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AGRICULTURAL SUITABILITY OF REFERENCE SOILS

The Automated Land Evaluation System

applied to

ISRIC Soil Information System

S. Mantel
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STRESS is a model for assessment of agricultural suitability of reference soils using the Automated Land Evaluation System (ALES). STRESS was built by S. Mantel, largely based on rating criteria developed during the National Soil Reference Collections and Databases (NASREC) Project. The data transfer facility, which is incorporated in the ISIS-menu, was made by T. van de Ven and P. Tempel.

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ABSTRACT

A reference soil is a (major) soil type that is representative for an (agro) ecological zone in a region or country. Since 1980, the International Soil Reference and Information Centre has supported the establishments of National Soil Reference Collections in 15 countries. For a NASREC to be of value to a wider range of users, an indication of agricultural potential of reference soils is imperative. With the objective of providing a standard assessment for qualitative land evaluation to enable a comparison of soils from different parts of the world, a qualitative land evaluation procedure ('STRESS') was developed. The procedure is based on the 'Framework for Land Evaluation' (FAO, 1976, 1983) using the Automated Land Evaluation System (ALES), (Rossiter, 1990, Rossiter and Van Wambeke, 1993).

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 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 involves the comparison ("matching") of the requirements of a specified land use with the properties of the land.

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, 1993). The ALES program works with *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).

STRESS is a qualitative model for physical land evaluation using ALES and with which data from ISRIC Soil Information System (ISIS) can be evaluated. Reference soils are evaluated for a Major kind of Land Use (MLU): 'rainfed, low input arable farming'. This MLU is characterized by 15 land use requirements and evaluated by 'matching' the land use requirements with the corresponding land qualities. Up to now, more specific Land Utilization Types (LUTs) defined in STRESS are: rainfed cultivated maize and sorghum (low/medium technology).

The attributes available for ALES are entered through *data entry templates*, being lists of land characteristics which are included in the evaluation by the model builder. Related data items for the STRESS models where grouped in five data entry templates.
A facility for transfer of data from ISIS to ALES has been incorporated in the ISIS menu.

Two examples of STRESS evaluations are presented. The first example, given in paragraph 5.2, concerns the assessment of major constraints for agriculture of a reference soil from Jamaica. In another example, STRESS is applied on a large set of reference soil data from the humid tropics. Major constraints are indicated for dominant soils of the humid tropics.

STRESS provides a standard assessment for qualitative land evaluation that enables a comparison of soils from different parts of the world. It facilitates national institutions, in a regional context, to communicate on reference soil evaluation for agricultural suitability.
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 its use is crucial to the success of the approach. Validation of the procedure is desirable.

1. INTRODUCTION

National Soil Reference Collections and Databases (NASREC)
A reference soil is a soil type that is representative for an (agro-) ecological zone in a region or country. The establishment of National Soil Reference Collections (NASREC) is the major aim of the NASREC programme. Since 1980, ISRIC has supported the establishment of such collections in 15 countries. A NASREC includes a soil exposition, a soil database and accompanying publications (Country Reports, Soil Briefs). The exposition of soil monoliths can be used for training and research purposes by students and soil scientists and also by non-soil scientists from agricultural, environmental or related organisations.

Once information on reference soils and their distribution is established, implications of the differences in soil and their characteristics for agricultural use can be assessed. For a NASREC to be of value to a wider range of users, an indication of agricultural potential of reference soils is imperative. Information on agricultural quality of reference soils is presented in soil expositions and in specific publications, called Soil Briefs (e.g. Hennemann & Mantel, 1995).

Land evaluation using National Soil Reference Collection data
In soil exposition posters and in Soil Briefs, suitability ratings are given of single soil parameters using five classes, ranging from very low (1) to very high (5). This rating is the first step in the assessment of soil-related limitations for agriculture, as rating criteria are determined considering general crop requirements. The evaluation of reference soils was further elaborated into a complete evaluation of land for a specific use. A qualitative land evaluation procedure was developed ('STRESS'). The objective is to provide a standard assessment for qualitative land evaluation to enable a comparison of soils from different parts of the world. The procedure is based on the 'Framework for Land Evaluation' (FAO, 1976, 1983) using the Automated Land Evaluation System (ALES), (Rossiter, 1990, Rossiter & Van Wambeke, 1993).

Data on reference soils are stored in ISRIC Soil Information System (ISIS, Van Waveren & Bos, 1988), that includes information on the profiles of the exposition as well as that of other profiles, representing all major soil types within a country (ISRIC, 1993, 1995). This relational database system permits handling and analysis of: (1) site data, including attributes on location, geology, landform, soil surface properties, hydrology, land use and vegetation; (2) climatic data; and (3) profile data, including soil profile descriptions, soil classification and physical, chemical and mineralogical attributes per soil horizon (Kauffman *et al*, 1995). The data readily available in ISIS facilitate analysis of land suitability, assessment of major limitations for agriculture and their alleviation.

The main aim of this report is to introduce a qualitative land evaluation procedure that enables a comparison of soils from different parts of the world. 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). Relevant soil data, and their adequacy for (qualitative) assessment of agricultural potential are discussed in paragraph 4.2 ('Land qualities and their assessment'). Concepts and definitions of land evaluation are discussed in Chapter 2. Principles of the Automated Land Evaluation System are described in chapter 3. The land evaluation procedure is described in Chapter 4. In Chapter 5 some examples of evaluations using STRESS are given. This report is concluded with Chapter 6, in which future work and links to other systems and approaches are indicated. Data transfer between ISIS and ALES-STRESS is explained in Appendix 1.

2. LAND EVALUATION

2.1 Concepts and definitions

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 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 involves the comparison ("matching") of the requirements of a specified land use with the properties of the land.

Land
The spatial entities that are evaluated are land units (LU), or Land Mapping Units (LMU). A LMU comprises an area on a map which is relatively homogenous in terms of soil, climate, topography, hydrology. A land (mapping) unit need not to be uniform in all aspects. Relevant is 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 & 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). They can either be 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 it is a function of soil 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 specified 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 qualities that are evaluated in STRESS are discussed in paragraph 4.2.

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 expressed mainly as 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 order to arrive at a final suitability rating, the individual ratings of the various land qualities are translated into a qualitative suitability class 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 suitability class is determined by the severity level of one land quality (e.g. 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).

2.2 Scales and land evaluation

The degree of detail of conclusions that 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 biophysical and socio-economic information (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 STRESS evaluations are made on the basis of point data (reference soil). These results should not be translated to map units without further study. For this, more profiles representative of the same unit should be evaluated in order to include soil variability affecting the functioning of land in the overall suitability judgement.

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, and does not include by itself any knowledge about land and land use (Rossiter & Van Wambeke, 1993). 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).

ALES has the following six 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*, relating 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*, enabling model builders to understand and fine-tune their models;
- a *consultation mode*, enabling a casual user to query the system about one land use at a time; and
- a *report generator*.

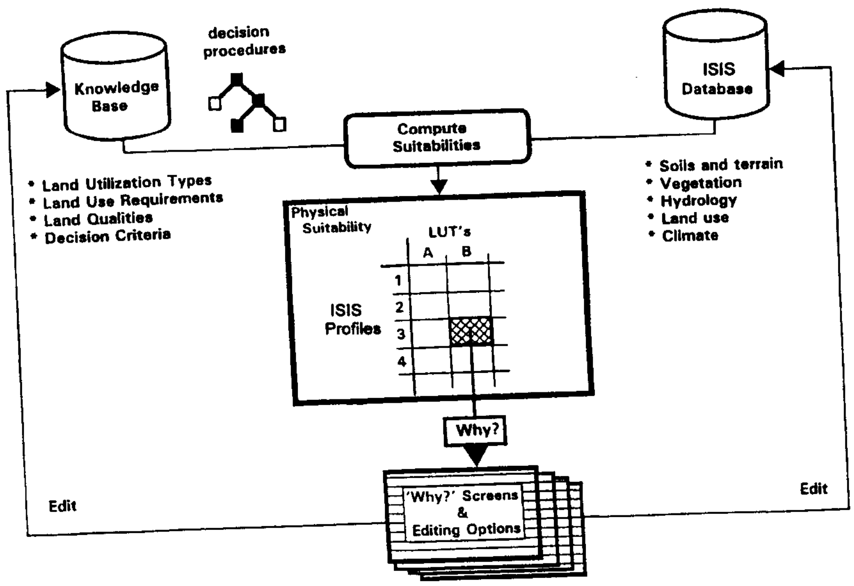
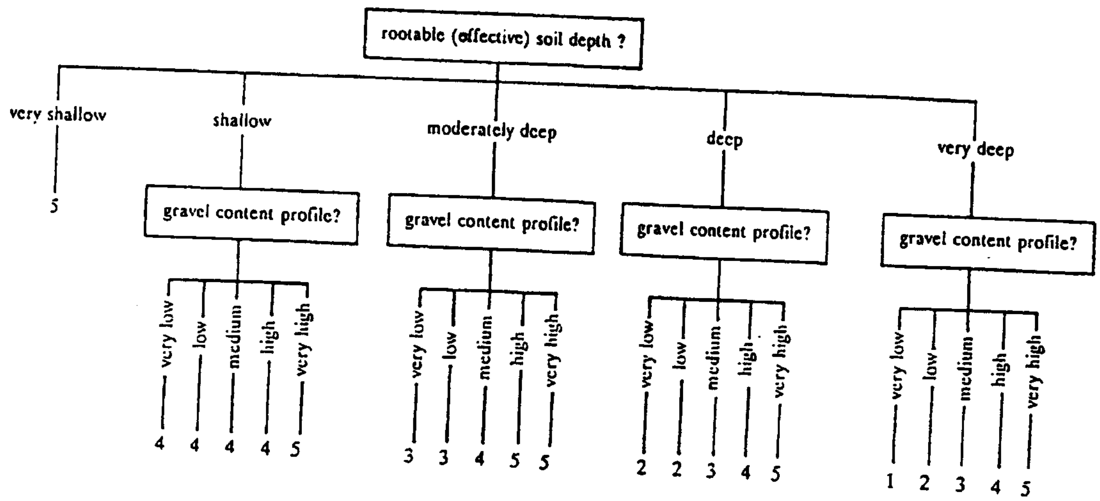


Figure 1: The ALES program flow (modified after Rossiter, 1990)

The ALES program works with *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 for determination of the severity level rating 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 for the land quality 'available foothold for roots' (Source: Mantel, 1995)

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

(1) **defining Land Utilization Types (LUTs)**. The LUTs defined in the STRESS model are (up to now) annual cropping, rainfed cultivated maize and sorghum, both under low technology and medium to low input.

(2) **formulating Land Use Requirements (LURs)** for each LUT. LURs describe the conditions of land which are necessary for successful and sustainable application of the LUT.

(3) **selecting relevant Land Characteristics (LCs)**, that describe the natural resources relevant for the considered LUT.

(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.

(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.

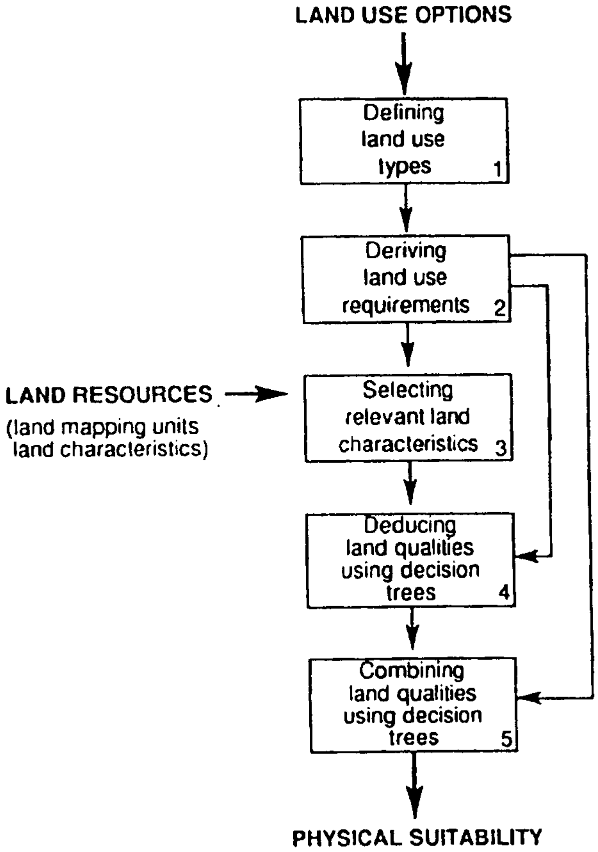


Figure 3: Relational diagram for assessing the physical suitability in ALES. (Source: Van Lanen, 1991).

3.2 Using ALES

Data selection in ISIS and transfer of data from ISIS to ALES is discussed 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** at 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. STRESS: ISIS-APPLICATION FOR AUTOMATED LAND EVALUATION

4.1 Introduction

STRESS is a qualitative model for physical land evaluation using ALES. With STRESS, data from ISIS can be evaluated. Reference soils can be evaluated for a major kind of land use (MLU): 'rain-fed, low input arable farming', thereby indicating possible 'stress-factors' for crop growth. This MLU is characterized by 15 land use requirements and evaluated by 'matching' the land use requirements with the corresponding land qualities (see evaluation table in Appendix 3 for a 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 for one to several land characteristics with the help of decision trees, before the final suitability rating can be determined. The following paragraphs explain which criteria were used for determining the sufficiency of the land qualities. The ratings of land characteristics used in STRESS are given in Appendix 4.

4.2.2 Moisture availability

An assessment of the land quality 'moisture availability' is often of key importance in land evaluation. The question is, whether the availability of water during the growing period restrains growth and development of a particular rainfed cultivated crop, and, if so, to what extent. There is no easy answer to this question, considering the large temporal (and spatial) variability. Furthermore, the sufficiency of this land quality depends on the dynamic interaction between soil, plant, climate and such factors as farm management.

Static water balance model approach
A quick and simple assessment of 'moisture availability' involves the comparison of monthly precipitation and potential evapotranspiration, combined with the moisture storage capacity of the soil. In this way possible growing periods are distinguished. The concept of possible growing periods was elaborated by the FAO Agro-Ecological Zones project (FAO, 1978). The beginning of a growing period is defined as the moment when the amount of precipitation equals half the rate of evapotranspiration ($P > 0.5 * PET$) after a dry period. When, after that, precipitation exceeds full evapotranspiration ($P > PET$) a humid period occurs. The possible growing period ends when the amount of precipitation is lower than half the rate of evapotranspiration and extends into the dry season until all 'available' stored soil moisture has been depleted. In Appendix 4, a rating is given for the length of growing period.

Dynamic water balance model approach
When uptake of water by roots cannot fully replenish transpiration losses, plants actively curb their water consumption (i.e. the rate of transpiration). 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 (Driessen & Konijn, 1992).
In a dynamic water balance model the values of some variables, e.g. precipitation (P), potential evapotranspiration (PET), actual soil moisture (SMAA) and rooted depth (RD) are considered constant for the duration of one interval. The values of P and PET are fixed for the duration of one time

interval, for instance one day, after which new values of P and PET are called from the climate file for calculations for the next time interval. The value of SMAA is used to calculate actual evapotranspiration rate (ETA), after which the value of SMAA is updated by adding the water influx over the rooted depth (RD) and subtracting the (calculated) water losses in the interval. This updated value of SMAA is considered constant over the next interval, and so on. SMAA is a 'state variable'; it is calculated anew for each interval in the crop cycle and expresses the state of the system during one interval. The sufficiency of water availability is often presented as the ratio of actual transpiration (TR) over transpiration maximum (TRM).

Another approach for quantitative assessment of 'moisture availability during the growing season' is running a crop growth simulation model. The sufficiency of moisture availability is then expressed by the ratio of the calculated potential production, restricted only by temperature and radiation, over the calculated water limited production, restricted by radiation, temperature *and* moisture availability.

Static vs dynamic water balance model approach
The advantage of the static water balance approach (Length of Growing Period) is that is it quick, few basic data are needed and a first indication of water availability is obtained. The drawbacks are that soil properties, apart from a static 'available water capacity', are not considered and plant characteristics are not included in the analysis (stored soil moisture is the same for all crops, while plants differ in drought resistance, soil moisture tension at which wilting occurs, etc) and *actual* precipitation is compared with *potential* evapotranspiration.

The advantage of using a dynamic water balance analysis as a tool for this purpose, over f.i. determining a fixed 'Length of Growing Period', is that it is land-use system (crop) specific. In addition to climatic factors, soil attributes, plant specific requirements and interactions are taken into account. With dynamic analysis, the temporal variability of land use requirements and land qualities are taken into account. However, a water balance model requires more data on soil, crop and climate compared to the LGP approach.

To resolve each problem, the appropriate tools should be selected. A quick and first indication of 'availability of moisture' is obtained using the LGP approach. More specific answers are obtained when a quantitative and dynamic simulation water balance model is used, which requires more time and data for running.

4.2.3 Nutrient availability

The availability of nutrients to crops is difficult to assess quantitatively, because key parameters are often very variable in both time and space. Furthermore, measurements of relevant indicators for the nutrient capacity of soils is problematic, as will be discussed in the following paragraphs.
For rating the sufficiency of 'availability of nutrients' in STRESS, a limited amount of variables was selected. These variables were regarded as the basic soil characteristics reflecting fertility conditions: (effective) cation exchange capacity, exchangeable bases, soil reaction (pH) and soil organic matter.

Soil test values and nutrient requirements
For purposes of land evaluation and farm management, a relationship between soil test value and crop yield is much desired. However, soil and seasonal variability make a determination of generic critical levels of soil test values difficult. 'Available' nutrient concentration is normally estimated by exposing a pre-treated (drying, grinding, sieving) soil sample to a 'mild' extraction agent (Driessen, 1994). Nutrient elements in a soil may occur in many forms, and are, depending on the conditions, more or less available to a crop. This availability does not only depend on soil factors, such as soil temperature, pH and moisture conditions, but also on weather conditions and farm management

practices. Moreover, crops differ in their demand for nutrients and some crops are more efficient in extracting elements than others. A relationship of local validity between soil test value and yield can be quantified with the help of multiple regression. However, as regression equations for soil test calibration are both site and season specific, one should repeat such work in both space and time in order to represent a range of uncontrollable variables. In Figure 4, the effect of seasonal variations in environmental factors on the relationship between soil test P and soybean yield is given. Sumner (1990) pointed out that this problem exists with all nutrients, not only P. As an alternative, Sumner proposes a boundary line technique in which ranges of soil test values for a particular yield are investigated by plotting a large number of (specific) soil test observations against multiple-year yield observations in a certain area of a specified crop. For further information, reference is made to Sumner (1990).

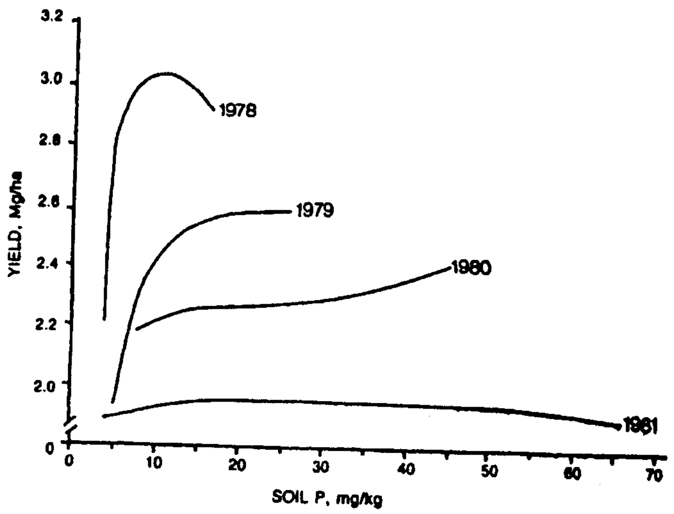


Figure 4: Effect of season on the relationship between soil test P and soybean yield (Sumner, 1990 taken from Hargrove *et al.*, 1984)

Cation Exchange Capacity

The Cation Exchange Capacity (CEC) of many soils consists of both a permanent and a variable component. In highly weathered tropical soils (e.g. Ferralsols, Ultisols) this is because of the presence of minerals such as iron and aluminum hydroxides, with an entirely pH-dependent charge, 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 weathered, tropical soils have a cation exchange capacity that is strongly pH-dependent and their field pH is often around 4.5 so that 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 1 M 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 STRESS both CEC-pH7 and ECEC (1M) are used for evaluation of nutrient retention capacity, the standard CEC 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 reasons mentioned in the preceding paragraph it is preferable to express base saturation as a percentage of the **Effective** CEC. However, in STRESS this problem was avoided altogether using the sum of bases, as a measure instead of base saturation. The remaining disadvantage of this is that the sum of bases does not distinguish between different bases because an imbalance in their relative proportions can have considerable effect on plant growth and can even cause severe nutritional problems.

soil reaction (pH)
The soil pH is used in STRESS 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 micronutrients (except for molybdenum).

Soil organic matter
In many (highly weathered) tropical soils, organic matter contributes to the bulk of ECEC. Moreover organic matter is, together with soil micro-organisms, the main nitrogen source in natural (unfertilized) lands.

4.2.4 Soil erodibility

For estimation of the erosion hazard in STRESS, emphasis is put on the soil and terrain factors that make a land area more or less susceptible to erosion (soil erodibility), because data on rainfall intensity are rare. As diagnostic factors for rating the sufficiency of this land quality were chosen: dominant slope, basic infiltration rate (however, often unavailable), and evidence of capping/sealing. The sensitivity of a soil 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 STRESS using one ISIS-item, viz. flooding frequency.

4.2.6 Available foothold for roots

The 'available foothold for roots' is evaluated and rated in STRESS 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 crops only the conditions in the topsoil matter. This land quality is rated on the basis of: size of structure elements, topsoil structure type, sensitivity to capping/sealing and surface stoniness. When clay content in the topsoil is below a critical value (arbitrarily set at 15%), the silt content and organic matter percentage are also evaluated (as an indication of sensitivity to capping/sealing).

4.2.8 Potential for mechanisation

The potential for mechanisation is assessed and rated in STRESS on the basis of the following land characteristics; rootable depth, surface stoniness, gravel content of the profile and the dominant slope. For the two specific LUTs now defined in STRESS, 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 hard to evaluate qualitatively. The way in which the growth of crops is affected by prolonged conditions of water saturation (= lack of oxygen) vary considerably. For rating this land quality, depth to ground water table and the qualitative description for 'drainage class' are used. The later 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 effect 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. The interpretation of mottling patterns is however difficult, it may be a 'relict' or 'paleo'-feature that is not indicative of actual hydrological conditions. Not all soils that are saturated during part the year show mottling, as reducing conditions are dependent on several factors such as pH, organic matter content, 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 negative effect of sodicity on soil structure is increased, when high sodium levels are combined with levels of low soluble salt.

Assessment
For most (annual) crops, rooting density decreases with depth in the soil profile. 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 (EC) and for evaluating the sodicity, the Exchangeable Sodium Percentage (ESP) is used:

ESP = exchangeable Na^+ / CEC * 100

where: exchangeable Na^+ = extractable Na^+ - soluble Na^+

For evaluation, the soil profile is divided into three layers (0-30 cm, 30-60 cm and 60-100 cm). Averaged values for the respective layers of EC and ESP are combined in the decisions trees to give ratings for salinity and sodicity, respectively.

4.2.11 Soil toxicities

Nature and effects
There are several element toxicities, under widely differing situations, that can affect crop growth. In STRESS for the LUTs defined only one element is considered in rating this LQ; aluminium. It could be argued to combine the evaluation of excess of salts and of aluminium toxicity into one land quality: 'excess of harmful elements'. However, for reason of transparency of the evaluation procedure these were kept separate. Aluminium toxicity refers to the harmful effects of the (high) concentration of Al^{3+} ions in the exchange complex. Concentrations of aluminium in the soil solution above 1 mg/L often cause direct yield reduction (Sanchez, 1976). Aluminium toxicity is strictly a problem on acid soils (mostly Acrisols and Ferralsols), as aluminium becomes exchangeable below pH-H_2O 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 Aluminium Saturation Percentage (ASP) for eight Ultisols and Oxisols, where aluminium first enters the exchange complex at a pH of approximately 5.4, rising to some 20% at about pH 4.9 and 50% or more below pH 4.3.
Crops differ in their tolerance to exchangeable aluminium concentrations in the soil solution. Pineapple is a well known example of a Al-tolerant crop, like tea, coffee, and rubber. Sanchez (1976), reports of pot studies that indicated that root growth of sorghum was affected at much lower Al levels than that of maize. Landon (1991), distinguishes three critical Aluminium saturation levels: 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:

$$ASP = (\text{exchangeable } Al^{3+} / ECEC) * 100$$

In STRESS, ASP is evaluated for three layers, as for salinity and sodicity.

4.2.12 Workability

Workability refers to the ease with which a soil can be tilled or cultivated, either by mechanised methods, ox-drawn tools or hand tools. Workability of a soil depends on a number of interrelated characteristics, such as texture, organic matter content, structure, consistence (particularly plasticity limits), and occurrence of gravels or stones in the surface layer. In general, lighter soils are easier tilled than heavier soils and well structured better than massive soils. Some soils can be cultivated at nearly any moisture condition, while other soils have a very narrow moisture range (FAO, 1984).

In STRESS, workability is assessed on the basis of the following properties: surface stoniness, consistence (wet/dry) and effective soil depth.

4.3 Final suitability rating

Overall suitability for the generic model for rainfed, low input, arable farming is determined by the lowest rated land quality; the maximum limiting factor. The final suitability for specific land utilization types is assessed with a physical suitability subclass decision tree. Through this tree, the ratings for the various land qualities are translated into a (comparative) suitability of a reference soil for the land use under study.

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. Economic parameters can be introduced into the ALES-model to allow for evaluations in physical *and* economic terms. Two kinds of economic evaluations can be performed in ALES: discounted cash flow analysis and gross margin analysis, for which reference is made to ALES Version 4 User's Manual (Rossiter and Van Wambeke, 1993). The advantage of economic evaluation is that it allows for comparison between land utilization types. 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 to a farmer than increasing yields/economic return. Social factors should therefore be considered as well (the availability of labour, knowledge of farmers, etc.).

5. CASE STUDIES OF STRESS APPLICATIONS

5.1 Introduction

In this Chapter two examples of STRESS evaluations are described. The first example concerns the assessment of major constraints for agriculture of a reference soil from Jamaica. A general description and basic data of the reference soil is given, and the evaluation results are presented in an evaluation table that is used in Soil Briefs and soil expositions (Appendix 3).
In another example, STRESS is applied on a large set of reference soil data from the humid tropics. Major constraints are indicated for dominant soils of the humid tropics.

5.2 Evaluation of a reference soil from Jamaica

Reference soil JM 4, as described by Hennemann & Mantel (1995), is a Ferric Acrisol and is representative of the deep, moderately well drained, prominently mottled, red acid clays of the Worthy park series, Jamaica. It occurs on old lacustrine terraces of inland basins in the Central and Eastern Limestone Sub-region of Jamaica.
The climate of the inland basin, Lluidas Vale, is of the tropical monsoon type and classified as Am in the Köppen system. The climate at Worthy Park is favourable for rainfed agriculture in the period from April to November. Major crops in the area, sugar cane and citrus, are mostly grown on plantations. The reference profile, however, was taken in an area of rough pasture.
The parent material underlying this soil consists of lacustrine sediments derived from acid, pre-weathered andesitic tuffs over hard dolomitic limestone. Nature of the parent material and soil hydrology, as reflected by the strongly mottled appearance of the subsoil, have influenced the development of this soil. The soil is classified as a Ferric Acrisol (FAO-Unesco, 1988) or Typic Paleudult (Soil Survey Staff, 1992). JM 4 is a moderately well drained, firm, dark red (2.5YR 3/6) clay overlying a dense, very strongly acid, clayey subsoil with prominent red-grey mottles. Table 1 shows key properties of JM 4.

Table 1: Key properties of profile JM 4

Key property:	
Texture	clay throughout, but with a sharp increase with depth, from 45% (topsoil) to 85% in subsoil and gradually decreasing to about 60-65% in lower subsoil
Organic C	high (3.6%) in the topsoil
Soil reaction ($pH-H_2O$)	strongly acid in topsoil, very strongly acid in subsoil ($pH-H_2O$ 4.1)
Effective cation exchange capacity	medium in topsoil (14 $cmol_c\ kg^{-1}$) and subsoil (between 10 to 17 $cmol_c\ kg^{-1}$)
Sum of bases	medium (12 $cmol_c\ kg^{-1}$) in topsoil, low to very low (0.3-5.2 $cmol_c\ kg^{-1}$) in subsoil
Al saturation (%CEC)	low (4%) in topsoil, moderate to high (40-70%) in subsoil
Base saturation (%CEC)	high (70%) in topsoil, medium (40%) in upper subsoil and very low (2-4%) in lower subsoil
Clay mineralogy	mainly kaolinite with appreciable amounts of 1:2 clays (smectite-chlorite); in the lower subsoil presence of swelling 2:1 clays (smectite)
Air capacity (% by vol, pF0 - pF2)	low (8-9%) in topsoil, very low (2-4%) in subsoil
Available water capacity (% by vol: pF2 - pF4.2)	medium (13%) in topsoil, low to very low (5-6%) in subsoil

Source: Hennemann & Mantel, 1995.

Land qualities and limitations of JM 4 for low input agriculture are presented in Appendix 3. Major limitations for low input agriculture are summarized below:

* *Unfavourable pore size distribution* (near-absence of medium and large pores). Consequently, both moisture holding capacity and air capacity are low. These factors, lead to the following soil physical limitations: a) poor rooting conditions, and b) low moisture availability.

* *Low level of available nutrients*. This refers in particular to low levels of calcium, magnesium and phosphorus in the profile.

* *Strong acidity and high levels of exchangeable aluminium* (subsoil Al-saturation of 70-75%); such levels are harmful to many crops. Aluminium toxicity may restrict effective rooting depth too and thereby reduces the volume for uptake of nutrients and water, restricts the foothold for roots, etc.

Successful cultivation of this soil requires, for most crops, a medium to high level of inputs. Soil management should primarily be directed towards conservation of the topsoil. Lime and fertilizer application (calcium and phosphorus) is recommended in order to improve rooting conditions and, at the same time, increase water holding and air capacity.

5.3 Major constraints of soils of the humid tropics

A study was made on characterization and major constraints of soils of the tropical rainforest areas (Kauffman *et al.*, 1995). Major constraints for agriculture were assessed using STRESS. In this study, 148 reference soils from the humid tropical zone were selected from ISIS. The soils originate from 20 countries and are distributed as follows: Brazil (7), China (3), Colombia (14), Costa Rica (10), Côte d'Ivoire (7), Cuba (5), Ecuador (4), Gabon (6), India (1), Indonesia (29), Jamaica (4), Malaysia (18), Nicaragua (4), Nigeria (10), Peru (11), Philippines (6), Samoa (3), Sri Lanka (1), Thailand (3) and Zaire (2). The locations of the profiles are rather well distributed throughout the humid tropical zone.

As can be seen from Table 2, major constraints for dominant soils of the humid tropics are: low level of plant nutrients, low nutrient retention capacity, and toxicity caused by high exchangeable aluminium levels.

The qualitative degree of limitation in table 2 reads as follows:

no	= no constraint or limitation, no yield reduction
weak	= slight limitation, little yield reduction
moderate	= moderate limitation, some yield reduction
serious	= severe limitation, clear yield reduction
very serious	= very severe limitation, strong yield reduction or no yield.

Because of rounding, the sum of percentages for each land quality may differ from 100.

Table 2: Frequency (%) of constraints by land quality of grouped dominant soils.

degree of constraints / land quality	no	weak	moderate	serious	very serious
length of growing period	70	30	0	0	0
drought hazard	100	0	0	0	0
soil moisture availability	5	39	36	13	6
oxygen availability	68	18	6	7	1
nutrient availability	2	9	13	33	43
nutrient retention capacity	7	5	12	38	38
rootable volume	58	29	10	3	0
conditions for germination	97	2	1	0	0
salinity	99	0	1	1	0
sodicity	79	7	7	1	6
aluminium toxicity	24	0	33	13	30
workability	21	57	15	7	0
potential for mechanisation	38	22	19	16	5
resistance to erosion	41	28	10	11	9
flooding hazard	77	14	8	0	1

Source: Kauffman *et al.*(1995).

Each dominant soil was evaluated for the land qualities indicated in table 2. Then, for each dominant soil, the median of the land quality ratings (1 = no limitation to 5 = severely limiting) was calculated. In Table 3, the major limitations (those that were moderately or (very) severely limiting for at least one soil type) are given for the dominant soils.

Table 3: Major limitations of dominant soils of the humid tropics.

land quality	Ferr	Acri	Luvi	Camb	Aren/Podz	All
Soil moisture	x	x	x		xxx	x
Nutrient availability	xxx	xxx		xx	xxx	xx
Nutrient retention	xxx	xx	x	xx	xxx	xx
Aluminium toxicity	xx	xx		x	x	x
Mechanisation			x			
Resistance to erosion			x			

Source: Kauffman *et al.* (1995). (**x** = moderately limiting, **xx** = severely limiting, **xxx** = very severely limiting.) (Ferr = Ferralsols, Acri = Acrisols, Luvi = Luvisols, Camb = Cambisols, Aren = Arenosols, Podz = Podzols and All = overall figure of 6 soils).

From this Table it can be seen that of the five dominant soils, Luvisols have the most favourable properties for agriculture. Cambisols have severe limitations with respect to availability and retention of nutrients and are moderately aluminium toxic. This study showed that Ferralsols and Acrisols, that cover 60 % of the humid tropics, have rather similar key properties, although variability of each key property for both soils is large. Their separation is based on a relatively small increase in clay content. Consequently, Ferralsols and Acrisols have similar limitations: (very) severe limiting nutrient retention and nutrient availability, severe aluminium toxicity and moderate soil moisture retention.

6. CONCLUSIONS

STRESS is a qualitative model for assessment of potential agricultural suitability of reference soils and enables a comparison of soils from different parts of the world. It facilitates communication, in a regional context, between national institutions on reference soil evaluation for agricultural suitability. Evaluations are based on data from ISIS and refer to point data of reference soils. Although the reference soils are considered representative of (major) soil type(s) in an agro-ecological zone, their actual extent or exact distribution is not known. Furthermore the range of their characteristics is often not quantified. Therefore results of agricultural suitability evaluation should not, be translated to soil map units, unless more reference soil data for the same soil type (or mapping unit) are available and soil variability affecting the suitability of land can be included in the overall judgement. The reference soils indicated as potentially suitable after a STRESS-evaluation have no major physical limitations for the defined land use. For more specific statements, like e.g. a potentially attainable yield, a quantified land evaluation, using dynamic crop growth simulation models, is necessary. The attractive feature of a qualitative land evaluation, preceding a quantified land evaluation, is that the time and data demanding, quantified study can focus on the potentially suitable areas. This is referred to as a 'mixed qualitative/ quantitative land evaluation' (Van Lanen et al; 1992). This approach is also proposed for SOTER (Global and National Soils and Terrain Digital Databases; Van Engelen & Wen, 1995), using an ALES-based model (SOTAL; Mantel, 1995) and a crop growth simulation model. SOTER is a 'geographically referenced' database, linked to a Geographic Information System. The advantage of a SOTER-based evaluations is, that they are done for SOTER (mapping) units and results can be presented, not for points, but for SOTER-*areas*.

The objective is to incorporate more LUTs in STRESS in the future, thereby allowing suitability evaluation of reference soils for a range of LUTs.

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Appendix 1: Data selection and transfer

ALES database and data entry templates

The attributes available for ALES are entered through *data entry templates*, being lists of land characteristics which are included in the evaluation by the model builder (See Rossiter & Van Wambeke, p. 49). Related data items for the STRESS models were grouped. There are five data entry templates, viz. DEF (land unit/reference profile designation), CLIM (climatic data), CHEM (chemical data), CHM2 (chemical data, continues the first CHEM template, which became too large to handle), PHYS (physical data) and SITE (data on profile site). Data can be entered from the keyboard or, more convenient, by importing ASCII-files obtained through automated data selection in the ISIS-menu. The ALES database can only store data for existing Land Mapping Units (LMU). Therefore, the LMU's, or reference profiles in this case, have to be defined first. This can be done from the keyboard or by importing ASCII-files (see next paragraphs).

Data selection in ISIS for STRESS

A facility for transfer of data from ISIS to ALES has been incorporated in the ISIS menu. The ISIS menu is started ('do ISIS ↵') in dBase (in the ISIS directory). The directories from which the data are selected (ISIS-directory) and where the selected output files have to be written to, have to be selected first (option under the 'Data Management' heading). Then the option 'Data output - Export to ALES' is chosen (Figure 5).

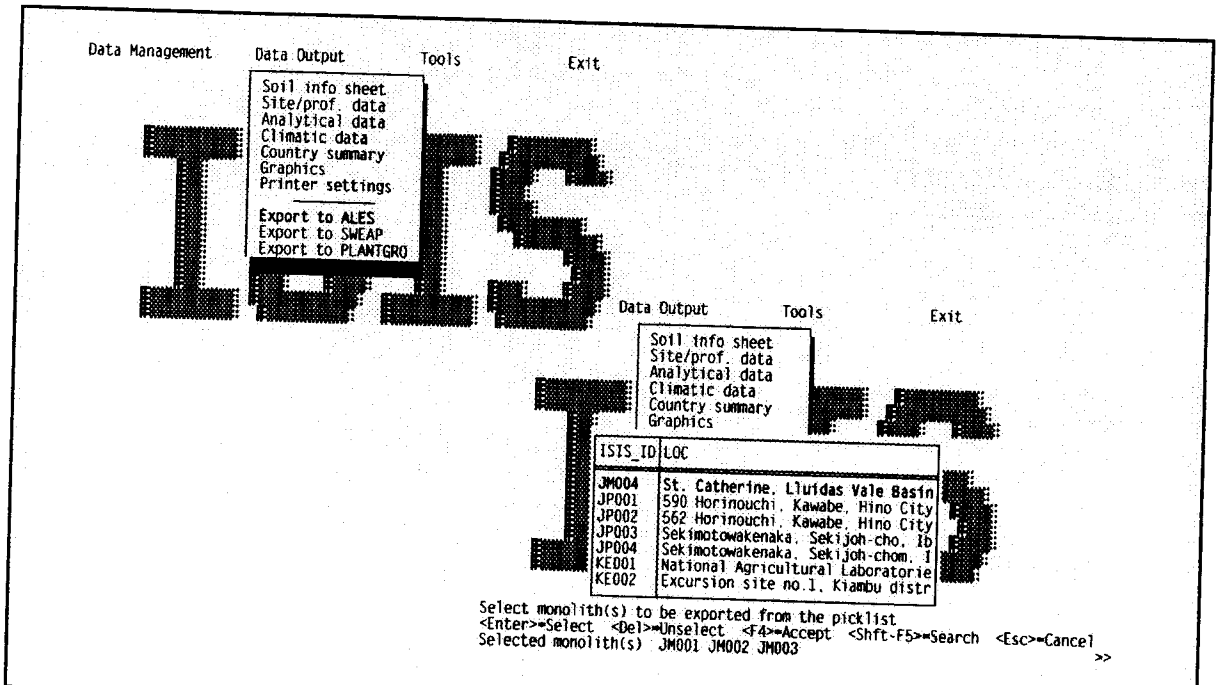

Figure 5: Selection in ISIS of data for export to ALES-STRESS.

When the user has selected the profiles from which the data are to be extracted, 'F4' is pressed (accept). Some profile data are averaged over the whole profile, for other data only the surface layer needs to be considered. Therefore, in the transfer, some data are averaged over a maximum depth, while others are averaged over a 'rooting depth'. The two depths can be changed. After profile selection, the user is asked to give the rooting depth (over which soil fertility parameters will be averaged) and the maximum soil depth to be considered over which data are averaged (see Figure 6).

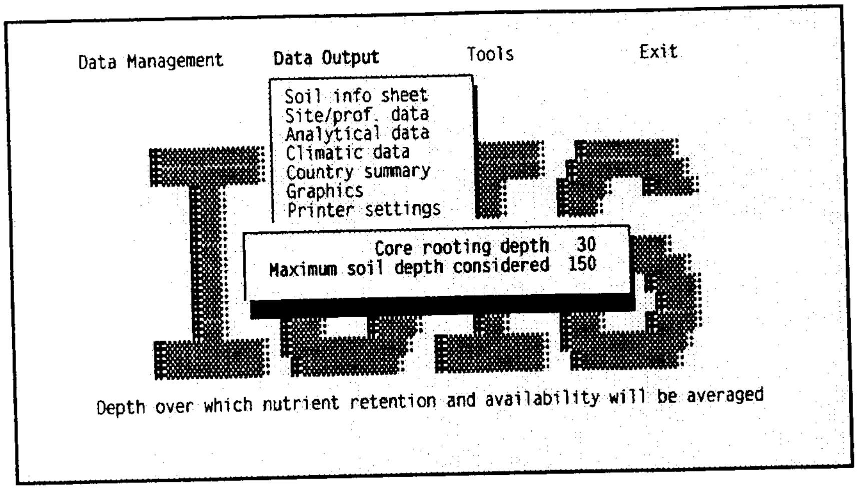

Figure 6: Selection of relevant depths for ISIS-STRESS transfer.

5.3 Importing data into ALES

The selected data from ISIS are written to the selected ISIS-output directory. The ALES selection is stored in 6 files:

ISISDEF.txt : profile codes and FAO-classification
ISISCHEM.txt : soil chemical data
ISISCHM2.txt : soil chemical data
ISISCLIM.txt : climatic data
ISISPHYS.txt : soil physical data
ISISSITE.txt : site data

The structure of the files is such that each line starts with the profile ID (in ALES terminology 'Land Mapping Unit ID'), which is followed by profile data on the same line.

ISISDEF.txt contains the following information: Land Mapping Unit ID (Reference profile ID), Name (FAO classification), Type (homogenous or compound) and Extent (hectares or acres). The last two items are related to mapping units and are, as they are mandatory, routinely given the values "h" (homogeneous) and "100". From the keyboard these data can be entered in ALES in the data entry template screens as shown in Figure 7:

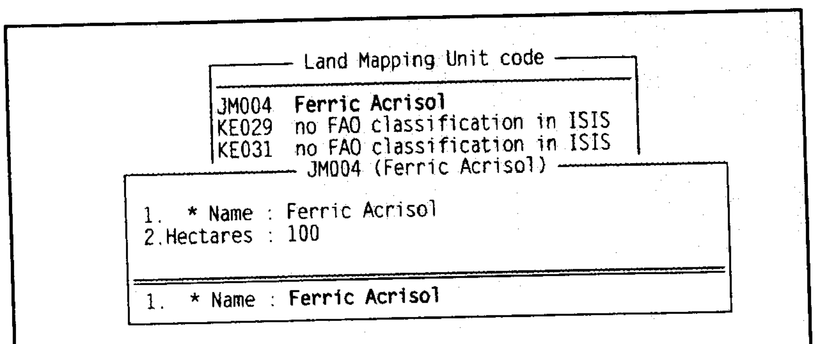

Figure 7: Definition of a Land Mapping Unit (Reference profile).

These data can also be entered by importing an ASCII-file. The format of the ASCII-file ISISDEF.TXT (containing the same information as the screens given above) is:
"JM004";"Ferric Acrisol";"h";100

The data of reference soils needed for evaluation in the ALES models, are defined in the data entry templates. With these templates, data can be entered from the keyboard. An example of the ALES data entry template PHYS is given in Figure 8:

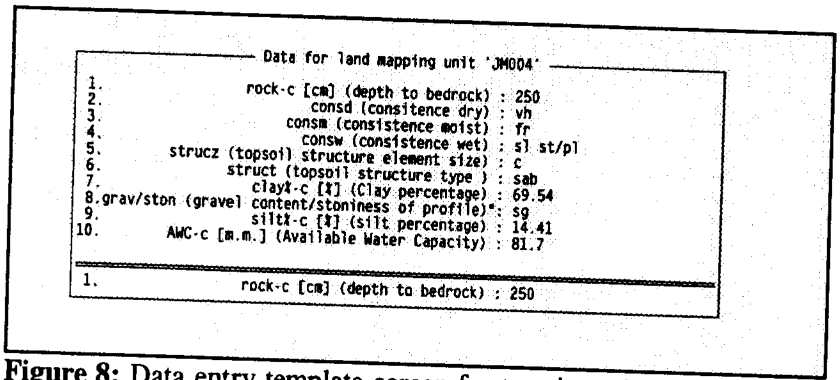

Figure 8: Data entry template screen for terrain and soil physical data.

The sequence of land characteristics defined in the data entry template, also determines the sequence in which the data are read from ASCII-files. The reference soil data files contain information on the values (either continuous or discrete) of defined land characteristics in the data entry templates of reference profiles (Land Mapping Units - LMUs). The ASCII-input file is build up in such a way that every line (record) contains information on one reference profile (LMU). Each line then reads: Reference profile ID (ISIS ID), value, value, etc. An example of the format of the ASCII-file ISISPHYS.txt of a reference profile (with the same data items as indicated in the template above):

"JM004";250;"vh";"fr";"sl st/pl";"c";"sab";69.54;1.25;14.41;81.7

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

In ALES option 1.3.2 is chosen ('Definitions, From disk file, read') to import the profile ID data into the ALES database. After that the reference soil data are imported by selecting the data entry templates and indicating the path were the ISIS-files are located. The pathway of importing the selected ISIS data into ALES is as is shown in Figure 9:

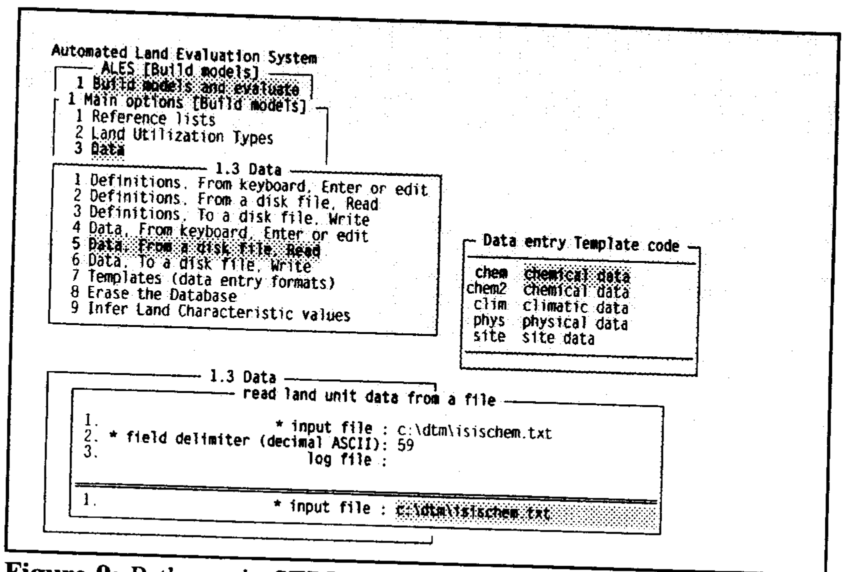

Figure 9: Pathway in STRESS for import of ISIS-data.

Appendix 2: Data entry templates with data for reference profile JM 4.

```
Data entry Template code
chem  chemical data

Data for land mapping unit 'JM004'
1.Alu-c [cmol(+)/kg] (Aluminium content of profile hig...) : 7.5
2.          ASP1-c [%] (Aluminium Saturation Percentage) : 14.9
3.          ASP2-c [%] (Aluminium Saturation Percentage) : 59.34
4.          ASP3-c [%] (Aluminium Saturation Percentage) : 72.23
5.        BAS-c [cmol(+)/dm3 soil] (Exchangeable Bases) :
6.              orgC%-c [%] (organic carbon percentage) : 2.12
7.     CEC7-c [cmol(+)/dm3 soil] (Cation Exchange Capacity) : 18.88
8.ECEC-c [cmol(+)/dm3] (Effective Cation Exchange Capa...) : 15.81
9.ECe1-c [dS/m] (Electrical conductivity between 0 -25...) : .54
10.ECe2-c [dS/m] (Electrical conductivity between 25-20...) : .28
11.ECe3-c [dS/m] (Electrical conductivity between 50 - ...) : .13
12.ECe4-c [dS/m] (Electrical conductivity between 100 -...) : 0.12
13.      ECe5-c [dS/m] (Electrical conductivity > 150 cm) : .1

1.Alu-c [cmol(+)/kg] (Aluminium content of profile hig...) : 7.5
```

```
Data entry Template code
chem   chemical data
chem2  chemical data

Data for land mapping unit 'JM004'
1.    ESP1-c [%] (ESP between 0 -25 cm) : 1.83
2.  ESP2-c [%] (ESP between 25 - 50 cm) : .75
3. ESP3-c [%] (ESP between 50 - 100 cm) : 1.79
4.ESP4-c [%] (ESP between 100 - 150 cm) : 1.49
5.          ESP5-c [%] (ESP > 150 cm) : .72
6.            sa-c [pH] (soil acidity) : 4.26
7.           sb-c [pH] (soil basicity) :
8.    phos-c [%] (phosphate retention) :

1.    ESP1-c [%] (ESP between 0 -25 cm) : 1.83
```

```
Data entry Template code
chem   chemical data
chem2  chemical data
clim   climatic data

Data for land mapping unit 'JM004'
1.      GROWP-c [days] (Growing period (days)) :
2.RRg-c [%] (Radiation regime - growing period) :
3.         RRa-c [%] (Radiation regime - annual) :
4.              r/ETO-c [r/ETO] (r/ETO - ratio) :

1.      GROWP-c [days] (Growing period (days)) :
```

```
Data entry Template code
chem   chemical data
chem2  chemical data
clim   climatic data
phys   physical data

Data for land mapping unit 'JM004'
1.                  rock-c [cm] (depth to bedrock) : 250
2.                        consd (consitence dry) : vh
3.                      consm (consistence moist) : fr
4.                        consw (consistence wet) : sl st/pl
5.        strucz (topsoil structure element size) : c
6.              struct (topsoil structure type ) : sab
7.                  clay%-c [%] (Clay percentage) : 69.54
8.grav/ston (gravel content/stoniness of profile)°: sg
9.                  silt%-c [%] (silt percentage) : 14.41
10.       AWC-c [m.m.] (Available Water Capacity) : 81.7

1.                  rock-c [cm] (depth to bedrock) : 250
```

```
Data entry Template code
chem   chemical data
chem2  chemical data
clim   climatic data
phys   physical data
site   site data

Data for land mapping unit 'JM004'
1.GWT-c [cm] (Depth to groundwater table (cm)) :
2.             Slo-c [%] (dominant slope) : 1
3.            drai (soil drainage class) : m
4.              flf (flooding frequency) : n
5.            rock2 (surface rockiness) : vf
6.roo-c [cm] (rootable (effective) soil depth) : 112
7.               erstat (erosion status) : no
8.       ecs (evidence of capping/sealing) : 0
9.               sst (surface stoniness) : n/f

1.GWT-c [cm] (Depth to groundwater table (cm)) :
```

Appendix 3: Evaluation of Land Qualities of JM 4 using STRESS

LAND QUALITY Availability (1)

Hazard/Limitation (2)

vh	h	m	l	vl
n	w	m	s	vs

vh = very high
h = high
m = moderate
l = low
vl = very low

n = not present
w = weak
m = moderate
s = serious
vs = very serious

JM 4

CLIMATE		vh / n	h / w	m / m	l / s	vl / vs
Radiation regime	1					
Temperature regime	1		■			
Climatic hazards (hailstorm, wind, frost)	2					
Length growing season	1		■			
Drought hazard during growing season	2					

SOIL		vh / n	h / w	m / m	l / s	vl / vs
Potential total soil moisture	1		■			
Oxygen availability	1		■			
Nutrient availability	1				■	
Nutrient retention capacity	1			■		
Rooting conditions	1		■			
Conditions affecting germination	1	■				
Excess of salts - salinity	2	■				
- sodicity	2	■				
Soil toxicities (e.g. high Al sat.)	2			■		

LAND MANAGEMENT		vh / n	h / w	m / m	l / s	vl / vs
Workability	1		■			
Potential for mechanization	1	■				
Erosion hazard - water	2	■				
Flood hazard	2	■				

COMMENTS

Limitations of JM 04 for agriculture.

Appendix 4: Rating and assessment of land qualities

CLIMATE

Length of growing period (rainfed)

The length of growing period can be determined using a water balance appraoch (see paragraph 4.2.2.).

Rating	Growing Period Days	Climatic zone
1	> 270	humid
2	180-270	seasonally dry
3	130-180	moist semi-arid
4	75-130	dry semi-arid
5	< 75	arid

SOIL

Total soil moisture

Rating	A.W.C.* in mm
1	> 200
2	100-200
3	50-100
4	25-50
5	< 25

Available Water Capacity calculated with pF curve information; being the amount of moisture held between pF2.0- pF4.2, over a depth of 100 cm, corrected for stones and gravel.

Oxygen Availability

Rating	Drainage class (FAO, 1990)	Depth to watertable (cm)
1	well - excess.	> 180
2	mod. well	120 - 180
3	imperfect	50 - 120
4	poor	20 - 50
5	very poor	< 20

Nutrient Availability [0-25 cm] and [25-50 cm]

Rating	Sum Bases $cmol_c\ kg^{-1}$ soil	pH-H_2O		org. C. %
1	> 16	5.5-7.0	7.0-7.5	> 2.0
2	8-16	5.0-5.5	7.5-8.0	1.0-2.0
3	4-8	4.5-5.0	8.0-8.5	0.6-1.0
4	1-4	4.0-4.5	8.5-9.0	0.3-0.6
5	< 1	< 4.0	> 9.0	< 0.3

Nutrient retention

Rating	CEC 7[1] $cmol_c\ kg^{-1}$ soil	ECEC[2] $cmol_c\ kg^{-1}$ soil
1	> 40	> 30
2	20-40	16-30
3	10-20	8-16
4	4-10	3-8
5	< 4	< 3

1) CEC at pH7
2) CEC at approximate field pH or sum of exchangeable cations plus the exchangeable acidity

Rooting conditions

Rating	Effective soil depth[1] cm	Stoniness vol. %
1	> 120	0-2
2	60-120	2-15
3	30-60	15-50
4	15-30	50-90
5	< 15	> 90

1) Effective soil depth; the depth to which root growth is unrestricted by physical or chemical barriers.

Conditions affecting germination

The assessment is focused on the tendency to slaking and crust formation.

Rating	Susceptibility surface sealing		Surface stoniness	Topsoil element size & structure
	silt[1] %	org. C.[1] %	%surface cover	
1	< 10	> 2.0	< 0.1	
2	10-25	1.0-2.0	0.1-3	very course grain-crumb, single grain, platy
3	25-50	0.5-1.0	3-15	coarse prismatic, columnar, massive and very
			15-90	coarse angular blocky (wedge shaped), subangular blocky
4	50-70	0.3-0.5	> 90	very coarse prismatic, columnar, massive
5	> 70	< 0.3		

1 = silt and organic C are taken into account if clay > 15%.

Excess of salts

The excess of salts is evaluated on the basis of three criteria: (i) electrical conductivity of the soil (salinity), (ii) the degree of saturation of the exchange complex with exchangeable sodium (sodicity) and, (iii) the depth at which either of the two characteristics occur.

a) Salinity

The electrical conductivity (EC) or salt content of the soil is a measure for salinity.

Rating	ECe dS/m	Salt %	Limitiation
1	0 - 4	0-0.15	Low (L)
2	4 - 15	0.15-0.65	Medium (M)
3	> 15	> 0.65	High(H)

b) Sodicity

The exchangeable sodium percentage (ESP) of the soil is a measure for sodicity.

Rating	ESP %	Limitation
1	> 10	Low (L)
2	10-25[1)]	Medium (M)
3	> 25	High (H)

1) for predominant kaolinitic clay soil, for predominantly 2:1 clay soil it is class 5 because the structure of such soil will serious deteriorate with an ESP > 15

The rating of both salinity and sodicity is explained below. Three classes of electrical conductivity and sodicity are distinghuised: low (L), medium (M) and high (H), see tables under a and b. These three classes can be combined with 5 depths. In the following table the rating is given for combinations of salinity/sodicity classes with depth of occurrence.

Rating:	1 1 2 2 3	1 1 2 2 3	1 1 2 3 4	1 1 3 4 5	1 3 4 5 5	3 3 4 5 5
depth:						
0 - 25	L L L L M	L L L L M	L L L L M	L L L L M	L L L L M	L L L L H
25 - 50	L L L M M	L L L M M	L L L M M	L L L M H	L L L M H	L L L H H
50 - 100	L L M M M	L L M M M	L L M M M	L L M H H	L L M H H	L L H H H
100 - 150	L M M M M	L M M M M	L M M M H	L M H H H	L M H H H	L H H H H
> 150	M M M M M	M M M M H	M M M H H	M M H H H	M H H H H	H H H H H

Soil toxicity

Rating	Exch. Al.# %
1	< 5
2	5-30
3	30-60
4	60-85
5	> 85

= the exchangeable Al percentage is only rated if pH < 5.5 (else rating is 1).

LAND MANAGEMENT

Workability

Rating	Stoniness/rocks % surface cover	Consistence dry	Consistence wet	rootable (effective) soil depth (cm)
1	< 0.1	loose	non sti/pls	> 60
2	0.1-3	soft	sl. sti/pls	> 60
3	3-15	sl. hard	sl. sti/pls	> 60
4	15-90	very hard	sticky/plastic	30-60
5	> 90	extr. hard	very sti/pls	< 30

Potential for mechanisation

Rating	Stoniness/rocks % surface cover	Gravel content of profile vol%	Slope %	(effective) soil depth (cm)
1	< 0.1	< 2	< 2	> 60
2	0.1 - 3	2 - 15	2 - 6	> 60
3	3 - 15	15 - 50	6 - 13	30 - 60
4	15 - 90	50 - 90	13 - 25	15 - 30
5	> 90	> 90	> 25	< 15

Erosion hazard (water)

Rating	Dominant slope %	length of slope m	Basic infiltration rate cm/h	Evidence of capping/sealing
1	< 2	< 50	< 0.5	none
2	2 - 6	50 - 200	0.5 - 2	partly slaked
3	6 - 13	> 200	2 - 6	slaked
4	13 - 25		6 - 12	capped/crust
5	> 25		> 12	

Flooding hazard

Rating	Flooding frequency
1	none
2	irregular
3	yearly
4	monthly
5	daily