total available soil moisture ($cm^3.cm^{-3}$).

Infiltration is determined by matric forces and by gravity forces:

$$IM = SPSI * DT^{-0.5} + K_{tr}$$

where:

IM	=	equivalent rate of infiltration ($cm.d^{-1}$).
SPSI	=	actual sorptivity ($cm.d^{-1}$).
K_{tr}	=	hydraulic permeability of the transmission zone ($cm.d^{-1}$); deduce from standard table of reference soil textures (table 5).
DT	=	length of interval (d).

Table 5: Indicative values for soil constants SM0[@], GAM[@], S0[#] and Ktr[#] for reference soil texture classes. Source: Rijtema, 1969 ([@]) and Driessen and Konijn, 1992 ([#]).

Texture	**SM0** ($cm^3.cm^{-3}$)	**GAM** (cm^{-2})	**S0** ($cm.d^{-0.5}$)	**Ktr** ($cm.d^{-1}$)
course sand	0.395	0.1000	50.16	119.23
loamy sand	0.439	0.0330	19.20	30.33
fine sand	0.364	0.0288	21.44	17.80
fine sandy loam	0.504	0.0207	17.57	9.36
silt loam	0.509	0.0185	14.46	5.32
loam	0.503	0.0180	11.73	3.97
loess loam	0.455	0.0169	13.05	8.88
sandy clayloam	0.432	0.0096	19.05	16.51
silty clayloam	0.475	0.0105	6.15	1.18
clayloam	0.445	0.0058	4.70	0.76
light clay	0.453	0.0085	10.74	2.66
silty clay	0.507	0.0065	3.98	0.80
heavy clay	0.540	0.0042	1.93	0.15
peat	0.863	0.0112	7.44	1.86

APPENDIX 5 DATA LISTING OF CROP.DAT

line #1:	"CROPLABEL$"						
line #2:	C3/C4, Tbase (°C), Tsum (°C.d), Tleaf (°C.d), Tlow (°C), RDSroot (0-1), RDm (cm), RDint (cm), PSI_{leaf} (cm)						
line #3:	SLAmax ($m^2.kg^{-1}$), SLAmin ($m^2.kg^{-1}$), ke, TCM, r(leaf), r(root), r(stem), r(s.o.), WETMAX(d)						
line #4:	Ec(leaf), Ec(root), Ec(stem), Ec(s.o.), dummy, dummy, dummy, dummy						
line #5:	NRPTS						
line #6:	RDS	0	1	2	3	.....	NRPTS
line #7:	fr(leaf)	.	.	.	.	.....	.
line #8:	fr(root)	.	.	.	.	.....	.
line #9:	fr(stem)	.	.	.	.	.....	.
line #10:	fr(s.o.)	.	.	.	.	.....	.

C3/C4	:	refers to photosynthetic mechanism of plant
Tbase	:	threshold temperature for development
Tsum	:	heat requirement for full development (°C d)
Tleaf	:	heat requirement for full leaf development (°C d)
Tlow	:	lowest tolerable temperature in growing season (°C)
RDSroot	:	RDS at which root growth ceases
RDm	:	maximum rooting depth
RDint	:	initial rooting depth at planting/germination
PSI_{leaf}	:	critical leaf water head (cm)
SLAmax	:	maximum specific leaf area ($m^2.kg^{-1}$)
SLAmin	:	minimum specific leaf area ($m^2.kg^{-1}$)
ke	:	extinction coefficient for visible light
TCM	:	maximum turbulence coefficient
r(organ)	:	organ specific maintenance respiration rate ($kg.kg^{-1}.d^{-1}$)
WETMAX(d)	:	the maximum number of consecutive days a crop can be exposed to saturated soil conditions (SMAA > SM0 - 0.02)
Ec(organ)	:	efficiency of assimilate conversion in plant part 'org' ($kg.kg^{-1}$)
NRPTS	:	number of points for interpolation
fr(org)	:	mass fraction of gross assimilate production allocated to organ 'org' ($kg.ha^{-1}.d^{-1}$)

For algorithms and theory, reference is made to Driessen and Konijn (1992).

APPENDIX 6 RATINGS OF LAND CHARACTERISTICS USED IN SOTAL

Aluminium Saturation Percentage (ASP)

0 - 10	very low
10 - 25	low
25 - 40	moderate
40 - 80	high
> 80	very high

Availability of moisture

no limitations	-	S1
some to severe stress	-	S2/S3
too dry, crop dies	-	N

Basic infiltration rate (cm h^{-1})

0 - 0.5	very slow
0.5 - 2	slow
2 - 6	moderate
6 - 12	rapid
> 12	very rapid

Depth to bedrock (cm)

0 - 25	very shallow
25 - 50	shallow
50 - 100	moderately deep
100 - 120	deep
> 120	very deep

Dominant slope (%)

0 - 2	flat
2 - 6	gently sloping
6 - 13	sloping
13 - 25	moderately steep
25 - 80	steep/very steep

Drainage class

well to excessively drained
moderately well drained
imperfectly drained
poorly drained
very poorly drained

Electrical conductivity topsoil (0-30 cm) - (dS m^{-1})

0 - 2	very low
2 - 4	low
4 - 8	medium
> 8	high

Electrical conductivity subsoil (30-120 cm) - (dS m^{-1})

0 - 4	very low
4 - 8	low
8 - 15	medium
> 15	high

Exchangeable Bases ($cmol_c$ kg^{-1})

0 - 2	very low
2 - 4	low
4 - 8	medium
8 - 16	high
> 16	very high

Exchangeable sodium percentage topsoil (0-30 cm)

0 - 6	very low
6 - 15	low
15 - 40	medium
> 40	high

Exchangeable sodium percentage subsoil (30-120 cm)

0 - 15	very low
15 - 40	low
40 - 80	medium
> 80	high

Frequency of flooding

none
daily to weekly
monthly
annually
biennial
once every 2 - 5 years
once every 5 - 10 years
rare (less than once every 10 years)
unknown

Flooding duration (days)

0	-	1
1	-	15
15	-	30
30	-	90
90	-	180
180	-	360

Gravel content/stoniness of profile (vol %)

0	-	2	few
2	-	15	common
15	-	40	many
40	-	80	abundant
	>	80	dominant

Organic carbon (%)

0	-	0.3	very low
0.3	-	0.5	low
0.5	-	1.0	medium
1.0	-	2.5	high
	>	2.5	very high

Rootable (effective) soil depth (cm)

0	-	30	very shallow
30	-	50	shallow
50	-	100	moderately deep
100	-	150	deep
	>	150	very deep

Sensitivity to capping/sealing

none
weak
moderate
strong

Size of structure elements

very fine to fine
medium to very coarse

Slope length (m)

0	-	50	short
50	-	200	medium
	>	200	long

Soil acidity (pH)

0	-	4	very acid
4	-	5.5	acid
5.5	-	7.0	slightly acid

Soil basicity (pH)

7	-	7.5	slightly basic
7.5	-	8.5	basic
8.5	-	10	very basic

Surface rockiness (%)

0	-	2	very few
2	-	15	few
15	-	40	common
40	-	70	many
	>	70	abundant

Surface stoniness (%)

0	-	2	none to very few
2	-	5	few
5	-	15	common
15	-	40	many
	>	40	abundant

Temperature

no limitations
too cold

Topsoil structure

single grain, crumb, granular, platy
medium subangular blocky
coarse subangular blocky
massive
prismatic

APPENDIX 7 PROGRAM LISTING WATSAT IN QUICKBASIC 4.5

```
CLS
SCREEN 9
COLOR 9, 10
LOCATE 5, 23: PRINT "WATSAT - A SIMPLE WATER BALANCE MODEL"
COLOR 15, 10
COLOR 9, 10
LOCATE 8, 23: PRINT "DRAFT - release 1.0   (October 1994)"
COLOR 15, 10
LOCATE 13, 10: PRINT "INTERNATIONAL SOIL REFERENCE AND INFORMATION
CENTRE"
LOCATE 14, 10: PRINT
LOCATE 15, 28: PRINT "P.O. BOX 353"
LOCATE 16, 28: PRINT "6700 AJ Wageningen"
LOCATE 17, 28: PRINT "The Netherlands"
LOCATE 25, 10: PRINT "PRESS ANY KEY TO CONTINUE"
WHILE INKEY$ = "": WEND
'
CLS
SCREEN 9
COLOR 14, 8
PRINT
PRINT
PRINT
PRINT" *******************************************************************
PRINT "*******************************************************************"
COLOR 15, 8
PRINT " *** WATSAT, A SIMPLE WATER BALANCE PROGRAM          ***"
PRINT " *** TO QUANTIFY THE SUFFICIENCY OF WATER SUPPLY     ***"
PRINT " *** TO A RAINFED ANNUAL CROP                        ***"
COLOR 14, 8
PRINT "*******************************************************************"
PRINT "**** Program for calculating the sufficiency of the land          ****"
PRINT "**** quality 'water availability to an annual crop during the     ****"
PRINT "**** growing season' for an ALES land evaluation procedure        ****"
PRINT "**** using SOTER data (SOTAL).                                    ****"
PRINT "**** ISRIC, Wageningen, March 1994. Author: S.Mantel              ****"
PRINT"********************************************************************"
'PRINT"********************************************************************"
PRINT"********************************************************************"
PRINT "* This program is based on theory and formula's by Doorenbos et *"
PRINT "* al (Yield response to water, FAO, Irrigation and Drainage      *"
PRINT "* paper 33), Driessen & Konijn (Land-use systems analysis,       *"
PRINT "* chap. 5 and 6) and the waterbalance program WATSUFA            *"
PRINT "* (Driessen, 1993).                                              *"
PRINT"********************************************************************"
PRINT
'
PRINT "PRESS ANY KEY TO CONTINUE"
WHILE INKEY$ = "": WEND
'
' The program consists of 3 main parts:
' (1) PROGRAM INITIALIZATION,
' (2) INTERVAL CALCULATIONS, and
' (3) OUTPUT OF RESULTS.
'
' *******************************************************
' **     PART (1): PROGRAM INITIALIZATION            **
' *******************************************************
'
' The climate data of the site are read from a sequential file which
' provides the name of the site (SITELABEL$) and the latitude (LAT),
' as well as, for each DAY in the year, the values of TMAX, TMIN, PREC,
' RHA and ET0.
'
DIM TMAX(365), TMIN(365), PREC(365), RHA(365), ET0(365), INTPERC(730)
DIM ETM(730), EM(730), TRM(730), TR(730), EA(730), INTSUFF(730) ', RDS(730)
DIM ERD(30), RD(30), SMPWP(30), ACCINTSUFF(730), ACCPERC(730)
DIM ETA(730), ACCETM(730), ACCTRM(730), ACCEM(730), ACCTR(730),
ACCEA(730)
DIM SITELABELS$(20), SOILLABEL$(20), CROPLABEL$(20)

'
'DIM RD(730), ETM(730), ETA(730), INTSUFF(730), SMPSI(730), SMCR(730)
'DIM SMPWP(730), NETSUP(730), TABEL(1 TO 2, 1 TO 9), p(730), ERD(20)
'DIM TRM(730), TR(730), EA(730), EM(730), ACCINTSUFF(730), ACCETM(730)
'DIM ACCEM(730), ACCTRM(730), ACCTR(730), ACCEA(730), ACCPERC(730)
'DIM ACCSMPSI (730), ACCNETSUP(730)

'DIM ACCSMPSI(730), ACCSMCR(730), ACCNETSUP(730)
'
GOSUB CLIMATEDATA
GOSUB SELECTSTATION
'
' The soil properties are constants; there are only few and they can
' be selected from a menu on the screen.
'
GOSUB SELECTSOIL
'
' The CROP PARAMETERS are known once the crop or variety has been
' selected from a menu. The crop data are: T0, TSUM, TCM, RDM, RDINT,
' PSILEAF and TLOW (lowest tolerable temperature in the growing season)
'
GOSUB SELECTCROP
'
' The only basic information on the Land Use System that is still
' missing concerns aspects of management, notably the germination or
' planting date (GERDAY) and the intial soil moisture content at the
' time of planting/germination (SMPSIint).
'
NEXTRUN:
GOSUB MANAGEMENT
'
' Before the calculations can start, a number of parameter values must
' be set to zero. Other parameters have an initial value other than
' zero (e.g. SMPSI = SMPSIint, DAY = GERDAY).
' Functions and numerical constants must be declared (PI, RAD, DEF FN)
'
GOSUB INITIALIZATION
'
NEWCYCLE:
' *******************************************************
' **     PART (2): INTERVAL CALCULATIONS             **
' *******************************************************
'
' -- DETERMINE THE RELATIVE DEVELOPMENT STAGE AT MID-INTERVAL --
'
' In this step, the daily temperature (T24H) is computed first. This
' is done by considering the TMAX(DAY) and TMIN(DAY) values over the
' day (DL) resp. the night (24-DL). The following order of the calcu-
' lations: DEC, SSIN, CCOS, SSCC, DL and T24H.
'
GOSUB DAYTEMP
'
IF LOWTEMP$ = "Y" AND TLOW > 0 THEN GOTO LOWTEMP
'
' -- INPUT OR CALCULATE THE KC-VALUE AND ETM --
'
' The approximate KC-value of a well watered crop is established on the basis
' of the KC-value of a hypothetical reference canopy (KCREF) and a Turbulence
' Coefficient (TC). KC = KCREF * TC. Once KC and TC are known, the momentary
' values of ETM, SMCR AND ETA can be computed.
'
GOSUB KCTRMEM
'
' -- CALCULATE THE RELATIVE DEVELOPMENT STAGE --
'
GOSUB RDSTAGE:
'
' -- CALCULATE THE ACTUAL TRANSPIRATION RATE --
'
GOSUB ACTEVAPO
'
' -- CALCULATE INTSUFF AND RDS AT INTERVAL END --
'
' First, RDS is upgraded to the value at interval end: RDS = RDS + 0.5*DRDS.
'
GOSUB INTSUFF
'
' -- ADJUSTMENT OF STATE VARIABLE PSI --
'
' Compute the soil moisture content (SMPSI). Next, RDS is matched
' with RDSroot and a new (end-of-interval) RD value is computed. The SMPSI
' value is subsequently adjusted. If SMPSI =< SMEQ, there is no percolation
' of water (INTPERC=0). If SMPSI>SMEQ, calculate INTPERC and adjust SMPSI
' (= SMEQ). Calculate the adjusted PSI value.
'

'IF DROUGHTLIMIT >= INT(PSIleaf / 2000 + .5) THEN GOTO CROPOUTDRY

IF DROUGHTLIMIT >= 4 THEN GOTO CROPOUTDRY
'
IF WETLIM >= WETMAX THEN GOTO CROPOUTWET
'
GOSUB NETSUPPLY
'
' This concludes one cycle of interval calculations.
```

```
'
' If RDS>= 1.0 the program branches to PART (3): OUTPUT OF RESULTS.
'
IF RDS >= 1! THEN GOTO NOMOREINTERVALS
'
DAY = DAY + DT
IF DAY = 366 THEN DAY = 1
YESINT = RUNDAY
RUNDAY = RUNDAY + DT
IF RUNDAY > 730 THEN GOTO TOOLONGONFIELD
'
GOTO NEWCYCLE
'
NOMOREINTERVALS:
'
' ****************************************************************
' **     PART (3): OUTPUT OF CALCULATION RESULTS          **
' ****************************************************************
'
' In this part, some of the calculation results that are stored in
' subscripted variables (var(ST,RUNDAY)) will be output on the screen.
' For practical reasons, the screen will show only selected variable
' values. Presented are the cumulative consumptive water use (ACCETM)
' for subsequent periods of 10 or 30 days, and the average TRM, EM,
' INPERC and INTSUFF values over these periods. The bottom row presents
' the cumulative values of water needs and water use over the growth
' cycle.
'
GOSUB OUTPUTRESULTS
'
' Now that the calculations for one scenario are finished, the user
' must decide whether to analyse another scenario or to END.
'
ANOTHERSCENARIO:
'
CLS
PRINT
PRINT
INPUT "  DO YOU WISH TO EXAMINE ANOTHER SCENARIO (Y/N) "; ANOTHER$
IF ANOTHER$ <> "Y" AND ANOTHER$ <> "y" THEN GOTO SIGNINGOFF
'
' To prepare the calculations on the new scenario:
'
RDS = 0: DRDS = 0: TRM = 0: TR = 0: EM = 0: EA = 0: ETM = 0: ETA = 0
DROUGHTLIMIT = 0: WETLIM = 0: TCOUNT = 0
LOWTEMP$ = "0": RUNDAY = 0

ERASE ACCETM, ACCTR, ACCTRM, INTPERC, RD, SMPWP, ACCPERC
ERASE ACCEM, ACCEA, TRM, TR, EM, EA 'ACCSMPSI, ACCNETSUP
'ERASE ACCETM, ACCETA, ACCSMPSI, ACCSMCR, ACCNETSUP, RD, SMPWP
'
PRINT
INPUT "    WILL THIS SCENARIO USE THE SAME CLIMATE DATA (Y/N) ";
SAMECLIM$
PRINT
INPUT "  WILL THIS SCENARIO USE THE SAME SOIL DATA (Y/N) "; SAMESOIL$
PRINT
INPUT "     WILL THIS SCENARIO USE THE SAME CROP DATA (Y/N) ";
SAMECROP$
'
IF SAMECLIM$ <> "Y" AND SAMECLIM$ <> "y" THEN
  ST = 0
  GOSUB CLIMATEDATA
  GOSUB SELECTSTATION
END IF
'
IF SAMESOIL$ <> "Y" AND SAMESOIL$ <> "y" THEN
     GOSUB SELECTSOIL
END IF
IF SAMECROP$ <> "Y" AND SAMECROP$ <> "y" THEN
     GOSUB SELECTCROP
END IF
'
GOTO NEXTRUN
'
LOWTEMP:
CLS
LOCATE 10, 10: PRINT " THIS SCENARIO IS NOT VIABLE DUE TO LOW
TEMPERATURES"
LOCATE 12, 10: PRINT " SUITABILITY CLASS N : too cold"
LOCATE 14, 10: PRINT " CALCULATIONS TERMINATED. PRESS ANY KEY"
WHILE INKEY$ = "": WEND
GOTO ANOTHERSCENARIO
'
TOOLONGONFIELD:
CLS
LOCATE 10, 10: PRINT "   CROP MORE THAN 730 DAYS ON THE FIELD"
LOCATE 12, 10: PRINT "   SUITABILITY CLASS N : too long on field"
LOCATE 14, 10: PRINT "   CALCULATIONS TERMINATED. PRESS ANY KEY"
WHILE INKEY$ = "": WEND
GOTO ANOTHERSCENARIO
'
CROPOUTDRY:
CLS
LOCATE 5, 10: PRINT "Crop perishes after"; RUNDAY; "DAYS AS A CONSEQUENCE
OF"
LOCATE 6, 10: PRINT INT(PSIleaf / 2000 + .5); "CONSECUTIVE DAYS OF ZERO
TRANSPIRATION"
LOCATE 8, 10: PRINT "SUITABILITY CLASS N : too dry"
WHILE INKEY$ = "": WEND
GOTO ANOTHERSCENARIO
'
CROPOUTWET:
CLS
'LOCATE 5, 10: PRINT "CROP DIES AFTER"; WETMAX; "CONSECUTIVE DAYS OF
EXCESSIVE WETNESS"
LOCATE 5, 10: PRINT "CROP DIES DUE TO EXCESSIVE WETNESS"
LOCATE 7, 10: PRINT "SUITABILITY CLASS N : too wet"
WHILE INKEY$ = "": WEND
GOTO ANOTHERSCENARIO
'
SIGNINGOFF:
CLS
SCREEN 9
COLOR 9, 10
LOCATE 5, 23: PRINT "YOU'RE LEAVING WATSAT"
COLOR 15, 10
LOCATE 8, 10: PRINT "If you have questions and/or suggestions please write to the:"
LOCATE 10, 10: PRINT "INTERNATIONAL SOIL REFERENCE AND INFORMATION
CENTRE"
LOCATE 11, 10: PRINT
LOCATE 12, 28: PRINT "P.O. BOX 353"
LOCATE 13, 28: PRINT "6700 AJ Wageningen"
LOCATE 14, 28: PRINT "The Netherlands"
LOCATE 16, 23: PRINT "(With reference to S. Mantel)"
'
LOCATE 25, 10: PRINT "  PRESS ANY KEY TO CONTINUE ": WHILE INKEY$ = "":
WEND
'
END
'
CLIMATEDATA:
' ─────────────────────────────
' - SUBROUTINE TO SELECT APPROPRIATE CLIMATIC DATA -
' ─────────────────────────────
'
SELECTFILE:
CLS
PRINT
PRINT
INPUT "    SPECIFY THE NAME OF THE CLIMATE FILE (drv:name.ext): "; FILE$
PRINT
INPUT "    ==> DO YOU WISH TO CHANGE THIS FILE SPECIFICATION (Y/N) ";
FSEL$
IF FSEL$ = "Y" OR FSEL$ = "y" THEN GOTO SELECTFILE
'
CLS
LOCATE 8, 13: PRINT " COLLECTING THE NAMES OF ALL WEATHER STATIONS"
ST = 1
'
OPEN FILE$ FOR INPUT AS #1
'
WHILE NOT EOF(1)
          INPUT #1, SITELABELS$(ST), LAT, DUMMY, DUMMY
          FOR L = 1 TO 365
            LINE INPUT #1, c$: REM This is just a way to count lines.
          NEXT L
          ST = ST + 1: REM Go to the next station in the file.
WEND
'
CLOSE #1
S = ST - 1
' S is the number of stations in the file.
'
RETURN
'
SELECTSTATION:
'
' The stations counted in the foregoing will now be presented in a
' menu on the screen.
CLS
LOCATE 2, 4
```

```
PRINT "THERE ARE"; S; "CLIMATE STATIONS ON FILE; SELECT A SITE NUMBER"
'
IF S < 61 THEN COUNTERMAX = S ELSE COUNTERMAX = 60
FOR X = 1 TO COUNTERMAX
      IF X <= 15 THEN LOCATE (X + 4), 2
      IF X > 15 AND X <= 30 THEN LOCATE (X - 11), 22
      IF X > 30 AND X <= 45 THEN LOCATE (X - 26), 42
      IF X > 45 AND X <= 60 THEN LOCATE (X - 41), 62
      PRINT USING "###"; X; : PRINT ".  "; : PRINT LEFT$(SITELABELS$(X), 12)
NEXT X
IF S < 61 THEN GOTO ENDSTATIONLIST
LOCATE 22, 4: PRINT "MORE CHOICES ON NEXT SCREEN. PRESS 'ENTER'"
WHILE INKEY$ = "": WEND
'
CLS
' Now follow the same lines for the second screen (stations 61-120).
'
FOR X = 61 TO S
      IF X <= 75 THEN LOCATE (X - 56), 2
      IF X > 75 AND X <= 90 THEN LOCATE (X - 71), 22
      IF X > 90 AND X <= 105 THEN LOCATE (X - 86), 42
      IF X > 105 AND X <= 120 THEN LOCATE (X - 101), 62
      PRINT USING "###"; X; : PRINT ".  "; : PRINT LEFT$(SITELABELS$(X), 12)
NEXT X
'
ENDSTATIONLIST:
'
LOCATE 22, 4
INPUT "TYPE THE APPROPRIATE SITE NUMBER AND PRESS 'ENTER'"; site$
'
IF VAL(site$) < 1 OR VAL(site$) > S THEN GOTO SELECTSTATION
ST = VAL(site$)
'
CLS
LOCATE 10, 10: PRINT "READING THE CLIMATE DATA OF: "; SITELABELS$(ST)
OPEN FILES FOR INPUT AS #1
'
' Browse through the climate file until the selected station is reached.
'
IF ST <> 1 THEN
  FOR X = 1 TO (ST - 1)
      FOR L = 1 TO 366
      LINE INPUT #1, DUMMY$
      NEXT L
  NEXT X
END IF
'
' The selected station is now reached; climatic data are input.
'
INPUT #1, SITELABELS, LAT, DUMMY, DUMMY
FOR L = 1 TO 365
 INPUT #1, DUMMY1, TMAX(L), TMIN(L), PREC(L), RHA(L), DUMMY2, DUMMY3, ETO(L)
NEXT L
' DUMMY1 = JULDAY, DUMMY2 = E0, DUMMY3 = SUN HOURS
CLOSE #1
'
'
RETURN
'
SELECTSOIL:
' ------------------------------------------------
' -  SUBROUTINE TO SELECT THE APPROPRIATE SOIL DATA  -
' ------------------------------------------------
'
SOILFILE:
CLS
PRINT
PRINT
INPUT "     SPECIFY THE NAME OF THE SOIL FILE (drv:name.ext): "; SOILFILE$
PRINT
INPUT "     ==> DO YOU WISH TO CHANGE THIS FILE SPECIFICATION (Y/N) "; SFSEL$
IF SFSEL$ = "Y" OR SFSEL$ = "y" THEN GOTO SOILFILE
'
CLS
Soil = 1
'

OPEN SOILFILE$ FOR INPUT AS #1
'
WHILE NOT EOF(1)
      INPUT #1, SOILLABELS$(Soil)
      FOR L = 1 TO 4
                              LINE INPUT #1, DUMMY$
              NEXT L
              Soil = Soil + 1
WEND
CLOSE #1
Soil = Soil - 1
'
SOILCHOICE:
CLS
'
LOCATE 2, 4: PRINT "THERE ARE"; Soil; "SOTER PROFILES ON FILE"
'
SOILNUMBER = Soil
'
FOR X = 1 TO SOILNUMBER
              IF X > 0 AND X <= 15 THEN
                   LOCATE (X + 4), 2
              ELSEIF X > 15 AND X <= 30 THEN
                   LOCATE (X - 11), 40
              END IF
              PRINT USING "###"; X; : PRINT ".   "; LEFT$(SOILLABELS$(X), 35)
NEXT X
PRINT
LOCATE 22, 4: INPUT "TYPE THE APPROPRIATE SOIL NUMBER AND PRESS 'ENTER'"; Soil$
IF VAL(Soil$) < 1 OR VAL(Soil$) > Soil THEN GOTO SOILCHOICE
'
Soil = VAL(Soil$)
CLS
'
OPEN SOILFILE$ FOR INPUT AS #1
'
IF Soil = 1 THEN GOTO SOILOKE
FOR X = 1 TO (Soil - 1)
              FOR L = 1 TO 5
                   LINE INPUT #1, DUMMY$
              NEXT L
NEXT X
'
SOILOKE:
INPUT #1, SOILLABEL$
INPUT #1, SM0, ERD
INPUT #1, GRAV, GAM
INPUT #1, S0, Ktr
INPUT #1, DUMMY
'
CLOSE #1
'
' END OF SOIL DATA RETRIEVAL
'
CLS
PRINT
PRINT "  You have chosen: "; SOILLABEL$
PRINT
PRINT
PRINT "  Total Pore Space SM0:              "; SM0
PRINT "  Effective Rooting Depth:           "; ERD
PRINT "  Gravel percentage:                 "; GRAV
PRINT "  Texture spec. const. GAM:          "; GAM
PRINT "  Reference sorptivity S0:           "; S0
PRINT "  Transmission rate Ktr:             "; Ktr
PRINT
PRINT
INPUT "  ==> DO YOU WISH TO CHANGE YOUR SOIL SELECTION (Y/N) "; SSEL$
IF SSEL$ = "Y" OR SSEL$ = "y" THEN GOTO SELECTSOIL
'
RETURN
'
SELECTCROP:
' ------------------------------------------------
' -  SUBROUTINE TO COLLECT CROP DATA FROM FILE  -
' ------------------------------------------------
'
CLS
PRINT : PRINT
INPUT "   SPECIFY THE NAME OF THE CROP FILE (drv:name.ext): "; CROPFILE$
PRINT
INPUT "   ==> DO YOU WISH TO CHANGE THIS FILE SPECIFICATION (Y/N) "; CRFSEL$
IF CRFSEL$ = "Y" OR CRFSEL$ = "y" THEN GOTO SELECTCROP
'
CLS
CROP = 1
'
OPEN CROPFILE$ FOR INPUT AS #1
'
WHILE NOT EOF(1)
```

```
     INPUT #1, CROPLABEL$(CROP)
     FOR L = 1 TO 9
     LINE INPUT #1, DUMMY$
     NEXT L
     CROP = CROP + 1
WEND
CLOSE #1
CROP = CROP - 1
'
CORRECTCROPNR:
CLS
IF CROP < 31 THEN CROPNUMBER = CROP ELSE CROPNUMBER = 30
LOCATE 2, 4: PRINT "THERE ARE"; CROP; "CROPS/CULTIVARS ON FILE"
'
FOR X = 1 TO CROPNUMBER
     IF X <= 15 THEN
                              LOCATE (X + 4), 2
     ELSE
                              LOCATE (X - 11), 40
     END IF
     PRINT USING "###"; X; : PRINT ".   "; LEFT$(CROPLABEL$(X), 35)
NEXT X
PRINT
LOCATE 22, 4: INPUT "TYPE THE APPROPRIATE CROP NUMBER AND PRESS
'ENTER'"; CROP$
IF VAL(CROP$) < 1 OR VAL(CROP$) > CROP THEN GOTO CORRECTCROPNR
'
CROP = VAL(CROP$)
CLS
'
OPEN CROPFILE$ FOR INPUT AS #1
'
IF CROP = 1 THEN GOTO POSTCROPSEARCH
'
FOR X = 1 TO (CROP - 1)
     FOR L = 1 TO 10
                              LINE INPUT #1, DUMMY$
     NEXT L
NEXT X
'
POSTCROPSEARCH:
'
INPUT #1, CROPLABEL$
INPUT #1, C3C4$, T0, TSUM, TLEAF, TLOW, RDSROOT, RDM, RDINT, PSIleaf
INPUT #1, SLAMAX, SLAMIN, KE, TCM, RLEAF, RRT, RSTEM, RSO, WETMAX
INPUT #1, ECLEAF, ECROOT, ECSTEM, ECSO, NSO, NSTRAW, PSO, PSTRAW
INPUT #1, NRPTS
FOR y = 1 TO NRPTS
     INPUT #1, CRDS(y)
NEXT y
FOR y = 1 TO NRPTS
     INPUT #1, FRLEAF(y)
NEXT y
FOR y = 1 TO NRPTS
     INPUT #1, FRROOT(y)
NEXT y
FOR y = 1 TO NRPTS
     INPUT #1, FRSTEM(y)
NEXT y
FOR y = 1 TO NRPTS
     INPUT #1, FRSO(y)
NEXT y
'
CLOSE #1
'
CLS
PRINT
PRINT "   You have chosen:   "; CROPLABEL$
PRINT
PRINT
PRINT " Threshold Temperature for Development T0:        "; T0
PRINT " Heat Requirement for Full Development Tsum:      "; TSUM
PRINT " Maximum Turbulence Coefficient:                  "; TCM
PRINT " Root Growth until RDSroot:                       "; RDSROOT
PRINT " Maximum Rooting Depth RDm:                       "; RDM
PRINT " Initial Rooting Depth RDint:                     "; RDINT
PRINT " Critical Leaf Water Head PSIleaf:                "; PSIleaf
PRINT
PRINT
INPUT "    ==> DO YOU WISH TO CHANGE YOUR CROP SELECTION (Y/N) ";
CSEL$
IF CSEL$ = "Y" OR CSEL$ = "y" THEN GOTO SELECTCROP
'
RETURN
'
MANAGEMENT:
'
' ------------------------------------------------
' -- SUBROUTINE TO INPUT MANAGEMENT DATA FROM THE SCREEN --
' ------------------------------------------------
CLS
PRINT
PRINT
INPUT " * GIVE THE (JULIAN) DAY OF PLANTING/GERMINATION  (1-365): ";
GERDAY
IF GERDAY < 1 OR GERDAY > 365 THEN GOTO MANAGEMENT
PRINT
INPUT " * SPECIFY THE ACTUAL SURFACE STORAGE CAPACITY (ASSC, cm):";
ASSC
PRINT
INPUT " * SPECIFY THE INTIAL SURFACE STORAGE CAPACITY (SSint, cm):";
SSINT
PRINT
INPUT "   ==> DO YOU WISH TO CHANGE THESE VALUES (Y/N) "; MSEL$
IF MSEL$ = "Y" OR MSEL$ = "y" THEN GOTO MANAGEMENT
'
RETURN
'
INITIALIZATION:
' ------------------------------------
' -- SUBROUTINE TO INITIALIZE THE CALCULATIONS --
' ------------------------------------
'
CLS
PI = 3.14159: RAD = PI / 180: DT = 1
DEF FNASN (X) = ATN(X / SQR(1 - X ^ 2))
SMPSIINT = SM0 * 333 ^ (-GAM * LOG(333))
SMPSI = SMPSIINT: SS = SSINT: DAY = GERDAY: RUNDAY = 1
SMPWP = (SM0 * (1 - GRAV)) * PSIleaf ^ (-GAM * LOG(PSIleaf))
'
RETURN
'
DAYTEMP:
' ------------------------------------
' -- SUBROUTINE TO CALCULATE RDS AT MID-INTERVAL --
' ------------------------------------
LOCATE 10, 12: PRINT "Processing interval number"; RUNDAY
'
DEC = -23.45 * COS(2 * PI * (DAY + 10) / 365)
SSIN = SIN(LAT * RAD) * SIN(DEC * RAD)
CCOS = COS(LAT * RAD) * COS(DEC * RAD)
SSCC = SSIN / CCOS
'
DL = 12 * (PI + 2 * FNASN(SSCC)) / PI
T24H = (DL * TMAX(DAY) + (24 - DL) * TMIN(DAY)) / 24
'
DRDS = (T24H - T0) * DT / TSUM
IF DRDS < 0 THEN DRDS = 0
RDS = RDS + .5 * DRDS
'
' Check for too low ambient temperatures. Ten consecutive days below
' TLOW or one night with frost are supposed prohibitive conditions.
'
IF T24H > TLOW THEN TCOUNT = 0 ELSE TCOUNT = TCOUNT + 1
IF TMIN(DAY) < 0 OR TCOUNT > 10 THEN LOWTEMP$ = "Y"
'
RETURN
'
KCTRMEM:
' ------------------------------------------
' -- SUBROUTINE TO INPUT OR CALCULATE TC, KC, TRM AND EM --
' --              AT MID-INTERVAL                  --
' ------------------------------------------
'
KCREF = .33 + .73 * RDS + 1.93 * RDS ^ 2 - 2.33 * RDS ^ 3
TC = 1 + (KCREF - .33) * (TCM - 1) / .67
KC = KCREF * TC
'
TRM = ET0(DAY) * TC * (KCREF - .33) / .67
EM = KC * ET0(DAY) - TRM
IF TRM <= 0 THEN TRM = .01
IF EM <= 0 THEN EM = .01
'
ETM = TRM + EM
'
TRM(RUNDAY) = TRM
EM(RUNDAY) = EM
ETM(RUNDAY) = ETM
ACCTRM(RUNDAY) = ACCTRM(YESINT) + TRM * DT
ACCETM(RUNDAY) = ACCETM(YESINT) + (TRM + EM) * DT
ACCEM(RUNDAY) = ACCEM(YESINT) + EM * DT
'
RETURN
```

```
'
RDSTAGE:
'--------------------------------------------------
'- SUBROUTINE TO CALCULATE RD, KPSI, Rplant AND Rroot -
'-             AT MID-INTERVAL                        -
'--------------------------------------------------
'
IF RDS <= RDSROOT THEN
  RD = RDINT + RDS * (.5 * RDM - RDINT) / RDSROOT
ELSE
  RD = .5 * RDM
END IF
IF RD > (.7 * ERD) THEN RD = (.7 * ERD)
'
RETURN
'
ACTEVAPO:
'--------------------------------------------------
'- SUBROUTINE TO CALCULATE THE POTENTIALLY AVAILABLE SOIL -
'- MOISTURE AND THE ACTUAL EVAPORATION RATE AS A FUNCTION -
'- OF PSIMUL AND THE VAPOUR GRADIENT                      -
'--------------------------------------------------
'
' The actual transpiration rate is calculated according to the method
' described by Doorenbos et al. (1979). In which the moisture content
' of the soil at which stomata start to close (the critical volume
' fraction of moisture in soil, SMCR) is expressed as a function of the
' total available soil moisture. A depletion fraction of the total
' available soil moisture is determined (p, between 0 and 1). This
' fraction is soil independent, but crop specific. Crops can be grouped
' according to the fraction (p) to which the available soil water can be
' depleted while maintaining TR equal to TRM. This depletion fraction is
' a function of the physiological tolerance to drought of the crop and the
' maximum rate of water loss from the rooted soil to the atmosphere (ETM).
'
' First calculate the total amount of moisture the soil can hold potentially
'
SM6 = (SM0 - .06) * (1 - GRAV)
'
SM2 = (SM0 - .02) * (1 - GRAV)
'
'SMTOT = (SM0 - .04) * (1 - GRAV)
'
' Now depletion fraction p is determined
'
TABEL(1, 1) = .2
TABEL(1, 2) = .3
TABEL(1, 3) = .4
TABEL(1, 4) = .5
TABEL(1, 5) = .6
TABEL(1, 6) = .7
TABEL(1, 7) = .8
TABEL(1, 8) = .9
TABEL(1, 9) = 1
TABEL(2, 1) = .875
TABEL(2, 2) = .8
TABEL(2, 3) = .7
TABEL(2, 4) = .6
TABEL(2, 5) = .55
TABEL(2, 6) = .5
TABEL(2, 7) = .45
TABEL(2, 8) = .425
TABEL(2, 9) = .4
'
IF TRM < TABEL(1, 1) THEN
  p = TABEL(2, 1)
ELSEIF TRM >= TABEL(1, 9) THEN
  p = TABEL(2, 9)
ELSE
  I = 1
  DO WHILE I <= 9
        IF TRM >= TABEL(1, I) THEN
            I = I + 1
        ELSE
            EXIT DO
        END IF
  LOOP
END IF
'
IF TRM >= TABEL(1, 1) AND TRM < TABEL(1, 9) THEN
  p = TABEL(2, I - 1) - (TRM - TABEL(1, I - 1)) * (TABEL(2, I - 1) - TABEL(2, I)) / .1
END IF
'
SMCR = (1 - p) * (SM2 - SMPWP) + SMPWP     'in cm3.cm-3
'
IF SMPSI >= SM2 THEN
              TR = 0
  ELSEIF SMPSI <= SM2 AND SMPSI >= SM6 THEN TR = TRM * (SM2 - SMPSI) /
.04
  ELSEIF SMPSI < SM6 AND SMPSI >= SMCR THEN
              TR = TRM
  ELSEIF SMPSI < SMCR AND SMPSI > SMPWP THEN
              TR = TRM * (SMPSI - SMPWP) / (SMCR - SMPWP)
  ELSE TR = 0
END IF
IF TR < 0 THEN TR = .01
'
'SMCR(RUNDAY) = SMCR
'ACCSMCR(RUNDAY) = ACCSMCR(YESINT) + SMCR(RUNDAY) * DT
'
' Precise determination of the moisture content of air-dry soil (SMAD) is
' difficult. Here it is assumed that the moisture content of air-dry soil
' is approximately one tenth of SMPWP (cm3.cm-3).
'
SMAD = .1 * SMPWP
'
EA = EM * (SMPSI - SMAD) / (SM0 * (1 - GRAV) - SMAD)  ' in cm.d-1
'
IF EA < 0 THEN EA = 0
'
ETA = EA + TR
'
ETA(RUNDAY) = ETA
'ACCETA(RUNDAY) = ACCETA(YESINT) + (EA + TR) * DT
'
TR(RUNDAY) = TR
ACCTR(RUNDAY) = ACCTR(YESINT) + TR * DT
'
EA(RUNDAY) = EA
ACCEA(RUNDAY) = ACCEA(YESINT) + EA * DT
'
RETURN
'
INTSUFF:
'--------------------------------------------------
'- SUBROUTINE TO CALCULATE THE SUFFICIENCY            -
'- (INTSUFF) AND THE RDS                              -
'-            FOR THE END OF THE INTERVAL             -
'--------------------------------------------------
'
'INTSUFF(RUNDAY) = ETA(RUNDAY) / ETM(RUNDAY)
'
INTSUFF(RUNDAY) = TR(RUNDAY) / TRM(RUNDAY)
'
RDS = RDS + .5 * DRDS
'
RETURN
'
NETSUPPLY:
'--------------------------------------------------
'- SUBROUTINE TO CALCULATE THE ROOTING DEPTH AND SOIL  -
'- MOISTURE CONTENT AT INTERVAL END                    -
'--------------------------------------------------
'
IF RDS <= RDSROOT THEN
  RD = RDINT + RDS * (.5 * RDM - RDINT) / RDSROOT
ELSE
  RD = .5 * RDM
END IF
IF RD > (.7 * ERD) THEN RD = (.7 * ERD)
'
'RD(RUNDAY) = RD
'
NETSUP = PREC(DAY) * DT - ETA * DT
'
'NETSUP(RUNDAY) = NETSUP
'ACCNETSUP(RUNDAY) = ACCNETSUP(YESINT) + NETSUP(RUNDAY) * DT
'
'**************************************************
'* Calculation of the infiltration capacity (IM)        **
'**************************************************
'
IM = S0 * (1 - SMPSI / SM0) * DT ^ -.5 + Ktr '(rel. 9.15)
'
IF IM < 0 THEN IM = 0
'
IF NETSUP = IM THEN
              DS = 0
              SR = 0 '(relation 9.9a)
ELSEIF NETSUP < IM THEN
              IF (IM - NETSUP) >= SS / DT THEN
                  DS = SS / DT
```

```
                              SR = 0 'relation (9.9b)
    ELSE
                              DS = IM - NETSUP
                              SR = 0 '(relation 9.9c)
    END IF
ELSE
    IF (NETSUP - IM) > (ASSC - SS) / DT THEN
                              DS = -(AASC - SS) / DT
                              SR = NETSUP - IM + DS ' relation (9.9d)
                              END IF
END IF
'
UPFLUX = NETSUP + DS - SR
'
'SMPSI = SMPSI + UPFLUX * DT / RD
'
SMPSI = SMPSI + UPFLUX * DT / (RD * (1 - GRAV))
'
IF SMPSI < (.001 * SMPWP) THEN SMPSI = (.001 * SMPWP)
'
'IF SMPSI > SMTOT THEN SMPSI = SMTOT
'
IF SMPSI > SMPSIINT THEN
  INTPERC = (SMPSI - SMPSIINT) * RD / DT
  SMPSI = SMPSIINT
ELSE
  INTPERC = 0
END IF
'
IF SMPSI >= SM6 THEN
    WETLIM = WETLIM + 1
ELSE
    WETLIM = 0
END IF
'IF SMPSI <= SMPWP THEN GOTO CROPOUTDRY
IF SMPSI <= SMPWP THEN
    DROUGHTLIMIT = DROUGHTLIMIT + 1
ELSE
    DROUGHTLIMIT = 0
END IF
'
'PSI = EXP((1 / GAM * LOG(SMTOT / SMPSI)) ^ .5)
'
SS = SS - DS * DT '(rel. (9.18)
IF SS < 0 THEN SS = 0
'
'RD(RUNDAY) = RD
'
INTPERC(RUNDAY) = INTPERC
ACCPERC(RUNDAY) = ACCPERC(YESINT) + INTPERC
'
'SMPSI(RUNDAY) = SMPSI
'ACCSMSPI(RUNDAY) = SMPSI(YESINT) + SMPSI(RUNDAY) * DT
'
RETURN
'
OUTPUTRESULTS:
'------------------------------------------
' -- SUBROUTINE TO PRINT CALCULATION RESULTS ON THE SCREEN --
'------------------------------------------
'
CLS
Z = RUNDAY: ' To remember the last value of RUNDAY
LASTDAY = (GERDAY + Z)
IF LASTDAY > 365 AND LASTDAY <= 730 THEN LASTDAY = LASTDAY - 365
IF LASTDAY > 730 THEN LASTDAY = LASTDAY - 730
'
PRINT "              SUMMARY CHART "
PRINT
PRINT " "; CROPLABEL$; " grown on soil "; SOILLABEL$; ""
PRINT " (SMAAint = "; : PRINT USING "##.##"; SMPSIINT; : PRINT ")";
PRINT " at "; SITELABEL$(ST); " from DAY"; GERDAY; "onwards"; " to DAY ";
USING "###"; LASTDAY;
PRINT " could complete growing cycle, however with slight to severe moisture"
PRINT " stress (Class - S2)"
PRINT " DAY   CUM. USE   TRM     TR     EM     EA";
PRINT "   PERCOLATION    SUFF."
FOR X = 1 TO 74: PRINT "-"; : NEXT
PRINT
W = 10
IF Z > 150 THEN W = 30
'
CROPDAY = GERDAY: COUNTER = 0: TELLER = 0: RUNDAY = 0: RESTANT = 0
'
DO WHILE RUNDAY < (Z - W)
   CROPDAY = CROPDAY + W
   IF CROPDAY > 365 AND CROPDAY <= 730 THEN CROPDAY = CROPDAY - 365
   IF CROPDAY > 730 THEN CROPDAY = CROPDAY - 730
     DO
             TELLER = TELLER + DT: RUNDAY = RUNDAY + DT
             SUMINTPERC = SUMINTPERC + INTPERC(RUNDAY)
'       SUMSMPSI = SUMSMPSI + SMPSI(RUNDAY)
             SUMINTSUFF = SUMINTSUFF + INTSUFF(RUNDAY)
             SUMTRM = SUMTRM + TRM(RUNDAY)
             SUMTR = SUMTR + TR(RUNDAY)
             SUMEM = SUMEM + EM(RUNDAY)
             SUMEA = SUMEA + EA(RUNDAY)
     LOOP WHILE TELLER < W
   TELLER = 0
   PRINT USING "####"; CROPDAY;
   PRINT USING "######.##"; ACCETM(RUNDAY); SUMTRM / W; SUMTR / W;
   PRINT USING "######.##"; SUMEM / W; SUMEA / W;
'   PRINT USING "#########.##"; SUMSMPSI / W; SUMINTSUFF / W
   PRINT USING "#########.##"; SUMINTPERC / W; SUMINTSUFF / W
   SUMINTPERC = 0: SUMINTSUFF = 0: SUMTRM = 0: SUMTR = 0
   SUMEM = 0: SUMEA = 0: TELLER = 0
   SUMSMPSI = 0
LOOP
'
LASTDAY = (GERDAY + Z)
IF LASTDAY > 365 AND LASTDAY <= 730 THEN LASTDAY = LASTDAY - 365
IF LASTDAY > 730 THEN LASTDAY = LASTDAY - 730
'
DO UNTIL RUNDAY >= Z
  SUMINTPERC = SUMINTPERC + INTPERC(RUNDAY)
'  SUMSMPSI = SUMSMPSI + SMPSI(RUNDAY)
  SUMINTSUFF = SUMINTSUFF + INTSUFF(RUNDAY)
  SUMTRM = SUMTRM + TRM(RUNDAY)
  SUMTR = SUMTR + TR(RUNDAY)
  SUMEM = SUMEM + EM(RUNDAY)
  SUMEA = SUMEA + EA(RUNDAY)
  RUNDAY = RUNDAY + DT
  RESTANT = RESTANT + DT
LOOP
'
PRINT USING "####"; LASTDAY;
PRINT USING "######.##"; ACCETM(Z); SUMTRM / RESTANT; SUMTR / RESTANT;
PRINT USING "######.##"; SUMEM / RESTANT; SUMEA / RESTANT;
'PRINT USING "#########.##"; SUMSMPSI / RESTANT; SUMINTSUFF / RESTANT
PRINT USING "#########.##"; SUMINTPERC /RESTANT; SUMINTSUFF /RESTANT
SUMINTPERC = 0: SUMINTSUFF = 0: SUMTRM = 0: SUMTR = 0: SUMEM = 0:
SUMEA = 0: SUMPSI = 0
FOR X = 1 TO 74: PRINT "-"; : NEXT
PRINT
PRINT "SUM:";
PRINT USING "######.##"; ACCETM(Z); ACCTRM(Z); ACCTR(Z); ACCEM(Z);
ACCEA(Z);
PRINT USING "#########.##"; ACCPERC(Z); ACCTR(Z) / ACCTRM(Z)
'PRINT
PRINT
'PRINT "SMAA = Actual available soil moisture fraction."
'PRINT "SMCR = Critical volume fraction of moisture in soil."
PRINT "  PRESS ANY KEY TO CONTINUE  ": WHILE INKEY$ = "": WEND
CLS
'
GOTO ANOTHERSCENARIO
'
RETURN
'
```