Netherlands Scientific Council for Government Policy

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Crop production potential of rural areas within the European Communities

II : A physical land evaluation procedure for annual crops and grass

G.J. Reinds

H.A.J. van Lanen

The Hague, March 1992

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PREFACE

The Netherlands Scientific Council for Government Policy has asked the Winand Staring Centre in Wageningen to investigate the crop production potential of the rural areas within the European Communities. The Council needed this information for a project on the possible future developments in the rural areas of the EC as a result of an ongoing growth in agricultural productivity. To get a clear view the Council explored the possible changes in the rural areas.

When exploring possible developments or options it is crucial to define the objectives at stake. Within agriculture not only production is of importance, but also (regional) employment, emissions of pesticides and nutrients to the environment, impact on the landscape, etc. Land use is taken as the key factor in the explorations by the Council. Through different types of land use different goals can be attained. The explorations show the differences in possible future land use when a certain priority is given to the various objectives.

Information on the physical possibilities for land use was absolutely necessary to carry out the explorations. A team from the Winand Staring Centre consisting of Ir. J.D. Bulens, Ir. A.K. Bregt, Ir. C.A. van Diepen, Ir. C.M.A. Hendriks, Ir. G.H. de Koning and Ir. G.J. Reinds led by Dr.ir. H.A.J. van Lanen compiled this information. A report of their research is given in a series of five separate documents under the common title 'Crop production potential of rural areas within the European Community'. The series consists of:

I : GIS and datamodel (W65)
II : A physical land evaluation procedure for annual crops and grass (W66)
III : Soils, climate and administrative regions (W67)
IV : Potential, water-limited and actual crop production (W68)
V : Qualitative suitability assessment for forestry and perennial crops (W69)

The full report shows that a combination of Geographical Information Systems and simulation models can provide useful quantitative information on crop production potentials for different crops at different locations. With this approach the Winand Staring Centre opened up a new and promising line of research.

Prof.dr.ir. R.Rabbinge

ACKNOWLEDGEMENT

At the request of the Dutch Scientific Council for Government Policy (WRR) the Winand Staring Centre (SC) in Wageningen conducted a study on the crop production potential of the rural areas within the European Communities (EC). We gratefully acknowledge the grant provided by the Council. The SC study was supervised by a WRR team comprising Prof.dr.ir. R. Rabbinge (chairman), Drs. H.C. van Latesteijn (secretary), Drs. D. Scheele, Ir. H. Hengsdijk and Drs. E. Bolsius.
The digitized maps and some attribute data used in our study were supplied in a compatible form by the CORINE project team (DG XI, Commission of the European Communities, Brussels). The support of Mr. M.H. Cornaert and Ir. J. Maes is greatly appreciated.
Meteoconsult B.V. in Wageningen provided records of historical weather data for many meteorological stations within the EC.
Furthermore valuable data on crops were provided by colleagues at the Centre of Agrobiological Research (CABO) in Wageningen.

Ir. G.J. Reinds
Dr.ir. H.A.J. van Lanen

1 INTRODUCTION

The Common Agricultural Policy (CAP) of the European Communities (EC) has stimulated agricultural production to such a level that surpluses of some major commodities, such as wheat, sugar, milk, and wine has become structural. In areas favourable for agriculture, farm size has increased, narrow crop rotations have been introduced, and large amounts of relatively inexpensive agro-chemicals and feedstuffs are being used. The intensification of agriculture in these regions has detrimentally affected the environment, nature and landscape (Briggs and Wilson, 1987). In areas less favoured for agriculture, the abandonment of land and associated social hardship occurs.

EC funds are increasingly called upon to mitigate the undesirable socio-economic and environmental effects of the CAP. However, little or nothing is known about the cost-effectiveness of investments for agricultural development in the various EC regions in relation to the long term perspectives.

Therefore, the Netherlands Scientific Council for Government Policy (WRR) has started a project on the possible developments of the rural areas in the EC. Different land use scenarios will be evaluated in terms of their impact on rural development, taking into account agricultural, socio-economic, environmental, and physical planning aspects.
The WRR will develop and apply a model for the General Optimal Allocation of Land use (GOAL). This model uses a method known as Interactive Multiple Goal Linear Programming. For the purpose this model the WRR requires, among other input data, information about the regional production potentials of major crops at different input levels.

At the request of the WRR, the Winand Staring Centre has investigated the physical crop production potential of rural areas in the EC. The yield potential of some indicator crops, when grown on major land units suitable for agricultural use, was determined by a combined use of physical land evaluation methods and a Geographical Information System (GIS).

This report describes in detail the land evaluation procedure used to estimate the crop growth potentials of the NUTS-1 regions within the European Communities for some annual crops and grass. The land evaluation is physical by nature, as final results are obtained in the form of yield levels. The crop growth potentials for perennial crops such as olives and citrus were assessed by means of a qualitative expert system. These evaluations are described elsewhere (Van Lanen et al., 1991).

The evaluation of rural land within the European Communities involved a large number of

land evaluation units and associated data. Furthermore, because the land evaluation procedure applied was fairly complicated, many operations and calculations were necessary before the final results were obtained. To facilitate the evaluations, an automated land evaluation procedure was developed that combined qualitative and quantitative physical land evaluation methods.
Such an automated procedure has major benefits. Calculations involving large amounts of data can be achieved quickly. This is especially beneficial when evaluations are made for the European Communities as a whole in one run (processing of many data) and when the sensitivity of the evaluation results to changes in input is tested (many calculations). Furthermore, when such a procedure is conscientiously developed and extensively tested, human errors in derivation and use of data are avoided and results are reproducible.

Chapter 2 delineates the evaluation scheme in general terms and briefly discusses the interface with the geographical information system (GIS). Chapter 3 describes the qualitative part of the mixed qualitative / quantitative land evaluation used in this study. The division of the land evaluation units in potentially suitable and unsuitable units is discussed, and the output of this procedure is briefly characterized. The data-conversion used to create input files required for the quantitative yield assessment by the crop growth simulation model WOFOST is outlined in chapter 4. The procedure for grouping identical land evaluation units is also described in this chapter. Chapter 5 delineates the processing of the results from the crop growth simulations. Several examples of different types of aggregation are given. These summaries allow simulation results to be examined quickly. In chapter 6, conclusions are drawn and a few recommendations are made.

A simplified overview of the land evaluation scheme is presented in Figure 2.1. Roman numerals used in the text refer to those in the figure.

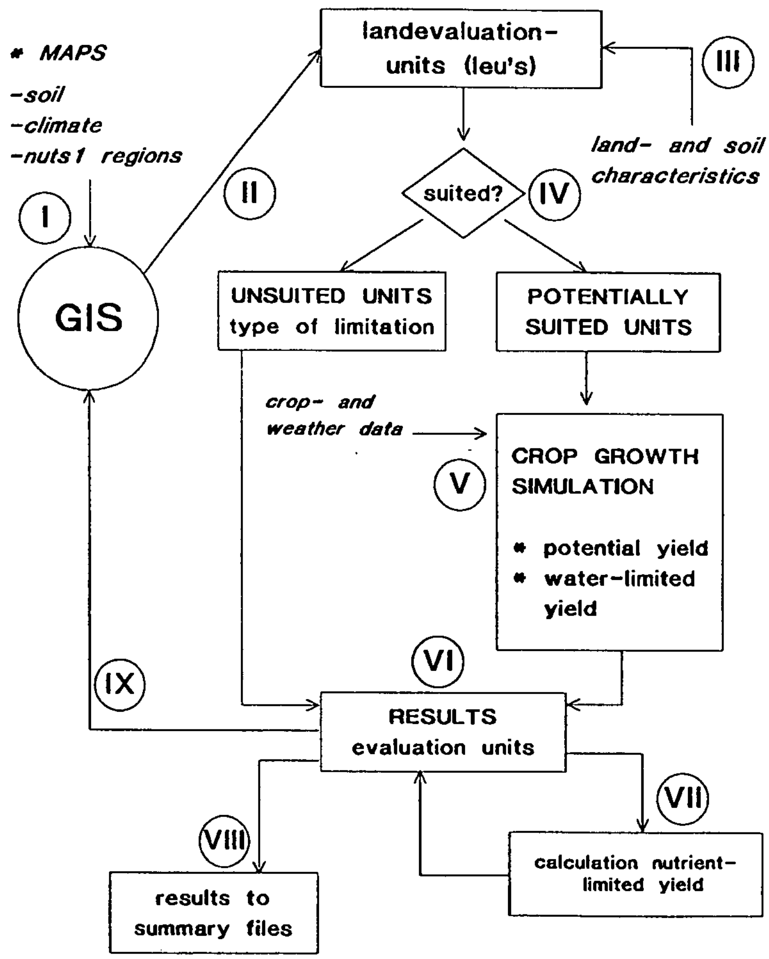

Figure 2.1 Simplified overview of the land evaluation procedure

The starting point in the evaluation procedure is the geographical information system (I). In this GIS three digitized maps are stored:

- the soil map of the EC at scale 1 : 1,000,000
- an agro-climatic map of the EC, comprising 109 agro-climatic zones

- a map with 61 administrative regions; according to the 'Nomenclature des Unites Territoriales Statistiques', level 1 (NUTS-1 regions))

By means of a digital overlay procedure, 4269 land evaluation units (LEUs) were distinguished, each of them being an unique combination of soil type, agro-climatic and NUTS-1 region. These units are distributed over more than 22000 map delineations. The subdivision of land evaluation units by NUTS-1 region allows regional aggregation of evaluation results to averaged productions significant for an administrative region. Consequently, statistical data on NUTS-1 level such as actual crop yield, can be compared with simulated results.
For a detailed description of the GIS, its databases and the overlay procedure the reader is referred to Bulens & Bregt (1991). The soil map, agro-climatic map and NUTS-1 map are discussed by Reinds et al. (1991).
To facilitate the data processing in the evaluations, all land evaluation units were coded during the overlay procedure. These codes were built up out of the code of the dominant soil type of each soil association, the code of the agro-climatic region and the code of the NUTS-1 region. A list of all LEUs was supplied by the GIS, together with the acreage of each LEU (II).
A record with soil and land characteristics was added to each of these coded land evaluation units (III).
These characteristics were derived from the EC soil map as outlined by Reinds et al. (1991). However, because they solely refer to the dominant soil unit of each soil association, all evaluations were restricted to the dominant soil of each soil association. Associated soils and inclusions were not evaluated (Reinds et al., 1991). A small fragment of the data file with LEUs and additional soil characteristics is given in Table 2.2.

Table 2.2 Fragment of data file with LEUs and attribute data

Evalun.	code	map_unit	name	tex	cec	b_s	org	caco	caso	sal	alk	rd_max	slo	dra	pha
100112	1001	Je-2a	Eutric Fluvisol	m	5-15	>50	>0.6	-	-	-	-	60	0-8	i	12
100211	1002	Jeg-1/4a	Gleyic Eutric Fluvisol	c/f	<5-40	>50	>0.6	-	-	-	-	80	0-8	i	11
100217	1002	Jeg-1/4a	Gleyic Eutric Fluvisol	c/f	<5-40	>50	>0.6	-	-	-	-	60	0-8	i	17
...															
109017	1090	Xy-3bc	Gypsic Xerosol	mf	15-30	100	>0.6	-	+	>4	-	40	8-25	w	17
109111	1091	Hh-3a	Haplic Phaeozem	mf	15-30	>50	>2.0	-	-	-	-	120	0-8	w	11
109211	1092	Hc-4a	Calcaric Phaeozem	f	30-40	100	>2.0	+	-	-	-	120	0-8	w	11
109311	1093	Hl-3a	Luvic Phaeozem	mf	15-30	>50	>2.0	-	-	-	-	120	0-8	w	11
200111	2001	Be-2b	Eutric Cambisol	m	5-15	>50	>0.6	-	-	-	-	120	8-15	w	11
200114	2001	Be-2b	Eutric Cambisol	m	5-15	>50	>0.6	-	-	-	-	40	8-15	w	14
200129	2001	Be-2b	Eutric Cambisol	m	5-15	>50	>0.6	-	-	-	-	120	8-15	w	29

tex = texture of the topsoil, (c=coarse, m=medium, mf=medium fine, f=fine)
cec = cation exchange capacity (meq/100gr)
b_s = base saturation (%)
org = organic matter content (% C)
caco = presence of free $CaCO_3$
caso = presence of free $CaSO_4$
sal = precense of salinity (indicated by EC > 4mmho/cm)
alk = precence of alkalinity
rd_max = maximum rooting depth of the soil (cm)
slo = slope (%)
dra = drainage (w=well, i=imperfect)
pha = precence of a phase (e.g. 11=no phase)

This data-file served as the soil data base for each evaluation.
A mixed qualitative/quantitative evaluation was applied to evaluate the crop growth potential for potatoes, sugarbeets, wheat, maize, oilseed rape and grass.
The first step in the mixed qualitative/quantitative physical land evaluation, was specification of the land use, crop type and related land use requiremets. Land use requirements were specified in terms of management requirements and some crop requirements. Each LEU was characterized as potentially suitable or as unsuitable for the specified land use by matching these requirements with the soil- and land characteristics (IV). The quantitative evaluation was subsequently applied to the potentially suitable land evaluation units. This qualitative pre-selection followed by a quantitative land evaluation for potentially suitable evaluation units only, is often called a 'mixed approach' and has recently been advocated by e.g. Van Lanen et al. (1989a). A detailed outline of this pre-selection procedure and of the selection criteria used, is given in section 3.1.

The input parameters required to run the crop growth simulation model WOFOST (Van Diepen et al. 1989) were derived for all potentially suitable land evaluation units . Since WOFOST does not take into account differences in soil chemical properties for instance, not all suitable LEUs were different in terms of WOFOST input. Therefore, a grouping-procedure was applied that grouped LEUs with identical WOFOST input. Consequently, crop growth calculations were made for groups of similar land evaluation units to avoid identical simulation runs. This grouping procedure and the input data needed for WOFOST are described in section 3.2.
The potential and water-limited yield of the specified crop were calculated by the simulation model WOFOST for each group of LEUs (V).
Following the crop growth simulations, calculated yields on group level were segregated to yields per land evaluation unit. Furthermore, unsuitable units with their type(s) of restrictions were included (VI). This information was stored in an output file that could serve as the basis for the calculation of nutrient-limited crop yields if the nutrient inputs for the LEUs were also known. In this study, nutrient limited crop yields were not assessed as the amounts of N,P and K applied for each land use type in a NUTS-1 region could not be accurately estimated from the readily available statistical data on fertilizer and manure use. Nutrient requirements and water use of each crop were calculated for the potential and water limited production situation (VII) (see section 5.1).

To facilitate an easy interpretation of the evaluation results, calculated yields were summarized for each agro-climatic region, soil type and NUTS-1 region (VIII). Finally, all non-aggregated results were stored in the geographical information system (IX). This GIS provides various options for spatial aggregation of the results and for the presentation of results on maps or in tables. The various options for handling the simulation results on LEU level (VII,VIII,IX) are discussed in greater detail in section 3.3.

All data handling modules IV to VIII, were written in FORTRAN-77. The entire evaluation procedure (from IV to VIII) was controlled by a module written in DEC Command Language (DCL).

3 SELECTION OF POTENTIALLY SUITABLE AND UNSUITABLE LAND EVALUATION UNITS.

3.1 Introduction to the mixed approach.

As the crop growth potentials of the different regions in the EC needed to be expressed in quantitative measures (e.g. yields in kg/ha), a quantitative land evaluation model was used to estimate the production potentials of the five annual crops and grass considered in this study. Such quantitative models, however, often require considerable computing time, especially when calculations are made for many evaluation units with lengthy historical records of meteorological data. Because computing time is often limited and costly, the number of simulation-runs should be restricted as much as possible, without affecting the quality of the results.
This can be achieved by applying a mixed qualitative / quantitative land evaluation. In such a procedure, recently described by Van Lanen et al. (1989a), all land evaluation units are screened for severe limitations for a particular land use. Land use requirements are matched with land characteristics dividing the land evaluation units into favoured or potentially suitable units and less favoured or unsuitable units. Quantitative evaluations are subsequently applied only to the potentially suitable land evaluation units.

3.2 Selection and subdivision of land evaluation units.

As outlined in chapter 2, each of the land evaluation units was supplemented with a record of soil and land characteristics. Furthermore, the acreage of each unit was added in km^2 and in % of the total EC soil map area. Since there was no consistent and detailed information available on the soil units on the EC soil map on a scale 1:1.000.000, most of the characteristics were derived from the information on the dominant soil unit of each association on the soil map (Reinds et al., 1991). Texture-class and slope class are known for each dominant soil type of each soil association. Other characteristics, such as maximum rooting depth and drainage conditions were derived from the pedogenetic name of the soil unit and the soil phase (e.g. stony, gravelly).
It will be obvious that such data extraction can yield only a broad description of soil and land characteristics. As the selection of suitable and unsuitable LEUs was entirely based on these characteristics, land evaluation units could only be broadly screened for limitations. The characteristics derived from the soil- and climatic map are listed in Table

3.1. Each of these characteristics was subdivided into a number of classes (Reinds et al., 1991).

Table 3.1 Land- and soil characteristics derived from the EC soil map.

- Texture	- CEC	- Organic matter content
- Salinity	- Alkalinity	- Drainage
- Phase	- Slope	- Maximum rooting depth
- Climatic region		

In principle all these characteristics can be used as selection parameters to separate suitable from unsuitable areas.
When growing C-4 crops requiring relative high temperatures for a proper development such as maize, in some regions of the EC climatic conditions can be restrictive. In relatively cold areas in the northern part of the EC, the temperature requirements of some C-4 crops will probably not be entirely met. Simulation will, however, show whether acceptable yields can be attained or not. Therefore, climatic variables such as temperature regime and annual precipitation surplus have not been used as a selection parameters. Some of the soil and land characteristics have only a slight influence on land suitability or were specified too broadly to serve as a selection criterium in the mixed approach. Hence, the number of selection parameters was limited to the following seven characteristics:

- texture
- slope
- drainage
- maximum rooting depth
- phase
- presence of salinity
- presence of alkalinity

Site requirements were defined in terms of critical class limits for the seven selection parameters for each specific crop type. These critical class limits or site requirements originate from expert knowledge and are mainly soil management-related. Selection was performed in such a way that land evaluation units not meeting the site requirements, because of, for instance, steep slopes, poor drainage conditions, stones etc., were characterized as unsuitable.
Drought sensitive soils were not excluded from further analyses with the simulation model. Soils in areas with high precipitation deficits during the growing season where no additional water is supplied, will normally be unsuitable for growing annual crops. Should sufficient irrigation water be supplied, however, reasonable yields can be attained on these soils. Very wet soils were characterized as unsuitable since improvement of the drainage of very

fine textured soils or soils such as histosols or gleysols, is often impossible or extremely costly.

A complicating factor in this selection procedure is the vast number of land evaluation units which have a compound texture class and/or a compound slope class (Reinds et al., 1991). For a reliable selection of suitable and unsuitable units, these land evaluation units cannot be treated in the same way as units with a single value slope and texture class. Often, only a part of these compound units is unsuitable for the considered land use (e.g. the part of the LEU with steep slopes), whereas another part of the unit is potentially suitable.

Unfortunately, the relative area of each of the single texture- and slope classes within the compound unit is not given for the soil units on the EC soil map. Since no composition data were available, each single value class was assumed to cover an equal area within the compound unit.

For instance, a soil unit with moderate to steep slopes (slope class ab) and a coarse to medium texture (texture class 1/2) was subdivided into four sub-units. One sub-unit with slope class a and texture class 1, one with slope class a and texture class 2, one with slope class b and texture class 1 and one with slope class b and texture class 2. Each of these sub-units was assumed to cover an equal area, namely 25% of the area of the soil unit.

The treatment in the qualitative selection of a land evaluation unit that contains a dominant soil unit with a compound slope and texture class, is illustrated in Figure 3.2.

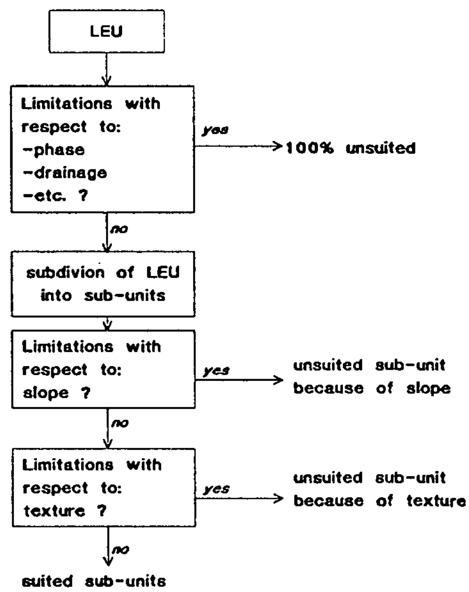

Figure 3.2 Handling of a LEU with a compound texture and slope class in the qualitative selection

Firstly the LEU was screened for limitations concerning drainage, maximum rooting depth, phase, salinity and alkalinity. If one of the requirements was not met, the evaluation unit was assumed to be unsuitable for the specified land use.

When there were no restrictions regarding these selection criteria, sub-units with a single slope and texture class were created. Hereafter, each of these sub-units was screened for limitations regarding texture and slope. As each sub-unit was assumed to cover an equal area, the percentage of the land evaluation unit unsuitable for the given land use could now be calculated from the number of unsuitable sub-units. Finally, suitable sub-units were grouped in such a way that new sub-units were created which only differed in texture.

Figure 3.3 shows how a land evaluation unit with a Eutric Cambisol (Be-2/4ac) as dominant soil, was screened for limitations. If we assume that this soil had no limitations regarding to drainage, stoniness, etc., it needed to be subdivided into 9 sub-units. Three of these sub-units were unsuitable because of slope (steeper than 15%): Be-2c, Be-3c and Be-4c. Subsequently, the remaining sub-units were screened for texture limitations. Figure 3.3 shows that two of these sub-units were unsuitable because of a very fine texture (more than 35% clay): Be-4a and Be-4b.
Be-4c had already been characterized as unsuitable because of slope; in fact it was unsuitable because of both slope and texture. Altogether, five out of nine sub-units did not meet the land use requirements, so 56 % of the LEU was unsuitable for the specified land use. Finally, all sub-units which only differed in slope were grouped, so two suitable sub-units remain: Be-2ab and Be-3ab.

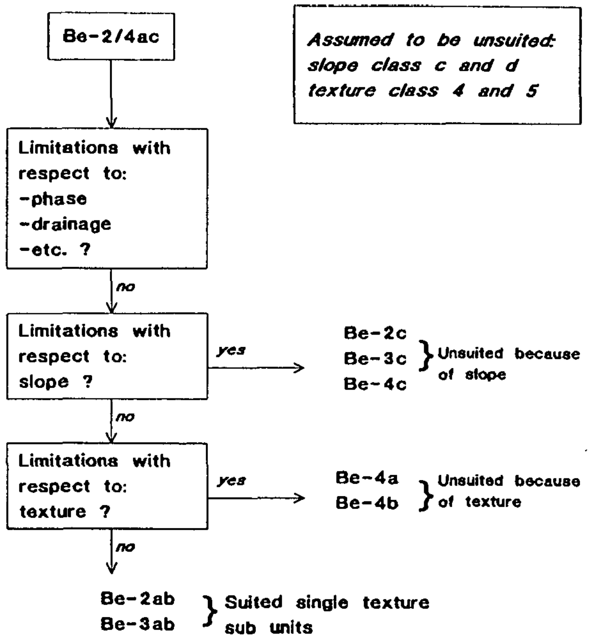

Figure 3.3 Example of handling of a LEU with compound slope and texture class

There was no profound reason to distinguish single slope sub-units (e.g. Be-2a and Be-2b). In the crop growth model WOFOST, used in the quantitative evaluation, slope only affects the surface runoff and the surface storage. Because of the broad definition of the slope classes, surface runoff could only roughly be estimated. Hence, parameters affecting surface runoff and surface storage could be specified for compound slope classes as well as for single value slope classes.
In the quantitative evaluation with WOFOST, separate calculations were made for each of the single texture sub-units Be-2ab and Be-3ab. This was believed to be necessary since calculations with a 'mean' texture class for a unit with a compound texture class can give misleading results, especially in case of a broad texture range.

Different selection criteria where used to screen the LEUs for severe limitations for each crop type. A full list of the selection criteria for each specific crop type is provided in Table 3.4.

The maximum number of single texture sub-units that can be produced from the 4269

Table 3.4 Specified land use requirements for the three crop types considered

Requirements for growing grass (intensive cultivation):

texture	less than 60% clay (EC-fine or coarser)
slope	not to exceed 15%
drainage	better than very poor
rooting depth	more than 10 cm
phase	gravelly and concretionary phase allowed
salinity	no excessive salinity
alkalinity	no excessive alkalinity

Requirements for growing cereals:

texture	less than 60% clay (EC-fine or coarser)
slope	not to exceed 15%
drainage	better than temporary poor
rooting depth	more than 10 cm
phase	gravelly and concretionary phase allowed
salinity	no excessive salinity
alkalinity	no excessive alkalinity

Requirements for growing root crops:

texture	less than 35% clay (medium fine or coarser)
slope	not to exceed 15%
drainage	better than temporary poor
rooting depth	more than 10 cm
phase	no phase allowed
salinity	no excessive salinity
alkalinity	no excessive alkalinity

compound-texture units, is 6834. After selection, the number of suitable sub-units for growing grass was 4187, 3779 for growing cereals and 2533 for growing potatoes or sugar beets.

3.3 Output

The selection of the suitable and unsuitable LEUs, was controlled by a FORTRAN module called ECMIXED.All relevant information made available during the selection procedure was stored in two output files. The first file contained the information on the suitability of the land evaluation units regarding the selected crop type (Figure 3.5). Under the headings, a block of information presents the prescribed unsuitable classes of each selection parameter. Three output lines were added to this file for each LEU. In the first line the LEU code is given, together with the symbol of the dominant soil, the number of class limits that could not be met, the fraction of the unit unsuitable for the specified crop

Table 3.5 Fragment of suitability file.

```
LAND USE/CROP : wheat in the ec

Unsuited   : 1. texture       class(es):    5
Unsuited   : 2. salinity      class(es):    2
Unsuited   : 3. alkalinity    class(es):    2
Unsuited   : 4. rootingdepth  class(es):    1
Unsuited   : 5. slope         class(es):    3   4
Unsuited   : 6. drainage      class(es):    1   2   3
Unsuited   : 7. phase         class(es):    2   3   5   6
                                            7   8   9   10
                                            11  12  13  14


100111_28_07650 Je-2a       0 0.0000  1



101211_22_07280 Jd-2/5a     1 0.2500  3
  1
tex   vf        5,
```

type and the number of suitable, single texture, sub-units. In the second output line the reason why the LEU was regarded (partly) unsuitable is given in the form of the numbers of the selection parameters for which the critical limits could not be met by the soil- and land characteristics of the land evaluation unit. The severity of the limitations is listed in the third output line by means of a description of the characteristics that did not meet the minimum requirements and their class number in the selection parameters. For instance, 25% of the LEU which contains the Dystric Fluvisol (Jd-2/5a) as dominant soil, was unsuitable for growing cereals because of a high clay content in the topsoil. So, three out of four sub-units were suitable, indicated by '3' at the end of the first output line. The remaining 25 % was unsuitable because of texture, indicated by the number of this soil characteristic in the second output line ('1'), and by 'texture class 5' in the third output line.

During the selection procedure, the total unsuitable acreage was calculated by multiplying the unsuitable fraction of each LEU by its acreage (Figure 3.6). Unsuitable areas were also calculated for all unsuitable classes within each selection parameter. The sum of the unsuitable areas for each unsuitable selection class is not equal to the total unsuitable area, as a land evaluation unit can be (partly) unsuitable for more than one reason. For instance, a land evaluation unit may be unsuitable to grow a certain crop, because of a very fine texture as well as a steep slope. However, in the calculation of the total unsuitable acreage the acreage of such a unit was only incorporated once. All suitable sub-units were written to the second output file, together

Table 3.6 Example of listing of unsuited acreage.

```
Land use: mechanized maize growing

    Unsuited because of          abs. area            rel. area
texture      class :  5      15014.530273 km2         0.65573 %

salinity     class :  2      11278.566406 km2         0.49257 %

alkalinity   class :  2       4893.568848 km2         0.21372 %

rootingdepth class :  1     113346.070313 km2         4.95019 %

slope        class :  3     507561.562500 km2        22.16687 %
slope        class :  4     341244.968750 km2        14.90327 %

drainage     class :  1      63533.511719 km2         2.77471 %
drainage     class :  2      33115.640625 km2         1.44627 %
drainage     class :  3      95692.929688 km2         4.17922 %

phase        class :  2     212536.781250 km2         9.28216 %
phase        class :  3     185739.562500 km2         8.11185 %
phase        class :  5      31598.857422 km2         1.38002 %
phase        class :  6      18289.302734 km2         0.79875 %
phase        class :  7       8785.940430 km2         0.38371 %
phase        class :  8      80384.695313 km2         3.51066 %
phase        class :  9          0.000000 km2         0.00000 %
phase        class :  10       990.640991 km2         0.04326 %
phase        class :  11     25302.593750 km2         1.10505 %
phase        class :  12       310.274994 km2         0.01355 %
phase        class :  13       501.627014 km2         0.02191 %
phase        class :  14     15223.650391 km2         0.66487 %
    Unsuited total:   55.4  % of map area
```

with their soil- and land characteristics. This file served as the basis for the determination of the input needed for the crop growth simulation model WOFOST. The procedure used to estimate WOFOST-input from the available soil-and land characteristics, will be discussed in the next section.

4 INPUT FOR WOFOST AND GROUPING OF SIMILAR UNITS.

4.1 Introduction

After the unsuitable land evaluation units were separated from suitable ones, quantitative calculations could be made. The dynamic crop growth model WOFOST (Van Diepen et al. 1989) was used in this study. Yields for various crops were calculated at two theoretical production levels: potential production situation and water-limited production situation. In the potential production situation, water and nutrient supply to the crop are assumed to be optimal and pests or diseases do not occur. The yield is thus determined by radiation, temperature and crop characteristics only. In the water limited production situation the crop production can be reduced by a shortage or an excess of water.
Extensive input is required to run this simulation model. Various parameter values must be given for each crop. Furthermore, weather data are needed on a daily or monthly basis, and a number of soil and land related data need to be specified. Crop and weather data are discussed elsewhere (De Koning et al., 1991, Reinds et al., 1991). In this chapter attention is paid to the soil and land related input data.
Firstly the conversion of available soil and land characteristics to WOFOST input parameters for all suitable sub-units is discussed. Secondly the procedure is described which groups similar land evaluation units into land evaluation groups.
This entire procedure is controlled by a module written in FORTRAN called WFINPUT.

4.2 Determination of soil and land related input data.

The version of the crop growth simulation model WOFOST applied in our study, uses 9 land and soil related input parameters:

- Texture class (with associated water retention data)
- Presence of groundwater influence in the root zone of the soil
- Initial groundwater depth in case of groundwater influence
- Presence of artificial drainage
- Draining depth in case of artificial drainage
- Maximum rooting depth of the soil
- Amount of water present in the soil at the beginning of the growing season

- Maximum surface storage
- Maximum non-infiltrating fraction of rainfall

For groundwater influenced soils, a hydraulic conductivity curve is required as well. Texture class and maximum rooting depth are parameters which were already specified as soil and land characteristics (see Reinds et al., 1991), so these values were directly used as input. For each texture class a soil water retention curve was defined (Reinds et al., 1991). The proper pF data for each soil are read by WOFOST from a data file using this texture class.

Whether a soil's root zone is influenced by groundwater or not, is hard to judge from the information provided on the EC soil map. There are no data supplied on groundwater depths and fluctuations (CEC, 1985). It should be realized, however, that only a minor part of the soils in the EC have groundwater influence in the root zone. The need for groundwater data for the soil units on the EC soil map, as expressed by Van Lanen et al. (1989b), is certainly valid but only for a relatively small area within the EC.
In this study all soils with a very poor, poor, temporary poor, and imperfect drainage (eg. Histosols, Gleysols, Fluvisols, and soils with a gleyic or stagnogleyic phase) were assumed to have groundwater influence in the root zone during the growing season. This estimate will not always be legitimate as in dry periods, for example, stagnogleyic soils are not necessarily influenced by groundwater.
Map I shows the distribution of soils with groundwater influence, according to our assumptions. On this map all soils presumed to be influenced by groundwater are shaded green, soils with free drainage are shaded yellowish brown.
WOFOST allows the use of a simple relationship between groundwater depth and downward water flux through the freatic level. Therefore, all groundwater influenced soils were assumed to have a kind of artificial drainage discharging excess water in case of shallow groundwater depths.
The unknown draining depth was set at such a depth that at static equilibrium and a groundwater level at draining depth, the pressure head in the middle of the root zone equals -120 cm. The groundwater depth at the beginning of the growing season was set at the draining depth.
The amount of water initially present in the soil profile was postulated as that sufficient to bring the maximum rooting zone of all soil types at field capacity. Water in excess of the amount needed to reach field capacity in the maximum rooting zone, is discharged.
The maximum amount of water that can be stored on the soil surface (surface storage) was set at 5 cm for all land evaluation units with slope class 'a' (0-8 % slope) and at 0 cm for all other units with steeper slopes.
The maximum non-infiltrating fraction of the rainfall is also dependent on the slope class. Estimated values are given in Table 4.2. The actual non-infiltrating fraction was calculated by the simulation model depending on the amount of rainfall on a particular day.

Table 4.2 Maximum non-infiltrating fraction of rainfall.

	Land Use	
Slope (%)	Grassland	Annual crops
0-8	0.00	0.00
0-15, 8-15	0.20	0.30
> 15, 8->15	0.30	0.50

4.3 Grouping of similar land evaluation units

As described in the foregoing section, each sub-unit was supplemented with a record of input data, needed to run the simulation model WOFOST.Since the number of land and soil related input parameters was relatively small and because the parameters were subdivided into a small number of classes, many sub-units were similar regarding WOFOST input.

Table 4.3 Fragment of a WOFOST input file

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	0	1	0	1	26	1	0	6	1	1	16	315	1	1.00	1.00	2	1	150.	1	150.	80.	30.0	5.0	0.0	EC	10866
..																										
9	0	1	0	1	26	1	0	6	1	1	16	315	1	1.00	1.00	4	0	150.	0	150.	120.	30.0	0.0	0.2	EC	8329
10	0	1	0	1	25	1	0	6	1	1	16	315	1	1.00	1.00	4	0	150.	0	150.	120.	30.0	0.0	0.2	EC	8180
..																										
485	0	1	0	1	26	1	0	6	1	1	16	315	1	1.00	1.00	3	0	150.	0	150.	40.	30.0	0.0	0.2	EC	7222
486	0	1	0	1	26	1	0	6	1	1	16	315	1	1.00	1.00	3	0	150.	0	150.	120.	30.0	0.0	0.2	EC	7150
..																										
870	0	1	0	1	26	1	0	6	1	1	16	315	1	1.00	1.00	3	1	150.	1	150.	60.	30.0	0.0	0.2	EC	16242
871	0	1	0	1	26	1	0	6	1	1	16	315	1	1.00	1.00	4	1	150.	1	150.	60.	30.0	0.0	0.2	EC	16242
872	0	1	0	1	26	1	0	6	1	1	16	315	1	1.00	1.00	3	0	150.	0	150.	120.	30.0	5.0	0.0	EC	7150
873	0	1	0	1	1	0	0	6	1	1	16	315	1	1.00	1.00	3	0	150.	0	150.	120.	30.0	5.0	0.0	EC	258

```
column 1: Land evaluation group
column 2: Type of weather data (monthly data = 0)
column 3: Number of years with daily weather data (monthly data = 1)
column 4: First year with daily weather data (monthly data = 0)
column 5: First year with monthly weather data
column 6: Number of years with monthly weather data
column 7: Generated rainfall for long term average weather (0 = yes)
column 8: Output to file, interval in days
column 9: Crop number
column 10: Crop variety number
column 11: Sowing date
column 12: Emergence date
column 13: Harvest date
column 14: Start option (0 = fixed start date, 1= fixed sowing date, 2=variable sowing date)
column 15: Correction factor development rate
column 16: Correction factor development rate
column 17: Soil number
column 18: Groundwater influence (1 = yes, 0 = no)
column 19: Initial groundwater depth (cm)
column 20: Artificial drainage (1 = yes, 0 = no)
column 21: Draining depth (cm)
column 22: Maximum rooting depth (cm)
column 23: Initial amount of water in soil profile (cm)
column 24: Maximum surface storage
column 25: Maximum non infiltrating fraction of rainfall
column 26: Station name
column 26: Number of meteorological station
```

To avoid identical, time-consuming simulation runs, all land evaluation sub-units with identical values for all input parameters were grouped together. For each of these so-

called land evaluation groups one representative input line was written to the WOFOST input file (Figure 4.3). This line contained 27 parameters. Some of these parameters were used to open the proper climatic data file, crop data file, and soil physical data file. Others were directly used as variables in the WOFOST model.
Grouping of similar units strongly reduced the number of calculations required. This is expressed in Figure 4.4. The number of potentially suitable sub-LEUs for each crop type is given together with the number of land evaluation groups. The number of land evaluation groups for the three specified crop types was about 35 % of the number of sub-units.

The simulations with the crop growth model WOFOST were made after the input file for the specified land use was created. For each land evaluation group the mean potential and water limited yield for a particular crop were calculated. Furthermore, the coefficients of variance for the crop yields in both production situations were determined. This variance in calculated yields stems from the use of a historical record of weather data. Such a historical record accounts for a wide range in weather conditions, required to obtain a reliable estimate of the mean yield.
For a detailed description of WOFOST and its principles, the reader is referred to Van Diepen et al., 1989.
Since crop growth was simulated at land evaluation group level, some data handling was needed to segregate all results to land evaluation unit level. This process will be described in the next chapter.

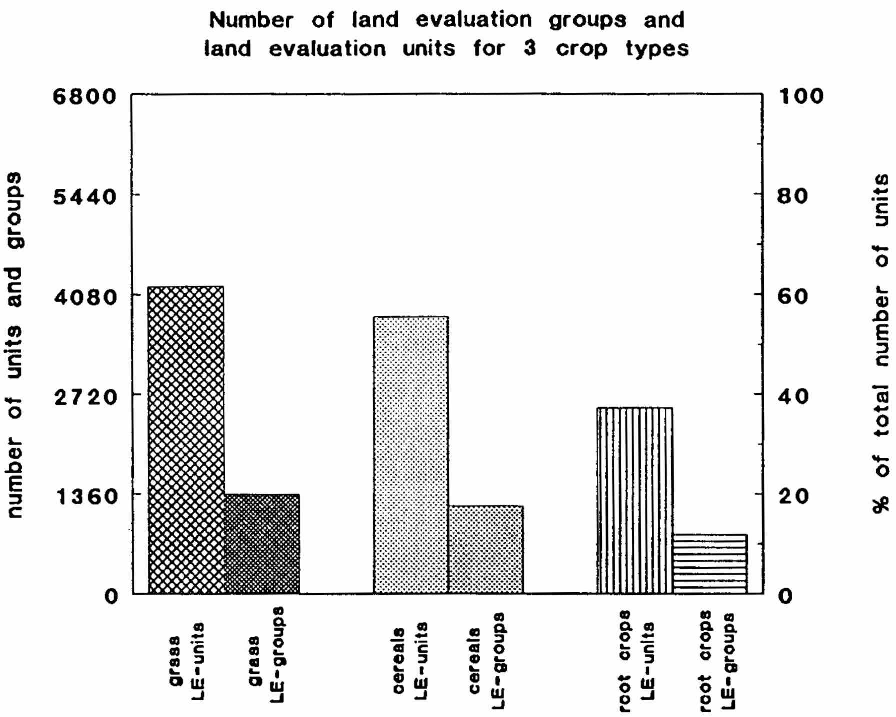

Figure 4.4 Number of land evaluation units and land evaluation groups

5 PROCESSING OF THE EVALUATION RESULTS

5.1 Segregation of data from group level to data on LEU level.

To allow further processing of the evaluation results, all simulated crop yields had to be segregated from land evaluation group level to land evaluation unit level. This procedure made use of the output of WOFOST and that of the selection procedure described in chapter 3.

For each LEU, results from the qualitative selection of suitable land evaluation units were combined with the simulated mean crop yields. A fragment of an output file showing the results of the mixed qualitative/quantitative procedure for each LEU is given in Table 5.1.

Table 5.1 Fragment of output file of the segregation procedure

```
evaluation unit uns crop limitations  leav_p stem_p stor_p vcpp leav_w stem_w stor_w vcwp   Nf    Pf    Kf   Nor   Por   Kor  Wats
                          1 2 3 4 5 6 7 8
100111_18_10866 0.000 1 0 0 0 0 0 0 0 0 4237. 10396. 8380. 7.47  3820.  9738.  8259.  6.34 -99. -99. -99. -99. -99. -99.
0.
100111_28_00265 0.000 1 0 0 0 0 0 0 0 0 3760. 11024. 8603. 0.00  3509. 10617.  8440.  4.87 -99. -99. -99. -99. -99. -99.
50.
100111_28_07650 0.000 1 0 0 0 0 0 0 0 0 3844. 10458. 8573. 6.77  3744. 10204.  4891. 57.22 -99. -99. -99. -99. -99. -99.
761.
100211_80_03962 0.000 1 0 0 0 0 0 0 0 0 3334. 10664. 8991. 9.76  2931. 10056.  8497. 16.36  55. -99. -99. -99. -99. -99.
60.
100217_32_16105 1.000 1 0 0 0 0 0 0 1 0
100217_33_16090 1.000 1 0 0 0 0 0 0 1 0
100217_33_16105 1.000 1 0 0 0 0 0 0 1 0
107529_A3_16714 1.000 1 0 0 0 0 1 0 0 0
107611_35_16242 0.500 1 0 0 0 0 1 0 0 0 3774. 10110. 8508. 5.42  3765. 10090.  7261. 27.69 -99. -99. -99. -99. -99. -99.
193.
107611_36_16242 0.500 1 0 0 0 0 1 0 0 0 3774. 10110. 8508. 5.42  3765. 10090.  7261. 27.69 -99. -99. -99. -99. -99. -99.
193.
107614_3B_16560 1.000 1 0 0 0 0 1 0 1 0
107711_22_07145 0.500 1 1 0 0 0 0 0 0 0 3671. 10540. 8874. 7.84  3668. 10443.  7557. 28.85 -99. -99. -99. -99. -99. -99.
203.
107711_26_07630 0.500 1 1 0 0 0 0 0 0 0 3563. 10430. 8499. 6.89  3562. 10386.  6878. 36.51 -99. -99. -99. -99. -99. -99.
279.

310929_7A_03100 1.000 1 0 0 0 0 0 1 0 0
```

```
evaluation unit  land evaluation unit : soil map unit (4 digits) and phase (2 digits) _ NUTS _ climate codes
uns              unsuited part
crop             crop number ( 1 - wheat, 2 - maize, 3 - potato, 4 - sugarbeet, 5 - fieldbean, 6 - grass)
limitations      reason for unsuitability (explanation of codes at end of file)
leav_p           average value of total dry weight of leaves produced in the potential production situation
stem_p           average value of total dry weight of stems produced in the potential production situation
stor_p           average value of total dry weight of storage organs (grains) produced in the potential production situation

vcpp             coefficient of variation of potential grain yield
leav_w           average value of total dry weight of leaves produced in the water-limited production situation
stem_w           average value of total dry weight of stems produced in the water-limited production situation
stor_w           average value of total dry weight of storage organs (grains) produced in the water-limited production
                   situation
vcwp             coefficient of variation of water-limited grain yield
Wats             nett crop irrigation requirement (m3/hectare/season)

COLUMNS FOR TYPE OF LIMITATION:
column 1 - texture
column 2 - salinity
column 3 - alkalinity
column 4 - rootable depth
column 5 - slope
column 6 - drainage
column 7 - phase
column 8 - climate
```

Calculated mean yields for each (partly) suitable evaluation unit were read from the WOFOST output file using the number of the land evaluation group in which the LEU was placed. The yield of a compound texture unit was calculated as the mean of the yields of

its related sub-units. The coefficient of variance for a compound land evaluation unit was calculated from the yields and coefficients of variance of each sub-unit.
For all (partly) unsuitable land evaluation units, the type of restrictions determined by the qualitative pre-selection, were added to the simulation results by means of 8 columns with binary variables. Each of these columns represents a selection parameter. A value of '1' for the binary variable means that the minimum site requirements for this selection parameter could not be met. A value of '0' means that the LEU had no limitations with regard to that specific selection parameter.
Furthermore, the water shortage (in cubic meters) in the water-limited production situation as compared to the potential production situation was calculated and written to the output file. This water shortage was computed as the difference between the crop water uptake in the potential production situation and the crop water uptake in the water-limited production situation.

The procedure described above was controlled by a FORTRAN module called ECJOIN. This module also has the capacity to include data on nutrient supply (in kg N, P and K per hectare) which, together with the simulated crop yields, can be used to calculate the nutrient limited crop yield. The fertilizer input per hectare is not specified in the output file shown in figure 5.1, as the amounts of N,P and K applied could not be estimated accurately from the readily available statistical data on fertilizer and manure use.
The nutrient requirements of the crop in the potential and water limited production situation were calculated from the simulated dry matter production and available data on the mean concentrations of N, P and K in the various plant organs.

5.2 Summaries for each NUTS-1 region, agro-climatic region and soil type

To achieve an efficient interpretation of the results from the physical land evaluation, all results had to be aggregated. Simulated yields of all crops were aggregated for each NUTS-1 region, climatic region and soil type.
Such aggregations were made by the GIS as well as by a FORTRAN module called ECSUMMARY.
An example of a summary of evaluation results on NUTS-1 level is presented in Table 5.2. For each NUTS-1 region all (partly) suitable LEUs are listed with their associated potential and water-limited yields. Furthermore, the deviation of these yields compared to the mean calculated yield over the NUTS-1 region is given as percentages. Such a summary on NUTS-1 region level gives insight in the variation in calculated yields over this region as caused by differences in climate and/or soil type. The data in Table 5.2 show that the calculated yields for the two agro-climatic regions in the NUTS-1 region Wales were about

Table 5.2 Example of a summary for NUTS-1 Wales.

Summary simulation results for each nuts1-region

cropnr: 3 potatoes				pot.pr.	dev	watl.pr.	dev
nuts1-region: 79 Wales			means =>	15675.		10918.	
100211_79_03302	Jeg1/4a	GleyicEutricFluvisol	VALLEY(UKw1)	15397.	-2.	14351.	31.
100211_79_03715	Jeg1/4a	GleyicEutricFluvisol	GLAMORGAN/RHOUSE_AP(UKw3)	15852.	1.	14519.	33.
101111_79_03302	Jcg1a	GleyicCalcaricFluvisol	VALLEY(UKw1)	15490.	-1.	13233.	21.
101111_79_03715	Jcg1a	GleyicCalcaricFluvisol	GLAMORGAN/RHOUSE_AP(UKw3)	15957.	2.	13513.	24.
103811_79_03302	Rc1b	CalcaricRegosol	VALLEY(UKw1)	15490.	-1.	7664.	-30.
103811_79_03715	Rc1b	CalcaricRegosol	GLAMORGAN/RHOUSE_AP(UKw3)	15957.	2.	8418.	-23.
105811_79_03715	Q11ac	LuvicArenosol	GLAMORGAN/RHOUSE_AP(UKw3)	15957.	2.	8418.	-23.
202611_79_03302	Be2/3ac	EutricCambisol	VALLEY(UKw1)	15350.	-2.	11490.	5.
202611_79_03715	Be2/3ac	EutricCambisol	GLAMORGAN/RHOUSE_AP(UKw3)	15800.	1.	11895.	9.
202711_79_03715	Be1/2a	EutricCambisol	GLAMORGAN/RHOUSE_AP(UKw3)	15906.	1.	11410.	5.
205811_79_03302	Bd1/2bc	DystricCambisol	VALLEY(UKw1)	15452.	-1.	9653.	-12.
205811_79_03715	Bd1/2bc	DystricCambisol	GLAMORGAN/RHOUSE_AP(UKw3)	15906.	1.	10234.	-6.
205829_79_03302	Bd1/2bc	DystricCambisol	VALLEY(UKw1)	15452.	-1.	9653.	-12.
206211_79_03302	Bd1/2bc	DystricCambisol	VALLEY(UKw1)	15452.	-1.	9653.	-12.
206211_79_03715	Bd1/2bc	DystricCambisol	GLAMORGAN/RHOUSE_AP(UKw3)	15906.	1.	10234.	-6.
206911_79_03302	Bds2bd	SpodoDystricCambisol	VALLEY(UKw1)	15413.	-2.	11116.	2.
206911_79_03715	Bds2bd	SpodoDystricCambisol	GLAMORGAN/RHOUSE_AP(UKw3)	15854.	1.	11574.	6.
207111_79_03302	Bds1ab	SpodoDystricCambisol	VALLEY(UKw1)	15490.	-1.	8190.	-25.
302311_79_03715	Lo3b	OrthicLuvisol	GLAMORGAN/RHOUSE_AP(UKw3)	15745.	0.	12215.	12.

the same.

The influence of soil type on the calculated potential yield is more pronounced. Calculations show that Calcaric Regosols, which are coarse, drought susceptible soils produce 20-30 % less than the mean yield in the water-limited production situation. Fluvisols, on the other hand produce about 30 % more than the mean water-limited yield in this region.

Table 5.3 Example of a summary for the agro-climatic region Nurnberg.

Summary simulation results for each meteorological station

cropnr: 3 potatoes			pot.pr.	dev	watl.pr.	dev
meteo_station NURNBERG(D-e3)		means =>	15483.		11881.	
100211_18_10763	Jeg1/4a	GleyicEutricFluvisol	15487.	0.	14133.	19.
100211_19_10763	Jeg1/4a	GleyicEutricFluvisol	15487.	0.	14133.	19.
100611_19_10763	Jcf1/4a	FluviCalcaricFluvisol	15487.	0.	14133.	19.
101311_18_10763	Jd1a	DystricFluvisol	15550.	0.	13030.	10.
101311_19_10763	Jd1a	DystricFluvisol	15550.	0.	13030.	10.
200611_19_10763	Be3a	EutricCambisol	15409.	0.	12715.	7.
205311_18_10763	Bd2b	DystricCambisol	15501.	0.	10900.	-8.
205311_19_10763	Bd2b	DystricCambisol	15501.	0.	10900.	-8.
205411_18_10763	Bd2a	DystricCambisol	15501.	0.	12182.	3.
205411_19_10763	Bd2a	DystricCambisol	15501.	0.	12182.	3.
300111_18_10763	Lo3ab	OrthicLuvisol	15409.	0.	11533.	-3.
300111_19_10763	Lo3ab	OrthicLuvisol	15409.	0.	11533.	-3.
300311_19_10763	Lo2/3ab	OrthicLuvisol	15455.	0.	11217.	-6.
300911_16_10763	Lo2/3a	OrthicLuvisol	15455.	0.	12449.	5.
300911_18_10763	Lo2/3a	OrthicLuvisol	15455.	0.	12449.	5.
300911_19_10763	Lo2/3a	OrthicLuvisol	15455.	0.	12449.	5.
301111_19_10763	Lo2ab	OrthicLuvisol	15501.	0.	10900.	-8.
301211_18_10763	Lo3a	OrthicLuvisol	15409.	0.	12715.	7.
301211_19_10763	Lo3a	OrthicLuvisol	15409.	0.	12715.	7.
301311_19_10763	Lo2a	OrthicLuvisol	15501.	0.	12182.	3.
307111_18_10763	Dd1/2ab	DystricPodzoluvisol	15526.	0.	9711.	-18.
307111_19_10763	Dd1/2ab	DystricPodzoluvisol	15526.	0.	9711.	-18.
308811_19_10763	Phf1a	FerroHumicPodzol	15550.	0.	9122.	-23.
308911_19_10763	Phf1a	FerroHumicPodzol	15550.	0.	9122.	-23.

If one is mainly interested in the effect of soil type on calculated yield, a summary can be

made for each of the agro-climatic regions (Table 5.3).
Such a summary shows the calculated yields for all (partly) suitable LEUs within a particular agro-climatic region. As the climatic data used were the same for each soil type within a agro-climatic region, all differences in calculated yields are related to soil and land characteristics.
The very small differences in potential yield that occur within one agro-climatic region were caused by differences in planting date. Planting date was related to the texture of the topsoil and the soil water conditions in spring. Pronounced differences are found between the water limited yields simulated for the various soil types within this agro-climatic region. Due to a higher water holding capacity and the influence of groundwater, the calculated water limited yield of most Fluvisols was about 40 % higher than that of the coarse textured Podzols.
The effect of climate on calculated yields can be derived from a summary of evaluation results for each soil type (Table 5.4).

Table 5.4 Example of a summary for Luvic Arenosols.

Summary simulation results for each soil-type

cropnr: 3	potatoes		pot.pr.	dev	watl.pr.	dev
soil_type	LuvicArenosol	means =>	15683.		6808.	
105811_21_07145	Q11ac	TRAPPES(F-w8)	16067.	2.	5833.	-14.
105811_21_07150	Q11ac	PARIS/LE_BOURGET(F-w2)	15964.	2.	5791.	-15.
105811_22_00241	Q11ac	TOURS(F-w7)	15564.	-1.	3996.	-41.
105811_22_06447	Q11ac	UCCLE(B-w1)	15223.	-3.	9140.	34.
105811_22_07145	Q11ac	TRAPPES(F-w8)	16067.	2.	5833.	-14.
105811_22_07150	Q11ac	PARIS/LE_BOURGET(F-w2)	15964.	2.	5791.	-15.
105811_22_07180	Q11ac	NANCY/ESSEY(F-e1)	15716.	0.	7835.	15.
105811_22_07255	Q11ac	BOURGES(F-e3)	15512.	-1.	4837.	-29.
105811_24_07180	Q11ac	NANCY/ESSEY(F-e1)	15716.	0.	7835.	15.
105811_26_00258	Q11ac	BIARITZ(F-s8)	15786.	1.	9867.	45.
105811_52_07150	Q11ac	PARIS/LE_BOURGET(F-w2)	15964.	2.	5791.	-15.
105811_52_07180	Q11ac	NANCY/ESSEY(F-e1)	15716.	0.	7835.	15.
105811_60_07180	Q11ac	NANCY/ESSEY(F-e1)	15716.	0.	7835.	15.
105811_60_07190	Q11ac	STRASBOURG/ENTZHEIM(F-e2)	15405.	-2.	7788.	14.
105811_72_03377	Q11ac	WADDINGTON(UKe1)	15662.	0.	7611.	12.
105811_73_03377	Q11ac	WADDINGTON(UKe1)	15662.	0.	7611.	12.
105811_74_03776	Q11ac	LONDON/GATWICK_AIRPORT(UKs1)	15960.	2.	7070.	4.
105811_75_03776	Q11ac	LONDON/GATWICK_AIRPORT(UKs1)	15960.	2.	7070.	4.
105811_75_03862	Q11ac	DURNEMOUTH/HURN_AP(UKs3)	16171.	3.	5492.	-19.
105811_76_03827	Q11ac	PLYMOUTH/MOUNT_BATTEN(UKs2)	16357.	4.	7625.	12.
105811_77_03334	Q11ac	MANCHESTER_AIRPORT(UKw2)	15383.	-2.	7383.	8.
105811_77_03534	Q11ac	BIRMINGHAM_AP(UKe2)	14612.	-7.	7084.	4.
105811_77_03715	Q11ac	GLAMORGAN/RHOUSE_AP(UKw3)	15957.	2.	8418.	24.
105811_78_03715	Q11ac	GLAMORGAN/RHOUSE_AP(UKw3)	15957.	2.	8418.	24.
105811_79_03715	Q11ac	GLAMORGAN/RHOUSE_AP(UKw3)	15957.	2.	8418.	24.
105811_B6_08554	Q11ac	FARO(P-s1)	14980.	-4.	919.	-86.
105811_B6_08562	Q11ac	BEJA(P-s2)	14477.	-8.	2294.	-66.
105911_74_03377	Q11a	WADDINGTON(UKe1)	15662.	0.	8404.	23.
106011_74_03377	Q11ab	WADDINGTON(UKe1)	15662.	0.	7611.	12.

Such a summary contains the simulated yields of all LEUs with identical dominant soil units. Soil and land properties were assumed to be independent of the soil's location. So all differences in calculated yields in this summary were caused by climatic differences. Soil and land properties, of course, are not always independent of location as climate is an important soil forming factor. However, since no soil data set was available, soil and land related data were derived from the general information on the soil map. A differentiation of soil and land properties depending on the climatic region would suggest a accuracy that cannot be justified due to the lack of basic data.

5.3 Linkage of the output to the geographical information system

The data in the output file of the data processing procedure outlined in section 5.1, were stored in the geographical information system. The GIS was used to calculate a mean area-weighted yield for each of the agro-climatic zones and NUTS-1 regions. This means that the area of each suitable LEU was used as a weighting factor when calculating the mean yield over a certain region.
These yield data were used to produce maps showing simulated water-limited and potential yields on LEU-level, agro-climatic zone level and NUTS-1 level. In addition, the GIS supplied tables showing the simulated yields in both production situations on the level of agro-climatical zones and NUTS-1 regions.
The area of potentially suitable land within different regions for growing a specific crop type, was illustrated by maps and tables.
Statistical data were used to produce maps and tables showing the actual acreage in each NUTS-1 region occupied by a specific crop and the actual yield for each of these crops on NUTS-1 level.
The technique of data storage in a data model and the production of maps and tables using the ARC-INFO package, are described in detail by Bulens and Bregt (1991).
All results from this mixed qualitative/quantitative evaluation procedure are presented and discussed by De Koning et al. (1991).

6 CONCLUSIONS AND RECOMMENDATIONS

The mixed qualitative/quantitative land evaluation procedure described in this report, has proven to be a very functional tool for physical land evaluations on this scale.
The exclusion of EC land with severe limitations from processing with detailed simulation models, and the grouping of land evaluation units with identical input data for WOFOST, significantly reduced the number of simulations required.
As the land evaluation procedure was completely automated, the processing of the large amount of land evaluation units and associated data was easy and reproducible. Without such an automated procedure the efforts needed for a proper handling of input, output and basic data would have been prohibitive.
Although satisfactory in most ways, the physical land evaluation procedure decribed, can be improved. Some of these improvements concern the procedure itself, but most of them are related to the input data needed for the evaluations.

The soil map of the EC on a scale 1:1.000.000 certainly contains valuable information that can be used in studies such as ours. Nevertheless, the number of related soil and land data for each soil association (soil mapping unit) is very limited. At present only the texture and the slope of the dominant soil unit of the soil association are specified by a texture and a slope class. These dominant soil units however, cover only about 60 % of the total map area (Reinds et al., 1991).
To allow a better characterization of the soil associations by representative soil and land data, more information about the associated soils of each soil association should be made available. Furthermore, for a dominant unit with a compound texture and/or slope class, the fraction of the unit-area occupied by each specific slope and/or texture class needs to be characterized. These composition data are important as the texture of the topsoil and the slope of a soil unit strongly determine its suitability for most types of land use. A more accurate assessment of the land suitability of compound soil units can only be made if these composition data were available.
More accurate crop growth simulations can be made if, apart from the above mentioned basic data, additional soil and land data would be known. In particular, data are needed on the rooting depth of the soil, subsoil texture, groundwater depth and fluctuation and on physical properties such as water retention.
If such data would be available, the WOFOST water balance calculations for example, would probably be more accurate and other, more comprehensive soil water modules could be used to describe the water movement in soils with ground water influence. In the present situation, the lack of basic soil physical data does not allow the use of a module simulating soil water flow in detail.

It is important to note that in the qualitative selection of potentially suitable soils, coarse textured soils were not excluded from detailed analysis as these soils could be productive if located in regions with sufficient precipitation during the growing season. In regions with a high precipitation deficit these soils could also produce reasonable yields if sufficient irrigation water is applied. So, for a proper assessment of the crop growth potentials in the potential production situation, the crop yields on coarse textured soils were calculated for all regions. As only minor parts of dry areas are irrigated, many of the sandy soils in these areas are actually not used for growing annual crops such as wheat or potatoes. The actual acreage within dry, warm regions used for arable farming is therefore far less than the potentially suitable acreage in these regions as determined by our selection method.

The selection of potentially suitable and unsuitable units has been performed in such a way that units which could not meet one of the prescribed land use requirements were characterized as unsuitable. Each land use requirement was directly related to one of the basic soil and land characteristics derived from the EC soil map. This selection of suitable units can be somewhat improved by using a procedure which allows the use of land use requirements related to a combination of characteristics. For example, in our study, all poorly drained soils were excluded from detailed analyses using the crop growth simulation model, independent of any of their other characteristics. It would be preferable to exclude poorly drained soils only if other characteristics, such as annual precipitation deficit, are unfavorable as well. Such a detailed selection of unsuitable and potentially suitable soils can be made by a qualitative land evaluation system such as ALES (Van Lanen et al., 1990). Unfortunately, a version of ALES capable of handling the large amount of evaluation units became available only after the mixed qualitative/quantitative land evaluations had been made.
A qualitative selection of potentially suitable units with ALES followed by a quantitative evaluation with WOFOST can, however, easily be implemented within the framework of the evaluation procedure outlined in this report.

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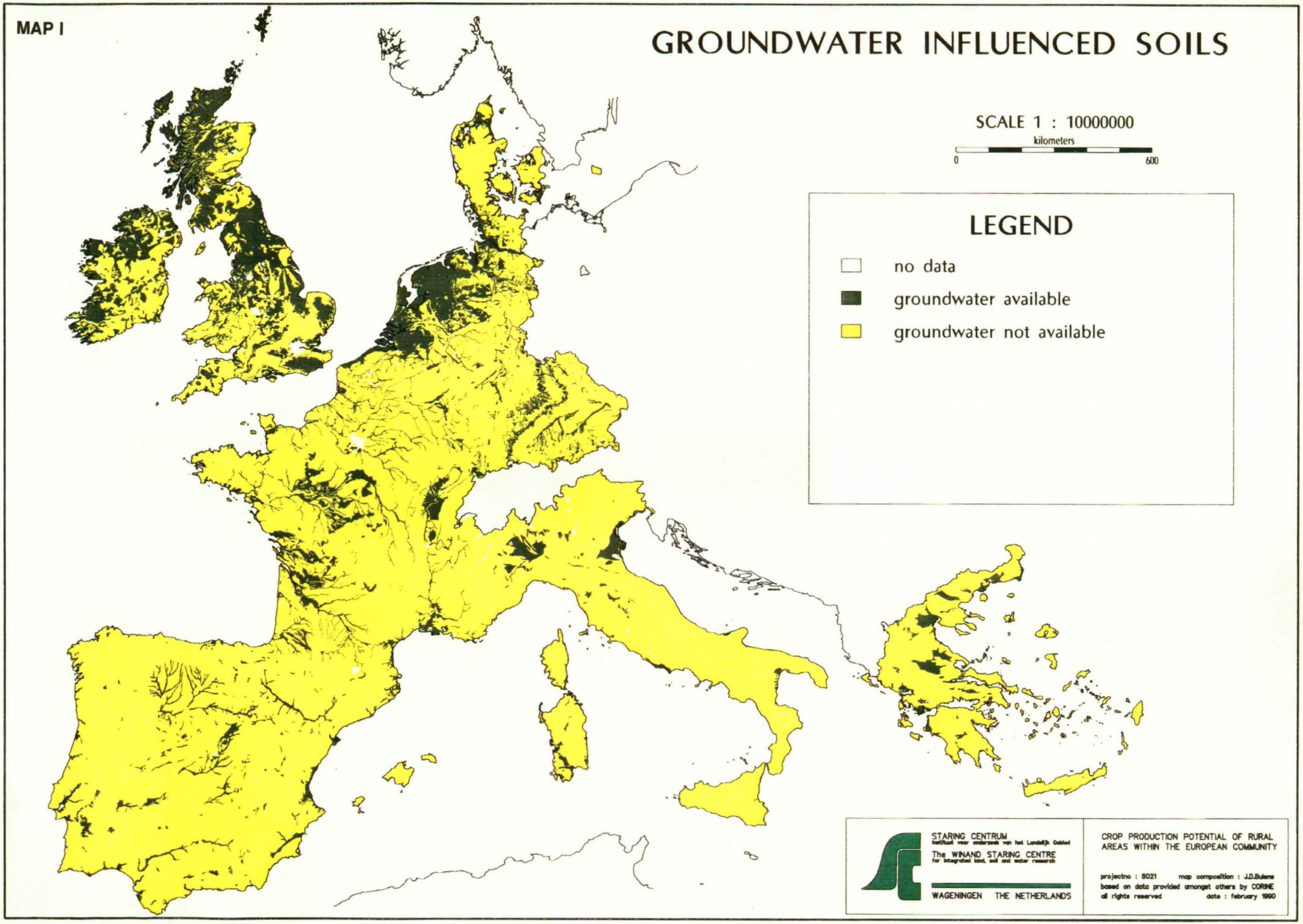

MAP I
GROUNDWATER INFLUENCED SOILS
SCALE 1 : 10000000
kilometers
0
600
LEGEND
no data
groundwater available
groundwater not available
STARING CENTRUM
Instituut voor onderzoek van het Landelijk Gebied
The WINAND STARING CENTRE
for integrated land, soil and water research
WAGENINGEN THE NETHERLANDS
CROP PRODUCTION POTENTIAL OF RURAL AREAS WITHIN THE EUROPEAN COMMUNITY
projectno : 8021 map composition : J.D.Bulens
based on data provided amongst others by CORINE
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