Land evaluation for rain fed agriculture in the Mediterranean Peyne area, Southern France

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Master thesis

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ABSTRACT

This thesis sets out to provide a land use recommendation report for a Mediterranean study area, with a focus on rain fed agriculture. We found that barley, grape, olive, sugar beet and wheat have a high chance of being successfully cultivated in this region as rain fed crops, while cultivation of citrus, maize, tomato and tobacco should be avoided. Crop suitability is mostly limited by availability of nutrients, moisture availability and potential soil erosion. Presently, grape, olive and wheat are the most common crop types. This study shows that barley and sugar beet form promising alternatives.

Crop suitability was assessed by performing a land evaluation, based on FAO guidelines. This procedure consists of selecting eligible Mediterranean crop types and determining their requirements in terms of climatic, soil and degradation factors. These are compared with corresponding land qualities to obtain suitability ratings. Necessary data were collected during a field campaign in 2011 in the Hérault province in Southern France, and combined with a literature study.

To allow a comparison with recommended crop types, present land use was classified using an object based approach. We selected a Landsat 7 image that corresponds with the field campaign as input. A classification rule set was developed from training data with use of a Classification and Regression Tree (CART) analysis. Overall accuracy of the classification is 52.1%, which is mainly a result of confusion between the vineyards, bare soil and grassland classes.

Keywords: land use, land evaluation, rain fed agriculture, FAO, OBIA, CART analysis.

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LIST OF SYMBOLS AND ABBREVIATIONS

CAP	Common Agriculture Policy
CEC	Cation exchange capacity
DBD	Dry bulk density
DEM	Digital elevation model
ETo	Potential evapotranspiration
FAO	Food and agriculture organization
LMU	Land mapping unit
LMUS	Land mapping unit subdivision
LQ	Land quality
LUR	Land use requirement
LUT	Land utilization type
MAR	Mean annual rainfall
OM	Organic matter
p	Precipitation
RUSLE	Revised Universal soil loss equation
SWI	Soil wetness index
T	Temperature
TWI	Topographic wetness index

β	Slope gradient
ϕ	Porosity
A	Soil loss
As	Specific catchment area
C	Cover management factor
K	Soil erodibility factor
L	Slope length factor
ms	Mass of soil sample
mst	Mass of CaCO3 standard
P	Support practice factor
R	Rainfall-runoff erosivity factor
S	Slope steepness factor
Vs	Volume of soil sample
Vst	Volume of CaCO3 by standard
Wd	Weight of soil sample after drying (110°C)
Wg	Weight of soil sample after heating (450°C)
Wr	Weight of sample ring
Ws	Saturated weight of soil sample

Chapter 1

INTRODUCTION

Land is an essential natural resource that performs a number of key environmental, economic, social and cultural functions which are vital for life. It forms the basis for agriculture and forest production, water catchment, recreation, and urban and industrial use (FAO, 2007b). At present the world is faced with rapid population growth and urban expansion leading to ever increasing demands on available land, especially through the need for food production. To feed the nearly 8 billion people expected to live on earth by 2025, food production will have to double the amount it produces at present (UN, 2010; UNFPA, 2001). Because of the strong competition between different uses of land nowadays and the discussion about multi-functional land use, available cropland is not expected to grow. This means that the increase in production will have to be achieved by increasing crop yields rather than by cultivating new lands (UNFPA, 2001).

In addition to increasing food production, the loss of valuable land by degradation and deterioration processes should be restricted as much as possible. Already 16% of arable land is degraded and this percentage is expected to rise (UNEP, 1999). Due to potentially rapid degradation rates and slow regeneration, land is a limited non-renewable natural resource. Degradation results in a loss of production potential, reducing the capabilities of land to perform its functions (FAO, 2007b).

To ensure the most optimal use of natural resources, while at the same time conserving these resources for the future, efficient land use planning is required. This way both the increasing food demands of the population can be met and land degradation reduced (FAO, 2007b). According to the UNCED (1993), land use planning is a decision-making process that *'facilitates the allocation of land to the uses that provide the greatest sustainable benefits'*, and is mainly focused on the use of land in the agricultural context. A valuable tool in the development of land use policies is land evaluation. Land evaluation can be defined as *'the assessment of land performance when used for specified purposes',* with as principal objective to select the optimum land use for defined land units (FAO, 1976). This process involves assessing landforms, soils, climate, vegetation and other physical aspects of land to identify and compare promising types of land use (FAO, 1983; FAO, 1993).

The Mediterranean region forms an interesting area to perform a land evaluation for several reasons. First, agriculture has always been an important type of land use in the coastal plains around the Mediterranean Sea, and continues to be so (Grigg, 1974).

Second, the Mediterranean climate is characterized by wet, mild winters, and dry, hot summers. Most precipitation falls in spring and autumn and often occurs in short, intense rain storms. These properties in combination with the hilly nature of the region make this a vulnerable area in terms of soil erosion and soil degradation. At the same time the moisture deficit during summer presents difficulties for agricultural land use (Lionello et al., 2006; Sluiter, 2005).

Finally, irrigation in the Mediterranean is not a recommendable practice. Mørch (1999) states that in a typical Mediterranean area such as Sicilia the irrigated area could not be raised above a sixth of total arable land because of limited water availability. Furthermore, water demand is expected to rise over the coming years due to increasing population and industrialization, and for agricultural purposes. Agriculture is the main water consuming factor in the Mediterranean area, accounting for approximately 63% of the total water demand. Presently water withdrawals near or even exceed the limit threshold of renewable resources. This means more water is extracted from reservoirs than can be supplemented, causing depletion of these resources. As a result policies are being developed aimed at decreasing water usage and improving the efficiency of use (UNEP, 2006).

A land evaluation focused on rain fed agriculture in this region is therefore of great value to ensure acceptable land degradation levels and to achieve maximum agricultural yields without the use of irrigation.

1.1 Aim

The aim of this study is to produce a land use recommendation report for rain fed agriculture of an area in Mediterranean France. To achieve this, a land evaluation based on ‘A Framework for Land Evaluation’ (FAO, 1976) and the ‘Guidelines for rain fed agriculture’ (FAO, 1983) will be performed. The objectives are:

- To perform a land evaluation procedure according to the FAO guidelines to determine the most suitable types of agricultural land use in the study area;
- To adjust the FAO method where required or necessary;
- To determine present land use in the study area with the use of remote sensing;
- To present land use recommendations and propose possible land improvements;
- To evaluate the suitability of present land use.

1.2 Content

The structure of this thesis is as follows: chapter 2 will provide an overview of the location, climate geology, soils and land use of the study area; chapter 3 provides a background of the FAO land evaluation procedure and Mediterranean agriculture; chapter 4 will outline the methods that are used to perform a land evaluation; chapter 5 and 6 present the results of this evaluation procedure and a land use recommendation report; finally chapter 7 contains a discussion of the results and chapter 8 the conclusions.

Chapter 2

STUDY AREA

In this chapter the study area is presented. The topics are the location, climate, geology, soils and actual land use of the area.

2.1 Location

The research area is located in the Hérault department of the Languedoc Roussillon region in Southern France. The study site is situated in the catchment area of the Peyne river, a tributary of the Hérault river (see *figure 2.1*), approximately 50 km west of Montpellier and 30 km from the Mediterranean Sea. The Peyne catchment is located east of the 'Montagne Noire' and south of the 'Massif Central'. The watershed displays a lot of variation in geology, soil types, and land use. This is due to its position on a transition zone between the coastal plain consisting of marine sediments, the alluvial sediment deposits of the Hérault river, and the metamorphous 'Massif Central' (Sluiter, 2005). The area of the watershed is approximately 100 km2 and consists of two main landscape units, based on land use. The upper part (north west) of the catchment is primarily made up of semi-natural vegetation, while the lower part (south east) is a cultivated area (Hill et al., 1996).

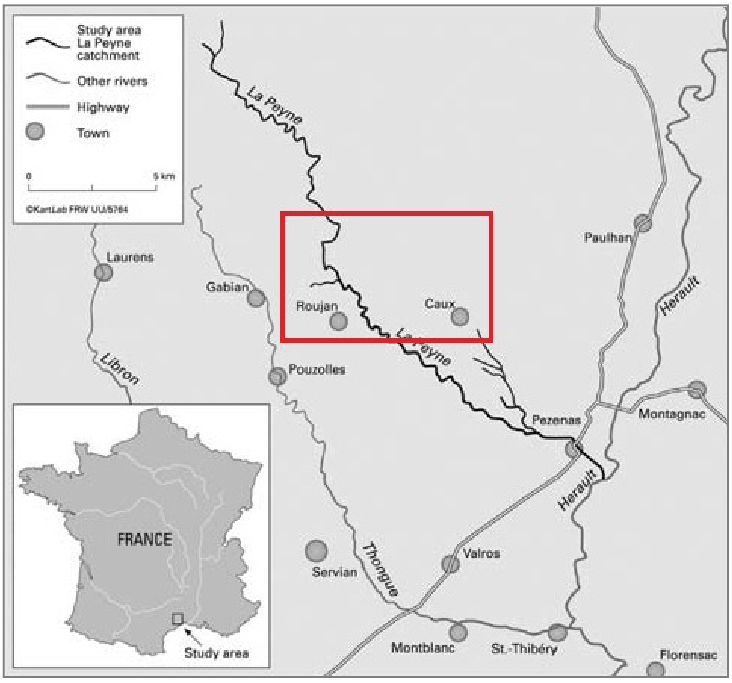


Figure 2.1: *Location of the study area in the Peyne catchment.*

The villages of Vailhan, Roujan, Caux and Fontés form the borders of the study area, with Neffiès located in the center, the coordinates of which are 43°32'N, 31°9'E. The study area is mainly located on the coastal plain, situated on the foothills of the *'Massif Central'*.

2.2 Climate

The study area has a Mediterranean climate consisting of mild, wet winters and dry, hot summers (Köppen climate class *Csa*). Mean temperatures for the coldest month (January) range between 4 and 10 °C, while temperatures for the warmest month (July) range between 20 and 30°C. Frost may occur but is generally short and not severe. Two thirds of the total precipitation falls in the winter period with peaks in rainfall in autumn and spring. Total amounts of precipitation range between 300 and 900 mm. The average annual rainfall is approximately 600 mm (ECA&D, 2002), but the total amount of precipitation varies from year to year. Rain often falls in intensive showers and rainstorms that can easily exceed 50 mm in 24 hours (Nijland, 2011). During summer no significant precipitation may occur for periods of 4 to 6 months. Average annual potential evapotranspiration is 1035.9 mm, calculated with the FAO Penman-Monteith equation (Allen et al., 1998; ECA&D, 2002; FAO, 2006). Because the periods of maximum temperatures and maximum precipitation are out of step, a water deficit occurs during summer (Lionello et al., 2006; Sluiter, 2005). *Figure 2.2* shows a graph of the mean monthly precipitation (p) and temperature (T). To illustrate the moisture deficit during summer, half of the potential evapotranspiration (ETo/2) is shown. The reason for this is that according to FAO definitions, one speaks of a dry period when precipitation is lower than half of the potential evapotranspiration, and these criteria mark a period in which crop growth is not possible (FAO, 1978).

Mediterranean climate poses strong limits on crop cultivation. Because of the moisture deficit during summer, it only allows drought resistant or winter crops to be grown. Furthermore, the intensive showers and rain storms in spring and autumn cause soil erosion and land degradation. A land evaluation procedure in this area should take these factors into account. The crops under evaluation must be able to cope with the climatic stress. At the same time crops are preferred that do not increase, and maybe even decrease soil erosion.

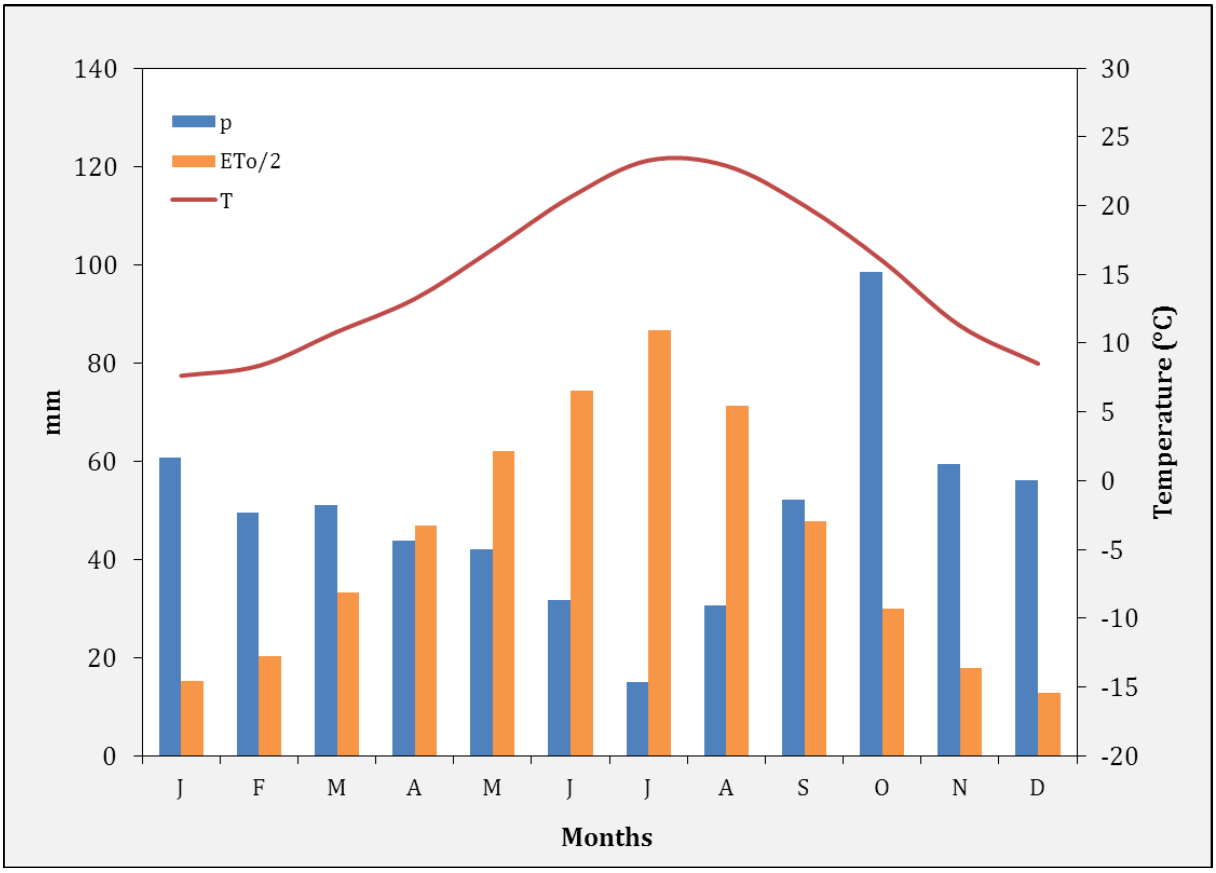


Figure 2.2: *Climograph showing mean precipitation, temperature and half potential evapotranspiration (sources: ECA KNMI data Sète (ECA&D, 2002); CLIMWAT 2.0 (FAO, 2006)).*

2.3 Geology

As mentioned in *section 2.1* the study area is located in the transition zone from the coastal plains to the 'Massif Central', and therefore shows a high variability in geological substrates. The older formations are sedimentary sandstones, mudstones and limestones which are moderately metamorphic. On top of these substrates young volcanic tuffs and basalt outflows of Quaternary age are present. Because of their resistance to weathering and erosion the basalt outflows are now positioned as high plateaus that are intersected by v-shaped valleys, although they were originally formed in the valleys of the landscape. In valley bottoms and parts of the coastal plain to the south, younger alluvial substrates can be found while marine deposits make up most of the coastal plain (Bonfils, 1993; Nijland, 2011; Sluiter, 2005).

2.4 Soils

As a result of the differences in geological substrates the study area shows a large variability in soil types. The 1:100.000 soil map of Lodève (Bonfils, 1993) provides an extensive description of these soil types. The soils in this area, similar to most soils in the Mediterranean, are shallow and poorly developed. This is the result of the Mediterranean climate, the topography of the area and human activities.

Soil forming processes require heat and humidity, which occur during different seasons in Mediterranean climates (see *chapter 2.2*). Consequently soil development is limited and the mineralization process is slowed down. The fact that the organic material in the soils breaks down slowly limits nutrient release. In addition the violent rain storms in autumn in combination with steep slopes make this area vulnerable for loss of soil due to erosion. Since in past times land degradation was further increased through the removal of natural vegetation to allow for agriculture, most present soils are shallow (Nijland, 2011).

According to the FAO soil classification system (FAO, 1974) these shallow soils classify as lithosols, luvisols, fluvisols or regosols. Lithosols are found on steeper slopes and are degraded soils without organic horizons. Luvisols are stonier soils with clay-rich B-horizons that are located on less sloping terrain, atop limestone or calcaric conglomerates. Fluvisols and regosols are the younger and more suitable soils located in sedimentation areas in depressions, valleys, and coastal plains (Hill et al., 1996).

The diversity in soil and geological substrates makes this an interesting area for a land evaluation, because it allows several different soil types to be evaluated on a small test site. In addition, soils in this area are often poorly developed and degraded. Cultivating this kind of soil is difficult. A land evaluation can aid farmers in choosing crop types that can deal with such conditions, and will show satisfactory yields.

2.5 Land use

The transition of the catchment from an agricultural into a semi-natural part is located just north of Neffiès, and coincides with the transition from coastal plain to the foothills of the *'Massif Central'*. The change in topography and soil types makes the area less suitable for agriculture. Factors such as steep slopes, poor soils, large rocks/boulders and high erosion risk lead to *'negative agricultural selection'* (Nijland, 2011).

By far the most important agricultural activity in this region is viticulture. The study area is located in a region where according to the INRA (French agronomic institute) approximately 90% of the fields is used for the cultivation of wine grapes (Bonfils, 1993). Olives, almonds, wheat, and figs make up the remaining grown crops. In the woodlands logging takes place, while the basaltic plateaus are sometimes used for grazing. North of Neffiès some areas are used to cultivate pine production forests (Sluiter, 2005).

The natural vegetation types range from grasslands to a dense shrub-type vegetation that is dominated by evergreen species. Climax vegetation is considered to be a mixed deciduous/evergreen oak forest with dense undergrowth (Nijland, 2011). Due to human activities however, the soils show too much degradation for vegetation to reach this climax state. The shrubby formations are referred to as *'matorral'*, which is defined as *'a formation of woody plants, whose aerial parts are not differentiated into trunk and leaves, because they are much ramified from the base, and are of shrubby habit'*. Matorral can be further divided by height, density and species composition. The tallest and most dense type of matorral is called *'maquis'* with dense shrubs of 2 to 5 m high, and is considered to be the regional climax. The most dominant species are *Querces ilex* and *Arbutus unedo* (Sluiter, 2005).

Performing an agricultural land evaluation in this region is useful to provide alternatives to the dominant viticulture. This is especially important because in 2008 the European Union adopted regulations to reorganize the European wine market. One of the goals of these reforms is to decrease the surplus of wine that is produced in Europe each year (the 'wine lake'). This is achieved by changing the subsidy system for wine farmers, and by promoting a decrease in vineyard area (EC, 2008). In 2011 France was the global leader in wine production; the Languedoc Roussillon region in turn produced the most wine of France (FAO, 2013). Land evaluation could aid farmers in choosing different crops for cultivation.

Chapter 3

THEORY

In this chapter land evaluation is described, in particular the land evaluation method for rain fed agriculture as presented by the Food and Agriculture Organization of the United Nations (FAO, 1976; FAO, 1983). In addition Mediterranean agriculture is discussed.

3.1 Land evaluation

Land use planning is performed to ensure the optimum use of land resources, while at the same time conserving these resources for the future by reducing land degradation (UNEP, 1999). A valuable tool for land use planning is land evaluation, which can be defined as *'the assessment of land performance when used for specified purposes'* (FAO, 1976) or as *'all methods to explain or predict the use potential of land'* (Diepen et al., 1991). Carrying out a land evaluation should result in an indication of the most suitable land use for a predefined region.

Many systems have been created to classify land for specific purposes. The most important and widely used of these is the FAO method, which is extensively discussed in *section 3.1.1* and *section 3.2*.

3.1.1 FAO framework for land evaluation

A general concept of land evaluation is outlined in 'A framework for land evaluation' by the Food and Agriculture Organization of the United Nations (FAO, 1976). This framework in itself does not constitute an evaluation system, but is rather a set of principles and concepts on the basis of which land evaluation systems can be constructed. The six key principles of the framework are as follows:

- Land suitability is assessed and classified with respect to specific kinds of use;
- Evaluation requires a comparison of the outputs obtained and the inputs needed on different types of land;
- An interdisciplinary approach is required;
- Evaluation is made in terms relevant to the physical, economic, and social context of the area concerned;
- Suitability refers to use on a sustained basis;
- Evaluation involves comparison of more than one kind of use.

The broad scope of the framework allows for a number of different approaches to land evaluation and the required data collection.

First, a distinction is made between different types of land suitability classification (FAO, 1983):

- *A qualitative land suitability classification:* results are expressed in qualitative terms only, without specific estimates of outputs;
- A quantitative land suitability classification: results are expressed in numerical terms.

Of which the quantitative classification can be divided into:

- *A quantitative physical evaluation:* results are expressed in quantitative estimates of outputs. To achieve this quantitative inputs are required (e.g. amount of fertilizer used, number of weeding's, pesticides etc.);
- *An economic land suitability classification:* results are expressed in economic or financial terms. Prices and costs of inputs and outputs are required.

Qualitative evaluations are appropriate for surveys of large areas with a wide range of uses, for example the identification of areas for specific crops. Quantitative evaluations are applied in surveys that cover a limited number of land uses and for which potential production estimates are required (FAO, 1983).

Second, two options are available for the organization of a land evaluation; they are shown in *figure 3.1*. In the *two-stage approach* land suitability is first assessed on the basis of physical properties, resulting in a qualitative land classification. Usually (but not necessarily) this first stage is followed by an economic and social analysis on the most promising alternatives to produce a quantitative classification. In the *parallel approach* the economic and social analysis take place simultaneously with the analysis of the physical properties. The advantage of the *parallel approach* is that it is able to give more precise results in a shorter amount of time since the physical and economic analyses are integrated. The downside is that this approach is very susceptible to price variations. The *two-stage approach* is more straightforward to perform, because it contains a clear sequence of actions to be carried out. In addition the physical classification remains relevant for a long time, so an economic analysis can be performed several times if necessary (FAO, 1976; FAO, 1983). In this study the first stage of a two stage-stage approach is carried out. Basic surveys will be performed with a qualitative land classification as intended result. This leaves room to add a quantitative classification based on an economic and social analysis.

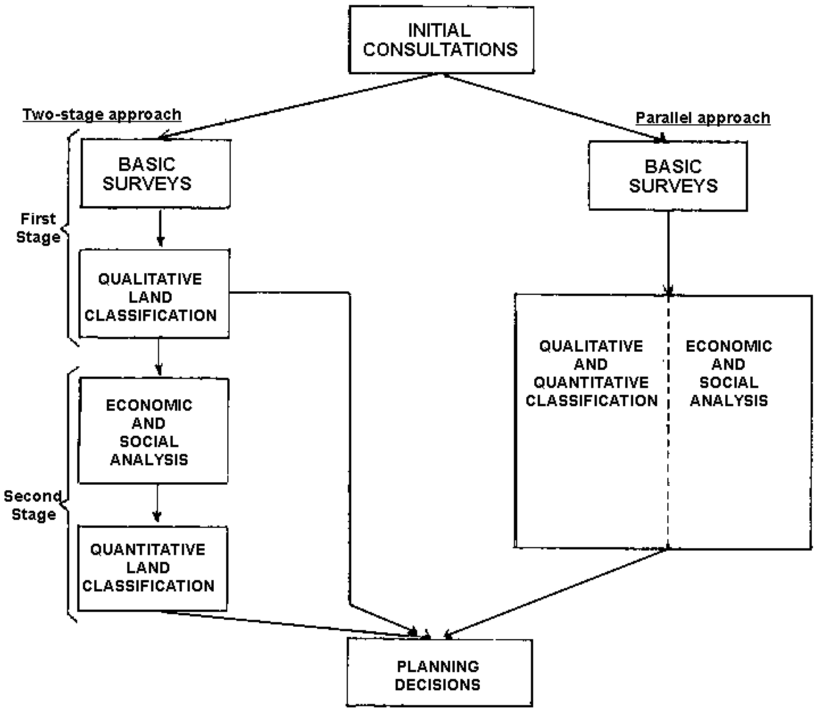


Figure 3.1: *Two-stage and parallel approaches to land evaluation (FAO, 1976).*

Based on the framework a number of guidelines were created for more specific evaluation procedures. Since this study will focus mainly on rain fed agriculture, the ‘Guidelines: land evaluation for rain fed agriculture’ (FAO, 1983) is most relevant.

3.2 FAO guidelines for rain fed agriculture

The guidelines for rain fed agriculture were developed by the FAO out of a demand for a practical manual on land evaluation for rain fed crops. They provide a methodology for carrying out strategies presented in the framework. However they do not contain specific crop requirement data. The guidelines for rain fed agriculture mainly employ a *two-stage approach* for evaluation. Because the aim of this study is to classify an area based on its physical properties this chapter will only describe the first stage of this approach, which entails a number of surveys and procedures that result in a *qualitative* land suitability classification (see *figure 3.1*) (FAO, 1983). *Figure 3.2* shows a schematic overview of the evaluation procedure as outlined by the guidelines, followed by an explanation of its components.

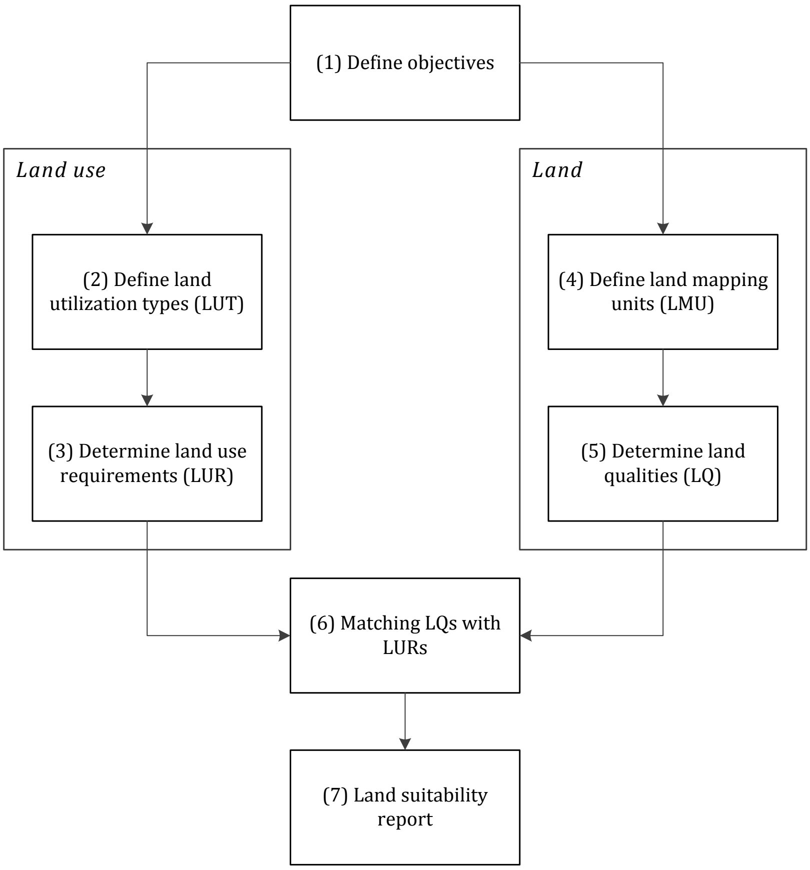


Figure 3.2: *Schematic overview of the evaluation procedure as outlined by the FAO guidelines (FAO, 1983).*

3.2.1 Define objectives

The first step in performing a land evaluation is defining the objectives of the evaluation. The guidelines for rain fed agriculture distinguish between two levels of detail in the specification of study objectives: a *general purpose* land evaluation and a *special purpose* evaluation. In a *general purpose* evaluation a large number of possible land uses are assessed. This usually results in the comparison of an area for different kinds of major land use, e.g. the suitability for urbanization versus the suitability for agriculture. In a *special purpose* evaluation the types of land use that will be compared are restricted and are at least partly stated in the objectives. Often the scale of the research area is smaller than in a *general purpose* evaluation, and only a small number or a single major type of land use is selected. Within that major type of land use smaller scale types of land use are then evaluated. Thus defining objectives has consequences for the scale at which the evaluation is performed and therefore also on defining the land mapping units and land utilization types (FAO, 1983).

3.2.2 Define land mapping units (LMUs)

A land unit is an area of land with specified characteristics which is used as a basis for a land evaluation procedure. It is actually a term of convenience to cover any unit of land used for evaluation; as such it can vary in scale depending on the level of detail employed in the evaluation. In evaluations for rain fed agriculture it is common practice to use two kinds of land units at different stages: (1) agroclimatic zones (used for initial selection of crops for consideration: in this case typical crops for a Mediterranean climate), and (2) more detailed land units based on some combination of landforms and soils. Land units should meet the following requirements (FAO, 1983):

- Land units should be as homogeneous as possible;
- The grouping should have practical value, in relation to the proposed land use;
- It should be possible to map the units consistently;
- Units should be defined as simply as possible and based on properties that are readily observable in the field. Subsequent evaluation should not be held up by overly complicated land unit mapping;
- Defining properties of the units should be stable and unlikely to change rapidly.

Although soil variation often proves to be the defining factor in choosing land units, it should be kept in mind that land is a wider concept than soil alone. Therefore the fitness of soils for land use cannot be assessed in isolation of other aspects of the environment. Geomorphological units such as river terraces, plateaus, glacis etc. can also be used as a basis for defining land mapping units (FAO, 1976; FAO, 1983).

3.2.3 Define land utilization types (LUTs)

The first key principle of the framework is '*Land suitability is assessed and classified with respect to specified kinds of use*' (FAO, 1976). So in order to perform a land evaluation, the specific kinds of land use that are to be compared should be defined. The framework distinguishes between *major kind of land use* and *land utilization type.* A major kind of land use is a major subdivision of rural land use, such as rain fed agriculture, irrigated agriculture, grassland, forestry or recreation. Land utilization types are kinds of land use which are described in more detail and subdivide major land use further. Depending on the objective of an evaluation the land utilization types may vary: in the case of rain fed agriculture land utilization types may consist of individual crops, but also crop combinations or farming systems (FAO, 1983).

3.2.4 *Determine land use requirements (LURs)*

After defining land utilization types the next step is to determine the requirements for their operation. Three conditions should be established for each land utilization type (FAO, 1983):

- The conditions that are best for its operation (optimum);
- The range of conditions which are less than optimal but still acceptable;
- The conditions that are unacceptable.

Land use requirements are expressed in terms of land qualities (see *section 3.2.5*). 'Factor rating' is a method which expresses how well a land use requirement is satisfied by the properties of the land. *Table 3.1* shows an example of the factor ratings in 5 classes (the yields are percentages of the yields under optimal conditions, often based on potential yields derived from crop growth models; they are an example and can vary, e.g. in some cases a 40% yield is acceptable, in some it is not (FAO, 1983)).

Table 3.1: *Example of factor ratings classes and their definition in terms of yield (FAO, 1983; Sys, 1985).*

Factor rating class		Yields
s1	Highly suitable	> 80%
s2	Moderately suitable	40-80%
s3	Marginally suitable	20-40%
n1	Unsuitable, potentially suitable	0-20%
n2	Actually and potentially unsuitable	0%

In this method every land use requirement that is used in the evaluation has a range of values which are divided into factor ratings based on the effects on crop yield. *Table 3.2* shows a land use requirement table for a specified land utilization type (Barley) in factor ratings. Note that the land use requirements are expressed as land qualities and are shown with their associated land characteristics that serve as diagnostic factors.

Table 3.2: *Example of land use requirement table for barley (Sys et al., 1993). Land qualities are expressed in land characteristics which serve as diagnostic factors.*

		Factor rating classes				
Land quality	**Land characteristic**	***s1***	***s2***	***s3***	***n1***	***n2***
Temperature regime	Mean T at flowering (°C)	12-26	10-12 26-32	8-10 32-36	- -	< 8 > 36
Moisture availability	Annual rainfall (mm)	300-1100	200-300 1100-1300	150-200 1300-1500	- -	< 150 > 1500
Rooting conditions	Coarse fragments (%)	0-15	15-35	35-55	-	> 55
Soil toxicities	CaCO3 (%)	0-30	30-40	40-60	-	> 60
Potential for mechanization	Slope (%)	0-8	8-16	16-24	24-30	> 30

In the case of conservation requirements the same method can be applied, but factor rating class is defined in terms of acceptable or unacceptable levels of soil erosion or degradation.

When evaluating different crop types within a major kind of land use, a crop requirement inventory should be composed. To do this one should ask the following questions:

- Which crops should be included?
- Which requirements should be included?
- Which measurement parameters should be used?
- How should the limits between factor ratings be assessed?

The land use requirements that are defined should be similar to the land qualities used in the evaluation, since these two components will be compared. Although there are many options (see *table 3.3*); temperature, moisture, oxygen, nutrients, and rooting conditions are requirements that in most cases should be assessed for all crops. Moisture, oxygen and nutrients (corresponding land qualities are no. 3, 4 and 5 as shown in *table 3.3*) are considered to be the most important according to the guidelines for rain fed agriculture (FAO, 1976; FAO, 1983; Rossiter, 1994).

3.2.5 Determine land qualities (LQs)

A land quality is defined as 'a complex attribute of land which acts in a distinct manner in its influence on the suitability of the land for a specific kind of use' (FAO, 1976), and describes properties of the land. Examples of land qualities are temperature regime, moisture availability, drainage, and nutrient supply (see *table 3.3*). Usually the complexity of land qualities makes it very difficult or even impossible to measure or estimate them in surveys. For that reason the framework introduces land characteristics, which are defined as 'an attribute of the land which can be measured or estimated and which can be used for distinguishing between land units of differing suitability's for use and employed as a means of describing land qualities' (FAO, 1983). Examples of characteristics are mean annual rainfall, slope angle, soil drainage class, effective root depth etc. A land evaluation can be performed by using only land characteristics, but it is recommend by the FAO guidelines to use the land characteristics as diagnostic factors for the land qualities (see *table 3.3*). Because of their simplicity multiple land characteristics need to be determined to arrive at a single land quality.

Three main types of land quality can be distinguished (*table 3.3*): qualities 1 to 15 are primarily related to crop requirements and thus represent physical properties, qualities 16 to 23 are primarily related to management requirements, and qualities 24 and 25 are conservation requirements. Not all of the qualities will be relevant in assessing suitability, so those qualities that account for most of the variability in suitability should be selected. Significance of land qualities depends on the following three conditions:

- The quality has a known effect upon the crops or kinds of land use under consideration;
- Critical values of the quality (that might adversely or favorably affect crops or land use) occur in the study area;
- There are practicable means of collecting information for its measurement or estimation.

Land qualities should be selected in combination with the available land use requirements (see *chapter 3.2.4*) and the nature of the land units in the study area (FAO, 1976; FAO, 1983; Rossiter, 1994).

Table 3.3: *Land qualities and land characteristics for rain fed agriculture (FAO, 1983).*

No.	Land quality (suffix)	Land characteristic/diagnostic factor	Unit
1	Radiation regime (u)	Mean daily sunshine in growing season	h/day
2	Temperature regime (c)	Mean T in growing season	°C
3	Moisture availability (m)	Total rainfall in growing period	mm
4	Oxygen availability to roots (w)	Soil drainage class	class
5	Nutrient availability (n)	Indicator of availability: reaction	pH
6	Nutrient rentention capacity (n)	Texture class	class
7	Rooting conditions (r)	Bulk density	g/cm3
8	Conditions affecting germination (g)	Assessment class	class
9	Air humidity as affecting growth (h)	Mean relative humidity n	%
10	Conditions for ripening (i)	Successive dry days	days
11	Flood hazard (f)	Frequency of damaging floods	class
12	Climatic hazards (c)	Occurrence of damaging frosts	-
13	Excess of salts (z)	Total soluble salts	ppm
14	Soil toxicities (x)	CaCO3 in root zone	%
15	Pest and diseases (p)	Pest (known incidence)	-
16	Soil workability (k)	Topsoil texture	class
17	Potential for mechanization (q)	Slope	%
18	Conditions for land preparation/clearance (v)	Landforms	-
19	Conditions for storage/processing (j)	Relative humidity following harvest	%
20	Conditions affecting timing of production (y)	Date of flowering	date
21	Access within the production unit (a)	Terrain class	class
22	Size of potential management units (b)	Minimum size	ha
23	Location (l)	Distance from road	km
24	Erosion hazard (e)	Model to give soil loss (RUSLE)	t/ha/yr
25	Soil degradation hazard (d)	Index of crusting	-

3.2.6 Matching land qualities with land use requirements

In the final step of the evaluation procedure, the requirements of land utilization types are compared with the land qualities to obtain the suitability class of each land unit. The fundamental principle of matching is that each land unit gets assigned a factor rating for each land use requirement. By combining the factor ratings for all requirements an overall suitability rating is established. *Table 3.4* shows the structure of the suitability classification that is employed by the FAO. The classification consists of four categories with decreasing levels of detail: land suitability order, class, subclass, and unit. As one can see, suitability classes are similar to the factor ratings shown in *table 3.1.* The difference is that factor ratings are visualized by a lower case s and n rating, and an upper case S and N order for land suitability. Below, the classification structure will be briefly explained (FAO, 1976; FAO, 1983):

- Order: The order level simply indicates if a land unit is suitable or not suitable for a specific use.
- Class: The suitability class shows degrees of suitability, where S1 is highly suitable, S2 moderately suitable, S3 marginally suitable, N1 currently not suitable, and N2 permanently not suitable.
- Subclass: The subclass shows the kinds of limitations on suitability. The limiting land quality is signified by the LQ suffix (see *table 3.3*). A subclass of S2m indicates that the land unit is classified as S2 because of a limitation in moisture availability, while a subclass S2e indicates erosion hazard etc.
- Unit: all the units within a subclass have the same degree of suitability at the class level and similar limitations at the subclass level. They differ in their production characteristics or in minor aspects of their management requirements.

As the distinction between S3 and N1 is sometimes hard to make, these classes are often combined, resulting in a combined S3 class (S3 and N1) and a single N class (N2).

Table 3.4: *Structure of the land suitability classification (FAO, 1976).*

Order	**Class**	**Subclass**	**Unit**
S Suitable	S1		
	S2 ----------------	S2m	
	S3	S2e ----------------	S2e-1
		S2me	S2e-2
		etc.	etc.
N Not suitable	N1 ----------------	N1m	
	N2	N1e	
		etc.	

There are several methods available to combine the factors, four examples are discussed below (FAO, 1983; Sys, 1985):

- Subjective combination: if an evaluator has good knowledge of the ecology and technology of a land utilization type, an overall suitability can be achieved by subjective judgment. Advantages are that this permits a refinement not achieved by arithmetic procedures. Disadvantages are that it is subjective and expert knowledge is required.
- Simple limitation method: suitability is assigned according to the least favorable factor rating. The main advantage is simplicity; the disadvantage is accuracy (an S2 type soil may have all factor ratings s2, or only one factor s2).
- Complex limitation method: this limitation method has as a number of criteria number and intensity of limitations. For example to achieve an S2 suitability a LMU should have more than 3/4 slight limitations (s2) and/or no more than 2/3 moderate limitations (s3). The advantage is an increase in accuracy when compared to the simple limitation method; the disadvantage is that criteria have to be defined for each land evaluation, requiring expert knowledge.
- Parametric method: in this method a numerical rating is attributed to the limitation levels, where an optimal characteristic is given the highest value of 100. With the individual ratings an overall index is calculated. The suitability class will be determined by the index value.

  By varying the range of the ratings, a weighing factor can be introduced. Important characteristics are rated in a wider scale (e.g. 20 -100) than less important characteristics (e.g. 60 – 100). The wider the scale, the larger the potential impact on suitability.

The simple limitation method is preferred for combining LURs with LQs. The main advantage of this method over the others is that it does not require expert knowledge. Without extensive experience in crop cultivation, it is difficult to determine the extent to which different crop requirements affect suitability ratings. This is especially true for defining the weighing factor of the land use requirements of each land utilization type.

When expert knowledge is not an obstacle, the parametric method is recommended. It yields the most precise result, because suitability is expressed as a numerical value. In addition, the use of weighing factors ensures the difference in importance of LURs is taken into account (Sys, 1985).

3.2.7 Land suitability report

The final result is a land evaluation report. This report should contain a land suitability classification for each land utilization type. With this classification the optimum land use type can be selected for each mapping unit. In addition to providing an advice for the most suitable land use, the evaluation also shows the types of limitation land mapping units have for specific types of land use. By improving the limiting qualities, land suitability could be increased.

Depending on the extent and aim of the analysis, the report can be extended with an economic and social analysis, an environmental impact check, and field checks. For example the most suitable crop in terms of yield is not necessarily the highest grossing crop for a land unit (FAO, 1983).

3.3 Agricultural land use in the Mediterranean

To perform a land evaluation in the Mediterranean area, it is important to know the Mediterranean agriculture and typical crops that are used in the region. As one would expect, Mediterranean agriculture is adjusted to the particular characteristics of the Mediterranean region. The moisture deficit during summer, the frequently stormy nature of rainfall, and its variation from year to year often make this region and its vegetation suffer from climatic stress (Perez, 1990). Furthermore, the often mountainous and rugged topography impede cultivation as well, and shallow and stony soils form additional difficulties. To cope with these constraints farmers have adopted an agricultural strategy comprised of four components (Mørch, 1999): (1) winter annuals are fed by winter rain, (2) permanent crops that can survive the dry summer, (3) transhumance systems for livestock and (4) irrigated crops.

Annual crops are not able to survive the summer droughts and are therefore planted at the start of the autumn rains and harvested in early summer. Half of the available arable land in the Mediterranean is used for the cultivation of cereals. Productivity of these crops is strongly correlated to spring precipitation. Although cereals are widely used productivity of these crops in the Mediterranean is significantly lower than in Atlantic Europe for example. In more temperate climates wheat can yield an average of over 6000 kg/hectare, while in Mediterranean climates it yields an average of 2700 kg/hectare (Perez, 1990).The most commonly cultivated cereals are wheat, barley and oats (Burger, 1994; Grigg, 1974). Half of the area used for cereals in the Mediterranean area is occupied by wheat, making this the most important cereal crop. Maize is also used in some areas, but makes up only one eighth of the land used for cereals and usually requires supplementary irrigation. After the harvest of a crop the land is usually left fallow for the following summer and winter. The aim of this is to conserve soil moisture, and to let the nutrients in soils with low organic content rebuild. This practice leads to a long production cycle of crops, and large portions of arable land left fallow. In 1990 this portion ranged from 5 to 10% in Mediterranean France (Mørch, 1999).

Permanent crops are tree crops that are able to survive the dry summer period. Their extended root systems are able to better utilize shallow, stony and steep soils which are not suitable for arable agriculture. In addition their long roots allow the trees to survive summer droughts. Tree cropping can be performed on almost all terrains, but is most often applied to steeper slopes and soils that are less developed, so the better soils and level land can be used for annual crops. (Mørch, 1999) By far the most important tree crops are olives and grape-vines, and to a lesser extent figs and almonds (Burger, 1994; Grigg, 1974).

Livestock plays a minor role in Mediterranean agriculture. Livestock carrying capacity of the Mediterranean pasture is only 10 to 50% of that of Atlantic Europe (Perez, 1990). The reasons for this low livestock capacity are twofold: the summer droughts hamper good grazing, and fodder crops that can provide feed for livestock and replenish soil fertility are absent. As a result most arable crops are used for human consumption. Traditionally transhumance systems were used to overcome poor livestock capacity. This system entailed that livestock was moved to higher elevated, milder regions with more prosperous pastures during summer. Nowadays, transhumance is difficult to perform due to intensive farming and has lost its importance (Mørch, 1999), and is therefore not considered in this study.

Irrigation allows crops to be grown in the dry summer periods. A disadvantage is that irrigation cannot be applied everywhere because it depends on suitable terrain and available water. Irrigation allows for the cultivation of vegetables and fruits, as well as certain industrial crops (i.e. crops that are not used for consumption). Typical vegetables that are grown in the Mediterranean with the use of irrigation are: tomato, cucumber, potato, lettuce, onions, cauliflower, sweet pepper, peas and lentils. The most significant fruit is the citrus (orange), followed by less important fruits such as the pear, apple and peach (Grigg, 1974). A group of irrigated industrial crops that is cultivated in the Mediterranean consists of tobacco, sugar beet and cotton. Of course (supplementary) irrigation can also be applied to increase productivity and yields of rain fed cereals and tree crops (Mørch, 1999).

In addition there is an EU regulation in play called 'the Mediterranean package' (EC, 2004), which is a supplement to the Common Agricultural Policy (CAP) of June 2003 (EC, 2003). This regulation specifies a subsidy system, that is aimed at increasing the production of the following 4 types of crops: hops, cotton, olives (for oil), and tobacco. Farmers producing these crops are eligible for EU subsidy money. In *table 3.5* all previously mentioned crops are listed. They are divided on basis of crop type and whether they require irrigation or not.

Table 3.5: *List of typical Mediterranean crops, divided on crop type and irrigation requirement (Burger, 1994; Grigg, 1974; Mørch, 1999; Perez, 1990).*

Rain fed		**Irrigated**			
Cereals	*Tree crops*	*Cereals*	*Vegetables*	*Fruits*	*Industrial*
Wheat	Olive	Maize	Tomato	Citrus	Tobacco
Barley	Grape-vine		Potato	Apple	Sugar beet
Oats	Fig		Lettuce	Pear	Cotton
	Almond		Onion	Peach	Hops
			Cauliflower		
			Sweet pepper		
			Peas		
			Lentils		

Chapter 4

METHODS

This chapter presents the methodology of the evaluation procedure which consists of two main components: the land suitability assessment (*sections 4.1, 4.2* and *4.4*) and classification of present land use (*section 4.3*). These components can be divided into a preparation stage, a field and laboratory stage, and the final analysis stage, as shown in *figure 4.1*. For both components a field campaign was performed in September and October 2011 in southern France.

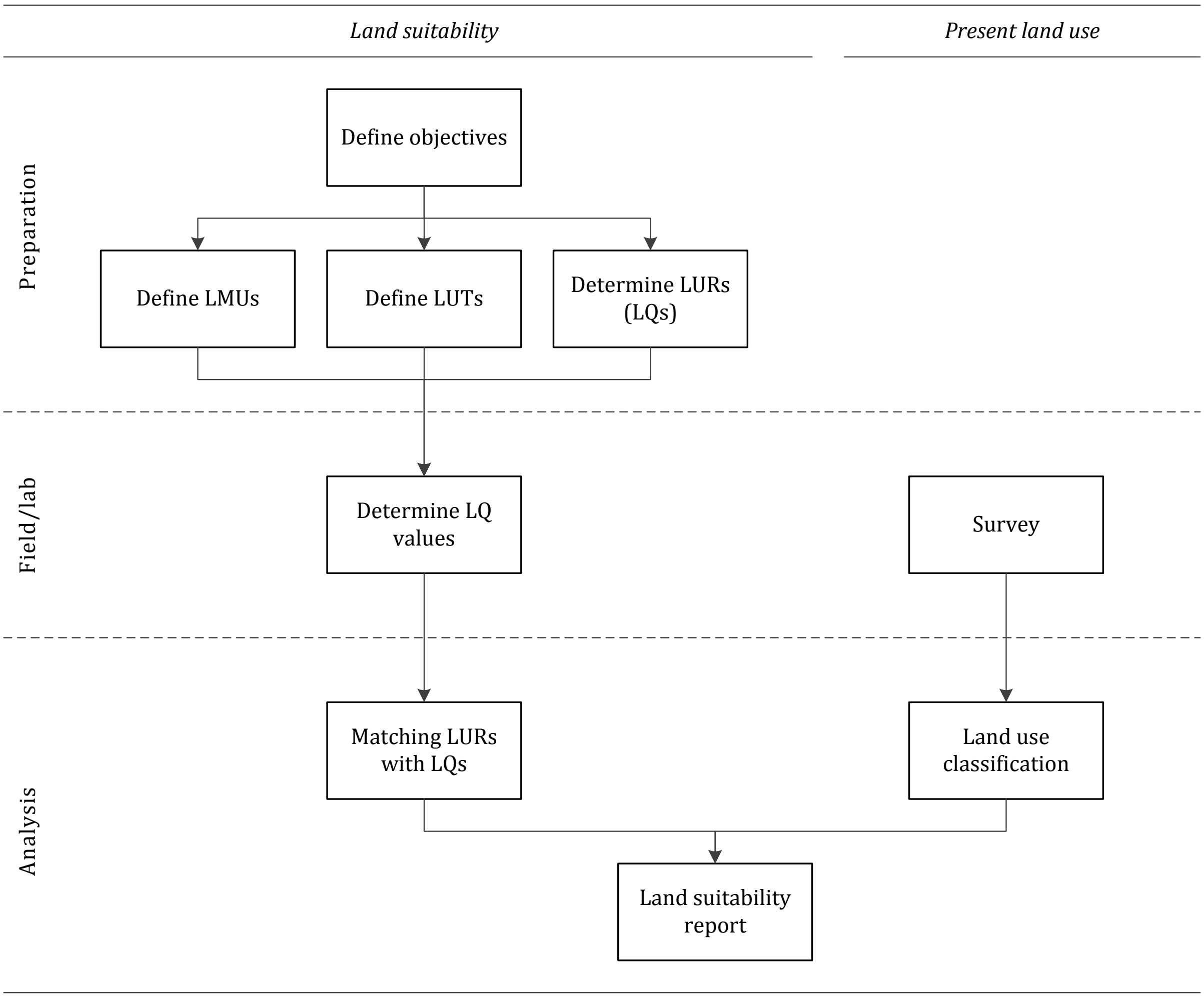


Figure 4.1: *An overview of the different components of the land evaluation procedure.*

4.1 Preparation phase

The first stage of the land evaluation procedure is the preparation phase. As shown in *figure 4.1* this starts with defining the objectives followed by defining the LMUs, LUTs and LURs.

4.1.1 Objectives

The aim of this study is to perform a land evaluation of an area in Mediterranean France in order to assess the optimum agricultural land use. Since irrigation is not always possible in this region (Mørch, 1999; UNEP, 2006), the study will focus on rain fed agriculture, which is defined by the FAO as a major kind of land use. Because rain fed agriculture is the only major land use under consideration, this study entails a special purpose evaluation (FAO, 1983). In addition, a comparison will be made between land suitability ratings when assessed on two different scale levels.

4.1.2 Land mapping units

As mentioned in *section 3.2.2,* a land evaluation usually employs land units with different scales and at different stages. In this study four levels of detail are recognized (from largest scale to smallest):

- Agroclimatic zone: in this case the Mediterranean climate zone.
- Study area: within the Peyne catchment area a smaller, mainly agricultural study area is defined.
- Land mapping unit (LMU): based on the 1:100.000 soil map of the Lodève (Bonfils, 1993); the study area is divided into smaller land units.
- Land mapping unit subdivision (LMUS): in some cases the soil units consists of spatially separated units; each of these is defined as a single land unit.

The agroclimatic zone is only used to select the appropriate land utilization types for this climate zone, i.e. Mediterranean crops. For the other mapping units LQ values are determined. On which scale level this is done depends on the land quality (see *section 4.2*).

The soil units of Bonfils (1993) were used as LMUs. Unlike in, for example, the FAO/UNESCO soil map of the world (FAO, 1974), formation processes, parent material, location, and even present land use are taken into account when defining these soil units. This results in a larger number of better defined and more homogeneous land units. Such units are preferred because they better meet the requirements for land mapping units posed by the FAO (FAO, 1976; FAO, 1983).

Figure 4.2 B shows the soil map of the Lodève cropped to the study area, which contains approximately 20 different soil units. Because this evaluation concerns itself with agricultural land uses, the 11 soil units that are mainly used for crop cultivation are selected as land mapping units. These units, their soil type, and a short description are given in *table 4.1*.

During the study, it was noticed that several LQ values show variation between the spatially separated components of a single LMU. The LMUs were therefore subdivided further into LMUSs (see *figure 4.2 C* and *D*). The advantages of using the LMUS scale are that the units are expected to be more homogenous, show less variation in LQ values, and that they allow for an evaluation on the extent to which the scale of land mapping units influences the suitability ratings.

Table 4.1: *A list of the soil units defined as LMUs in the land evaluation procedure (Bonfils, 1993).*

No.	Soil type	Description
27b	Regosol	- Calcareous, lithochromatic soil; - Formed on marl and sandstone of the Triassic; - Moderately deep, sandy clay texture, contains coarse sandstone gravel.
39b	Regosol	- Calcareous, alluvial soil; - Deep, sandy loam texture; contains pebbles of basalt throughout the profile.
43b	Lithosol	- Red calcareous, ferralitic soil; - Silty/clay texture; - Located in pockets on limestone plateaus and high altitude (>200m).
64	Regosol	- Calcareous, lithochromatic soil, deep; - Formed on sandy marlstones of the Helvetian; - Deep, loam/sand texture and contains gravel; - Borders on limestone reliefs.
65	Regosol	- Calcareous, lithochromatic soil; - Formed on sandy marlstones of the Helvetian; - Deep, loam/sand texture; contains nodules or strands of limestone at lower parts.
65a	Regosol	- Calcareous, lithochromatic soil; - Formed on sandy marlstones of the Helvetian; - Deep, loam/sand texture and contains nodules or strands of limestone at lower parts; - Has drainage system to reduce waterlogging and allow agriculture.
75	Lithosol	- Ferralitic soil, poorly developed and acidic; - Formed on glacis and terraces of the Villafranchien; - Sandy clay and loamy sand texture, contains siliceous gravel and quartz pebbles; - Located atop Miocene or Pliocene marlstones.
80	Fluvisol	- Brown, poorly developed, slightly acidic soil; - Medium height terraces formed by Montagne Noir rivers; - Sandy loam texture, contains a lot of gravel.
80a	Fluvisol	- Brown, poorly developed, slightly acidic soil; - Low height terraces formed by Montagne Noir rivers; - Contains small gravel at surface, pebble size at the bottom.
82a	Fluvisol	- Poorly developed, deep, alluvial soil; - Silty clay texture, well drained; - Located on the floodplains of the Orb and Hérault river and their tributaries.
83	Fluvisol	- Poorly developed soil; - Formed by colluvium and alluvium from upper watersheds; - Heterogenic texture, sometimes very stony.

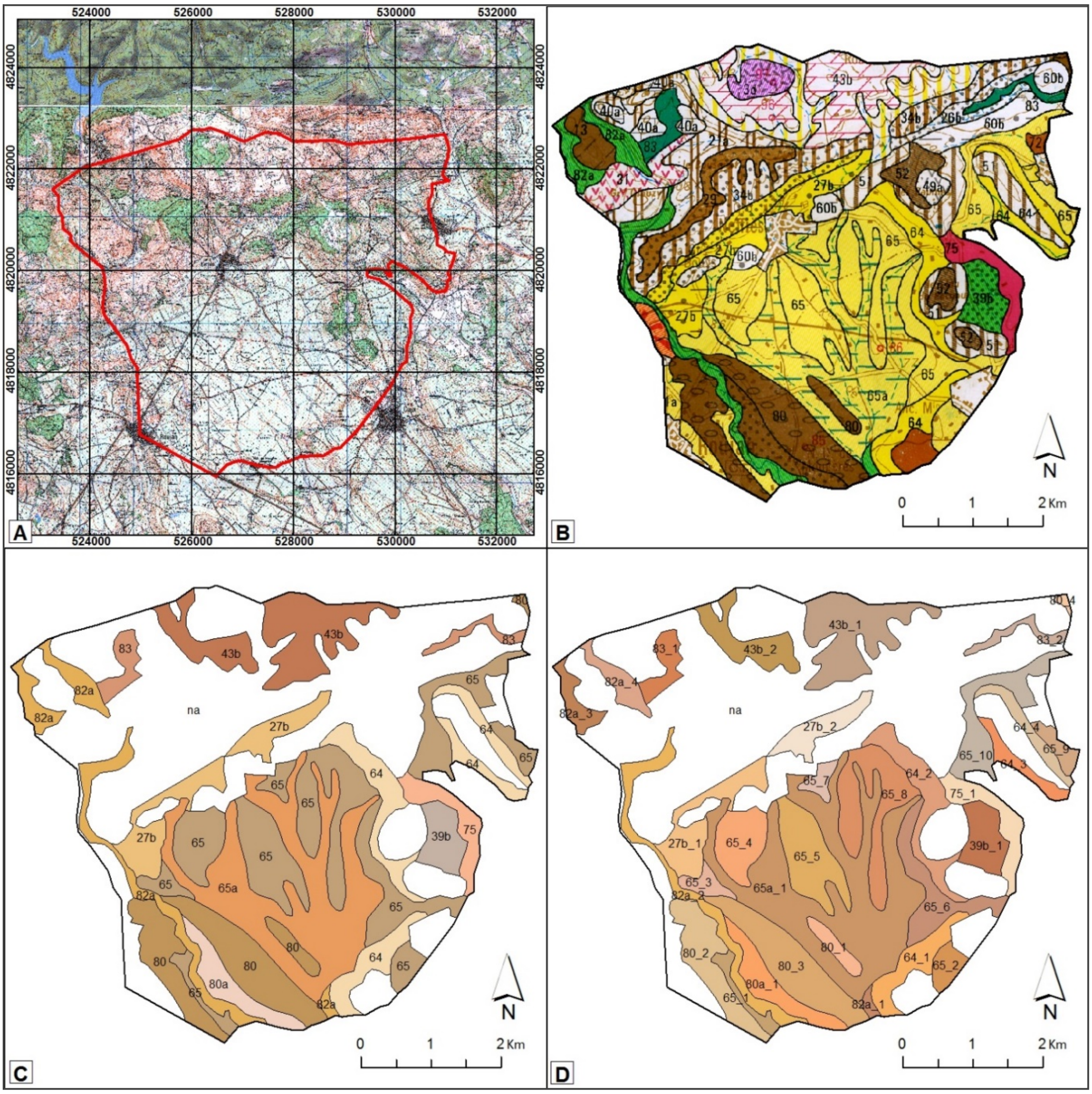


Figure 4.2: *A shows the study area on 1:25.000 topographic map (WGS 84, UTM 31n); B shows the soil map (Bonfils, 1993); C shows the LMUs based on the soil units ('na' was not included in the evaluation); D shows each land unit polygon as a separate LMUS (e.g. soil unit 43b is divided into 43b_1 and 43b_1).*

4.1.3 Land utilization types

Since the major land use type of this study is rain fed Mediterranean agriculture, the land utilization types should fall within that category. Subdivisions of this major kind of land use are crop types such as annuals, vegetables, fruits, and those which can be further subdivided into individual crops. *Table 3.5* shows the Mediterranean crops that could serve as LUTs in this study. A selection was made of these crops. The rain fed wheat, barley, olive, and grape-vine were chosen as LUTs because they are deemed the most important crops in the region (Grigg, 1974). In addition some crops were included that are widely cultivated in the Mediterranean region with use of irrigation. The intention of this selection is to investigate whether it is possible to grow these crops in the study area as rain fed crops. Of each crop type a single important crop was chosen as LUT (see *table 4.2*): maize for an irrigated (ir) cereal, tomato for a vegetable, and citrus for a fruit. The industrial crops tobacco and sugar beet were added because they represent an interesting alternative for farmers considering the CAP of the EU. In this policy, it is stated that farmers will receive subsidies when cultivating a number of crops, including sugar beet (EC, 2003) and tobacco (EC, 2004). Because it lowers the financial risk of a crop failure, cultivation of these crops is attractive.

Table 4.2: *LUTs used in this land evaluation procedure.*

Type	Crop
Cereals	Wheat
	Barley
	Maize (ir)
Tree crops	Olive
	Grape-vine
Vegetables	Tomato (ir)
Fruits	Citrus (ir)
Industrial crops	Tobacco (ir)
	Sugar beet (ir)

4.1.4 Land use requirements

As discussed in *section 3.2.4* land use requirements should be similar to land qualities. Because of this similarity, *chapter 4.2* on land quality assessment will provide a more extensive explanation of the individual LURs/LQs used in this evaluation procedure. The land use requirements used in this evaluation procedure were obtained by an extensive literature study. This resulted in requirement tables for each LUT, presented in *APPENDIX A*.

4.2 Field and laboratory methods

After defining the objectives and determining the LMUs, LUTs, and LURs, the land qualities should be assessed. The LQs and diagnostic factors that were selected for this land evaluation are shown in *table 4.3*. Not all qualities have the same scale level: some LQs are considered the same for the whole study area (e.g. climatic qualities), while others show variation within a soil unit and can be spatially continuously assessed (e.g. erosion hazard). To obtain all the necessary land qualities, three types of sources were used: field survey, literature, and modeling. The specifics of the field campaign and the individual land qualities are discussed below.

Table 4.3: *Shows land qualities and their diagnostic factors, scale and source as used in this land evaluation.*

No.	Land quality	Diagnostic factor	Scale	Source
2	Temperature regime (c)	Various	Study area	Literature
3	Moisture availability (m)	Various	Study area	Literature
4	Oxygen availability to roots (w)	Soil drainage class	LMUS	Model
5	Nutrient availability (n)	pH	LMU	Literature
		Organic matter	LMUS	Field
6	Nutrient retention (n)	Cation Exchange Capacity	LMU	Literature
7	Rooting conditions (r)	Texture	LMUS	Field
		Stones	LMUS	Field
		Porosity	LMUS	Field
		Dry bulk density	LMUS	Field
14	Soil toxicities (x)	$CaCO_3$	LMUS	Field
17	Potential for mechanization (q)	Slope	LMUS	Model
24	Erosion hazard (e)	RUSLE	LMUS	Model

4.2.1 Field campaign

Several diagnostic factors of LQs were obtained from a field survey. Five weeks of the field campaign in September and October 2011 were dedicated to obtaining these factors on site. A stratified random sampling technique was applied to acquire the data. This technique is based on separating a research area into smaller sub units (strata) that are considered to be more homogeneous. Within each of the strata random sampling is used, which means that the sampling locations are chosen at random (Mason, 1992). In this case the strata consist of the land mapping units. The number of locations per mapping unit depends on its size, with the aim of having the same sample per area ratio for each LMU. At each sampling site the following characteristics and samples were taken:

- Date, time, and sample number;
- Location: coordinates were recorded from a GPS device (WGS 84; UTM 31N);
- Land use class (see *section 4.3.1*);
- Texture/stones; texture and stone content were assessed onsite (see *section 4.2.6*);
- pH/organic matter/CaCO3 samples were taken, depth of sample was recorded (see *sections 4.2.4, 4.2.5* and *4.2.7*);
- Porosity/Dry bulk density samples were taken in a sample ring onsite (see *section 4.2.6*).

4.2.2 Temperature regime and moisture availability

Temperature and precipitation are considered to be the same for the entire study area. These land qualities are expressed in a number of different diagnostic factors, which vary per

LUT (Sys et al., 1991; Sys et al., 1993). The specific diagnostic factors for each crop type are shown in the LUR tables (see *APPENDIX A*), some examples are shown below:

- Mean annual temperature/precipitation;
- Mean temperature/precipitation during growing season;
- Mean temperature/precipitation during a specific growth stage (e.g. flowering);
- Minimum temperature of the coldest month.

The climate data necessary for these factors were obtained from the ECA&D meteorological stations in Sète and Nimes (ECA&D, 2002), and from the CLIMWAT 2.0 database of the FAO for Montpellier (FAO, 2006). The dataset from the Sète station consists of daily minimum, maximum, and mean temperatures (T in °C) and daily precipitation data (p in mm) for the period of 1951 to 2010. The Nimes station provides mean daily sunshine (SS) hours for the same period. The Montpellier data consist of long term monthly mean values for relative air humidity (AH in%) and wind speed (WS in km/day). These records are not dated but they cover the period of 1971 to 2001 and contain at least 15 years of data. In addition, the records were also used as input to calculate potential evapotranspiration (ETo in mm) with an 'ETo calculator' (Raes, 2012). *Table 4.4* below shows the average monthly values.

Table 4.4: *Average monthly climate data as used in this land evaluation procedure. Rainfall, mean, max and min T data obtained from Sète and sunshine hours from Nimes (ECA&D, 2002); relative air humidity and wind speed from Montpellier (FAO, 2006); and calculated potential evapotranspiration (Raes, 2012).*

Month	**p**	**Max T**	**Mean T**	**Min T**	**SS**	**AH**	**WS**	**ETo**
Jan	60.7	10.4	7.6	4.9	4.6	74	207.4	30.7
Feb	49.6	11.4	8.4	5.3	5.5	71	216	40.5
Mar	51.1	14.1	10.8	7.5	6.6	72	233.3	66.3
Apr	43.7	16.7	13.2	9.8	7.7	67	241.9	93.9
May	42.0	20.3	16.8	13.3	8.8	67	216	123.9
Jun	31.7	24.4	20.6	16.9	10.3	65	207.4	148.7
Jul	15.1	27.3	23.3	19.3	11.3	59	198.7	173.1
Aug	30.5	26.6	22.9	19.2	9.9	66	190.1	142.6
Sep	52.2	23.4	20	16.6	8.0	71	181.4	95.3
Oct	98.4	18.9	16	13.1	5.8	74	190.1	59.7
Nov	59.3	14	11.3	8.5	4.8	75	207.4	35.7
Dec	56.0	11.1	8.5	5.9	4.2	78	207.4	25.5
Yearly	***590.3***	***18.2***	***14.9***	***11.7***	***7.3***	***70***	***208.1***	***1035.9***

4.2.3 *Oxygen availability to roots*

Most plants need to take in oxygen through their root systems. Long periods of inundation make this impossible and result in damage to the crop. To assess this LQ the diagnostic factor ‘soil drainage class’ was used.

The soil drainage class is assigned based on the topographic wetness index (TWI) (also called soil wetness index (SWI)). This index quantifies the effect of topography on runoff generation, and approximates the location of zones of surface generation and the spatial distribution of soil water (Beven & Kirkby, 1979; Sörensen et al., 2006; Wilson & Gallant, 2000). The following formula is used to calculate this index:

$$TWI = \ln\left(\frac{A_s}{\tan\beta}\right)$$

Equation 4.1: *Topographic wetness index (Beven & Kirkby, 1979).*

Where A_s is the upslope contributing area per unit contour length (or specific catchment area) in m^2 m^{-1} and β is the slope gradient in degrees. This equation assumes steady-state conditions and uniform soil properties (i.e. soil moisture transmissivity is constant throughout the catchment). High index values indicate a poorly drained area, while low values indicate a well-drained area. A digital elevation model (DEM) with a grid cell size of 25m of the study area was used as input. Based on their average TWI value the land units were assigned 1 of 7 drainage classes, as shown in *table 4.5*:

Table 4.5: *A list of drainage classes and their accompanying TWI values.*

Drainage class	Abb.	TWI
Excessively well drained	E	0 - 8.4
Somewhat excessively drained	SE	8.4- 8.9
Well drained	W	8.9 - 9.5
Moderately well drained	MW	9.5 - 11
Imperfectly drained	I	11 - 12.3
Poorly drained	P	12.3 - 13.6
Very poorly drained	VP	> 13.6

4.2.4 *Nutrient availability*

To asses nutrient availability, two diagnostic factors were used: pH and organic matter content. pH values for each LMU were obtained from the soil unit descriptions provided by Bonfils (1993).

Organic matter content (OM) was obtained by analyzing soil samples taken during the field campaign. For this purpose the loss on ignition method was used. The procedure of this method is as follows (USDA, 2011): (1) the sample is dried in an oven at 110°C for 24 hours to remove all soil moisture; (2) the dried sample is weighed; (3) the sample is then heated to 450°C for 12 hours to remove all organic carbon; (4) the sample is weighed again. The difference in soil weight before and after heating is the organic matter content, which is expressed as percentage. The calculation is as follows:

$$OM = \left(\frac{(W_d - W_g)}{W_d}\right) * 100$$

Equation 4.2: *Calculation of fraction of organic matter in a soil sample (USDA, 2011).*

Where W_d is the weight (g) of the soil after drying at 110°C, and W_g is the weight after heating at 450°C.

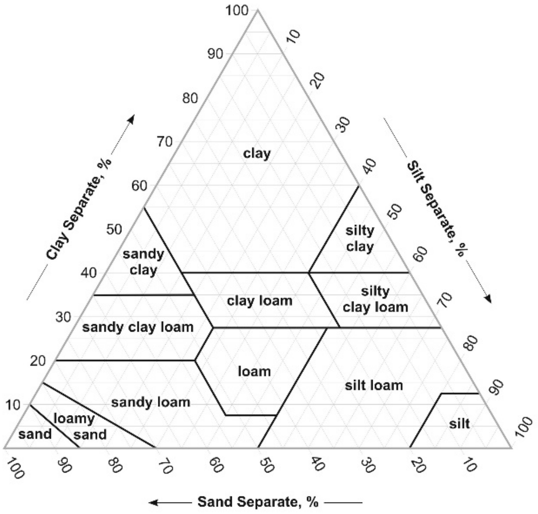
4.2.5 Nutrient retention

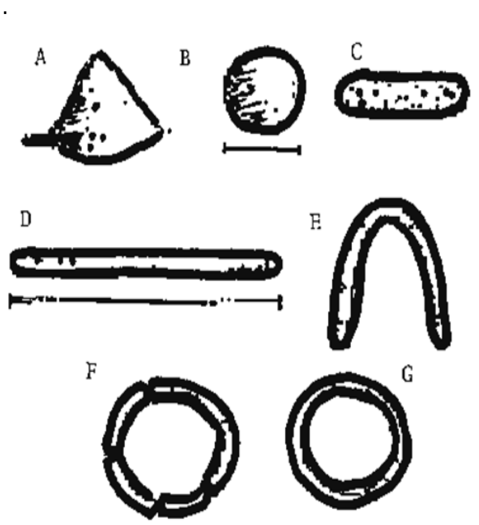
A measure for the nutrient retention capability of soils is the cation exchange capacity (CEC). Plant nutrients such as N, P, and K are held in the soil on these exchange sites, which prevents them from being removed by leaching. A larger CEC indicates that nutrients can be better retained (FAO, 1983). CEC values for each LMU were obtained from Bonfils (1993) and expressed as milliequivalent of hydrogen per 100g of dry soil (meq/100g).

4.2.6 Rooting conditions

The land quality is assessed by four diagnostic factors: texture, stones, porosity, and dry bulk density. All of these factors were obtained during the field campaign. Texture was classified according to the USDA soil texture classification system (USDA, 1993). *Figure 4.3* shows the texture triangle that is used to classify soil samples into soil texture classes based on particle size distribution. A manual method of assessing soil texture was applied in the field; based on the ability to mold a small, moisturized soil sample into various shapes, texture classes were assigned. How the shapes are related to texture classes is shown in *figure 4.4*:

Figure 4.3: *Soil texture triangle showing the percentages of clay, silt, and sand in the basic textural classes (USDA, 1993).*





Shape	Texture	Description
A	Sand	The soil stays loose and separated and can be accumulated only in the form of a pyramid.
B	Sand loam	The soil contains enough silt and clay to become sticky, and can be given the shape of an easy-to-take-apart ball.
C	Silt loam	Similar to a sandy loam, but the soil can be shaped by rolling it into a small short cylinder.
D	Loam	Contains almost equal amounts of sand, silt and clay. Can be rolled into approx. 14 cm long cylinder that breaks when bent.
E	Clay loam	Similar to the loam, but the rolled cylinder can be bent and given a U-shape (without forcing it) without breaking.
F	Fine clay	The soil cylinder can be bent into a circle, but shows some cracks.
G	Heavy clay	The soil can be shaped as a circle without any cracks.

Figure 4.4: *Hand assessment of soil texture: on the left the possible shapes are shown, on the right the corresponding texture class and description (Nachtergaele et al., 2011).*

Simultaneously stone content was estimated based on visual inspection and expressed as percentage. To determine both porosity (ϕ) and dry bulk density (DBD) a single soil sample was taken at each sampling location. The sample was taken by driving a stainless steel ring with an inner volume of 100cm^3 into the soil to obtain an undisturbed soil sample. The following procedure was then executed: (1) drying the sample in an oven at 110°C for 24 hours; (2) weighing the dried sample; (3) saturating the sample; (4) weighing the saturated sample; and (5) weighing the empty sample ring. The following calculations were applied:

$$DBD = \frac{(W_d - W_r)}{V_s}$$

Equation 4.3: *Calculation of dry bulk density in g cm^{-3} (Cammeraat et al., 2002).*

$$\phi = \left(\frac{(W_s - W_d)}{V_s} \right)$$

Equation 4.4: *Calculation of fraction of porosity (Cammeraat et al., 2002).*

Where W_r is the weight (g) of the sample ring, W_d is dry weight of the sample (including W_r), W_s is the saturated weight of the sample (including W_r) and V_s is the volume of the sample ring (in this case 100 cm^3).

All land utilization types have equal porosity and dry bulk density requirement values, so these diagnostic factors only serve to show differences in crop suitability per mapping unit.

Because of this, suitability rating is not determined by comparing the LQ value with the LUR value, instead suitability ratings are assigned based on *table 4.6* and *table 4.7*:

Table 4.6: *Factor rating values for DBD (in g cm^{-3}) per texture class (USDA, 2001).*

Texture class	s1	s2	s3	n
Sands, loamy sand	<1.6	1.6-1.69	1.69-1.8	>1.8
Sandy loams, loam	<1.4	1.4-1.63	1.63-1.8	>1.8
Sandy clay loam, clay loam	<1.4	1.4-1.6	1.6-1.75	>1.75
Silt, silt loam	<1.3	1.3-1.6	1.6-1.75	>1.75
Silt loams, silty clay loams	<1.4	1.4-1.55	1.55-1.65	>1.65
Sandy clays, silty clays, slay loams	<1.1	1.1-1.49	1.49-1.58	>1.58
Clays (>45%)	<1.1	1.1-1.39	1.39-1.47	>1.47

Table 4.7: *Factor rating values for porosity (in %) per texture class (Pearson et al., 1995).*

Texture class	s1	s2	s3	n
Fine loamy	>20	20-10	10-5	<5
Coarse silty	>20	20-10	10-5	<5
Fine silty	>20	20-10	10-5	<5
Clay 35-45%	>15	15-10	10-5	<5
Clay > 45%	>15	15-10	10-5	<5

4.2.7 Soil toxicities

Of the wide range of possible soil toxicities, usually only one is likely to affect crops in a specific region (FAO, 1983). Since the study area mainly consists of calcareous soils (Bonfils, 1993) calcium carbonate content is chosen as diagnostic factor for this LQ.

$CaCO_3$ content was determined for approximately half of the soil samples of each LMU. This was done using a calcimeter (Eijkelkamp, Giesbeek, The Netherlands). HCl reacts with $CaCO_3$ resulting in the release of CO_2; the calcimeter measures the volume of CO_2 gas which is an indicator of $CaCO_3$ content. To achieve this, a test measurement with a $CaCO_3$ standard is performed prior to measuring the soil samples. The procedure is as follows: (1) weigh standard sample (100% $CaCO_3$); (2) measure volume of released CO_2 of standard sample; (3) weigh soil sample; and (4) measure CO_2 of soil sample. The following calculation is used to determine the percentage of calcium carbonate:

$$\mathrm{CaCO_3} = \left(\frac{m_{st} \times V_s}{m_s \times V_{st}}\right)$$

Equation 4.5: *Calculation of fraction of $CaCO_3$ in a soil sample (USDA, 2011).*

4.2.8 Potential for mechanization

The slope of a certain area is used as diagnostic factor for mechanization potential, because the steepness of slopes determines for a large part what types of agricultural machinery can be utilized. A slope map was created from a 25m DEM of the study area.

4.2.9 Erosion hazard

One of the aims of every land evaluation procedure is to ensure land degradation is kept at a minimum. Erosion hazard is therefore an important land quality. To model soil erosion for each LUT, the 'Revised Universal Soil Loss Equation' (RUSLE) is used (Renard et al., 1997). The RUSLE predicts water erosion in terms of average annual soil loss. The equation is a simple product formula composed of 6 factors:

$$A = R * K * L * S * C * P$$

Equation 4.6: *The Revised Universal Soil Loss Equation (Renard et al., 1997).*

R is the rainfall-runoff erosivity factor, which is a measure of the amounts and intensities of individual rain storms over the year and the erosion force they exert. In this study a general correlation between mean annual rainfall (MAR) and R is used, also employed by Kassam et al. 1992):

$$R = 117.6 * \left(1.00105^{(MAR)}\right)$$

Equation 4.7: *Rainfall as a function of mean annual rainfall (Kassam et al., 1992).*

K is the soil erodibility factor which represents both susceptibility of soil to erosion and the runoff rate, as measured under a standard unit plot condition (defined as a 22,1m length of uniform slope of 9% in continuous clean-tilled fallow). Each textural class (see *section 4.2.6*) was assigned a K factor value based on organic matter content (Stewart et al., 1975).

The L and S factor are usually considered together and express the effect of slope length (L) and slope steepness (S) on erosion. Slope length can be defined as the distance from the source of runoff to the point where deposition or a defined channel begins. The LS factor is calculated using the following formula, with the DEM of the study area as main input:

$$LS = \left(\frac{A_s}{22.13}\right)^{0.4} * \left(\frac{\sin\beta}{0.0896}\right)^{1.4}$$

Equation 4.8: *Calculation of LS factor (Simms et al., 2003).*

Where A_s is the specific catchment area ($m^2\,m^{-1}$) and β is the slope gradient (in degrees).

C is the cover management factor which is the ratio of soil loss from an area with specified cover and management, to soil loss from an identical area in tilled continuous fallow. This factor depends both on crop type and tillage method. Since there is little information available on tillage methods used in the study area, it was not taken into account and the C factor depends solely on crop type. C values for each LUT were obtained from the literature (Hees et al., 1987).

The P factor reflects the impact of support practices on the average annual erosion rate. It is the ratio of soil loss with contouring, strip cropping and/or terracing, to that with straight row farming, up and down slope. No information was collected on support practices in the study area, but an assumption was made that most farmers use cross slope farming (Stone & Hilborn, 2000).

The final result of the RUSLE is the A factor, which is the soil loss in t ha^{-1} yr^{-1}. The effect of the different LUTs on the total amount of soil erosion solely depends on their C factor. For each LUT a separate RUSLE was performed, with as result the average yearly soil loss per LMU or LMUS. *Table 4.8* shows how the amount of soil loss is expressed in factor ratings.

Table 4.8: *Amount of soil loss as factor rating (FAO, 1983).*

Factor rating	Soil loss (t ha^{-1} yr^{-1})
s1	< 12
s2	12 - 25
s3	25 - 50
n1	50 - 100
n2	> 100

4.3 Present land use

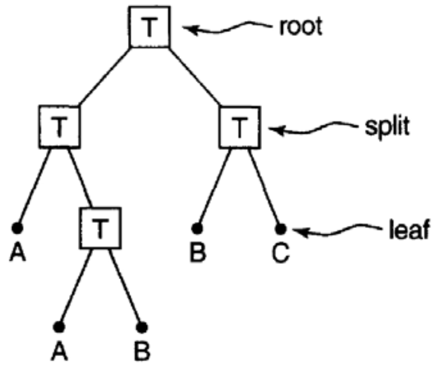
Present land use was determined by performing a land use classification of a remote sensing image of the study area. A Landsat 7 image taken on 12-10-2011 was acquired and used as input for this purpose (specifications of sensor shown in *table 4.9*). The acquisition date matches perfectly with the field campaign. To classify the image, 'object based image analysis' (OBIA) was used. OBIA is a technique for analyzing images based on objects instead of single pixels: an image is segmented into objects that consist of neighboring pixels with high spectral similarity. These objects contain additional spectral information (e.g. mean, max, min band values) when compared to single pixels, and also allow analysis of texture and shape of the objects (Blaschke, 2010; Blaschke & Strobl, 2001).

Because of their large number of features the objects were classified by using a decision tree. A decision tree is defined as a classification procedure that partitions data into smaller subdivisions based on a set of tests at nodes within the tree. It is composed of the root node, internal nodes (splits), and terminal nodes (leaves or end member), as shown in *figure 4.5*. The tree is a decision framework that subdivides a dataset into homogenous groups. The homogeneity of the groups is defined by the user chosen dependent (target) variable (i.e. land use classes), which is based on the values of independent (predictor) variables. A training set is necessary to create the classification tree, after which the tree is used to classify the rest of the dataset (Friedl & Brodley, 1997).

Table 4.9: *Specification of ETM+ sensor (USGS, 2012).*

Band	Wavelength (µm)	Res. (m)
1	0.45 – 0.52	30
2	0.52 – 0.60	30
3	0.63 – 0.69	30
4	0.76 – 0.90	30
5	1.55 – 1.75	30
7	2.08 – 2.35	30

Figure 4.5: *A schematic presentation of a decision tree (Friedl & Brodley, 1997).*



4.3.1 *Field survey*

During the field campaign, one week was dedicated to mapping land use in the study area. As many plots as possible were classified into the following land use categories: (1) urban, (2) natural vegetation, (3) vineyard, (4) olive grove, (5) almond grove, (6) wheat, and (8) bare soil. In addition, land use was documented during soil sampling. These data were used as a training set to develop a decision tree, and as a validation set to assess the accuracy of the classification procedure.

4.3.2 *Classification of remote sensing image*

The classification procedure was performed on two scale levels. First, a large scale procedure was applied to classify the area in three major kinds of land use classes: (1) urban, (2) natural vegetation, and (3) agriculture. Subsequently, the agriculture class is classified into five smaller scale land use classes: (1) vineyard, (2) orchard (olive and almond are joined because of their similarity), (3) wheat, (4) grassland, and (5) bare soil. Multiple scale levels were employed to increase the accuracy of the classification.

The first step is segmenting the Landsat image with use of the eCognition 8.7 software package: a multiresolution segmentation algorithm was applied to create objects. The scale parameter of the algorithm determines the size of the objects and was set at 15. The shape and color parameters were kept at default values (i.e. 0.5). A number of objects were then manually classified with the field survey data into the 3 main land use categories. With these classified objects a decision tree was made with the statistical software package SPSS 19 (IBM), which was then used to classify the entire dataset.

Subsequently, the agriculture land class was segmented again with the scale parameter set at 4, and the shape and color criterions at 0.5. This scale parameter was selected so that objects and agricultural plots have an equal size. Similar to the first level classification, a decision tree was constructed that classified the agricultural land class into the 5 smaller scale land uses. The accuracy of the classification was assessed by constructing an error matrix based on the validation data set.

4.4 Analysis

After determining all the land quality values and land use requirements, they can be matched to obtain the suitability rating of each LMU/LMUS for each LUT. The simple limitation method is used as matching procedure (see *section 3.2.6*) because of its simplicity, and the lack of sufficient expert knowledge of the LUTs under consideration.

The final suitability rating is provided on a subclass level to illustrate the most limiting land quality, which is useful for suggesting possible land improvements. Suitability ratings are determined for each LUT on both the LMU and LMUS scale. The suitability ratings in combination with present land use are used to produce a recommended land use report (see *chapter 6*).

Chapter 5

RESULTS

This chapter discusses the results of land suitability assessment and the land use classification, and consists of 5 sections. First the results of the literature study of the land use requirements are discussed, second the sample locations are presented, followed by the obtained LQ values, then land suitability ratings are presented, and finally the results of the land use classification are shown.

5.1 Land use requirements

The land use requirements (or crop requirements) were inferred from several different sources, although these proved scarce and often contradictory. Studies by Hees et al. (1987), Sys et al. (1993), Allen et al. (1998) and the Ecocrop database (FAO, 2007a) were used as the main sources. Where necessary they were added to, or verified with requirement data from Doorenbos et al. (1979), Narciso et al. (1992), Pearson et al. (1995), Ye et al. (2004) and the 'Soil quality test kit guide' (USDA, 2001). The land use requirement tables used for each LUT are shown in *APPENDIX A*, including their specific source.

Although usually each LUT has its own specific set of land use requirements, some LURs are equal for all crop types. This means that each crop type is assigned the same factor rating value for that requirement, with as purpose to show differentiation in suitability between land units. This applies to the land use requirements for dry bulk density and porosity, which were equal for each LUT.

5.2 Sampling

During the field campaign 152 sampling locations were visited (see *figure 5.1*):

APPENDIX B shows all the sample locations. Depending on the size, for each LMU between 8 and 26 sample locations were visited. Because some of the LMUSs were built-up, difficult to reach, or too small, not all of the units could be visited, therefore these units were excluded from the suitability evaluation.

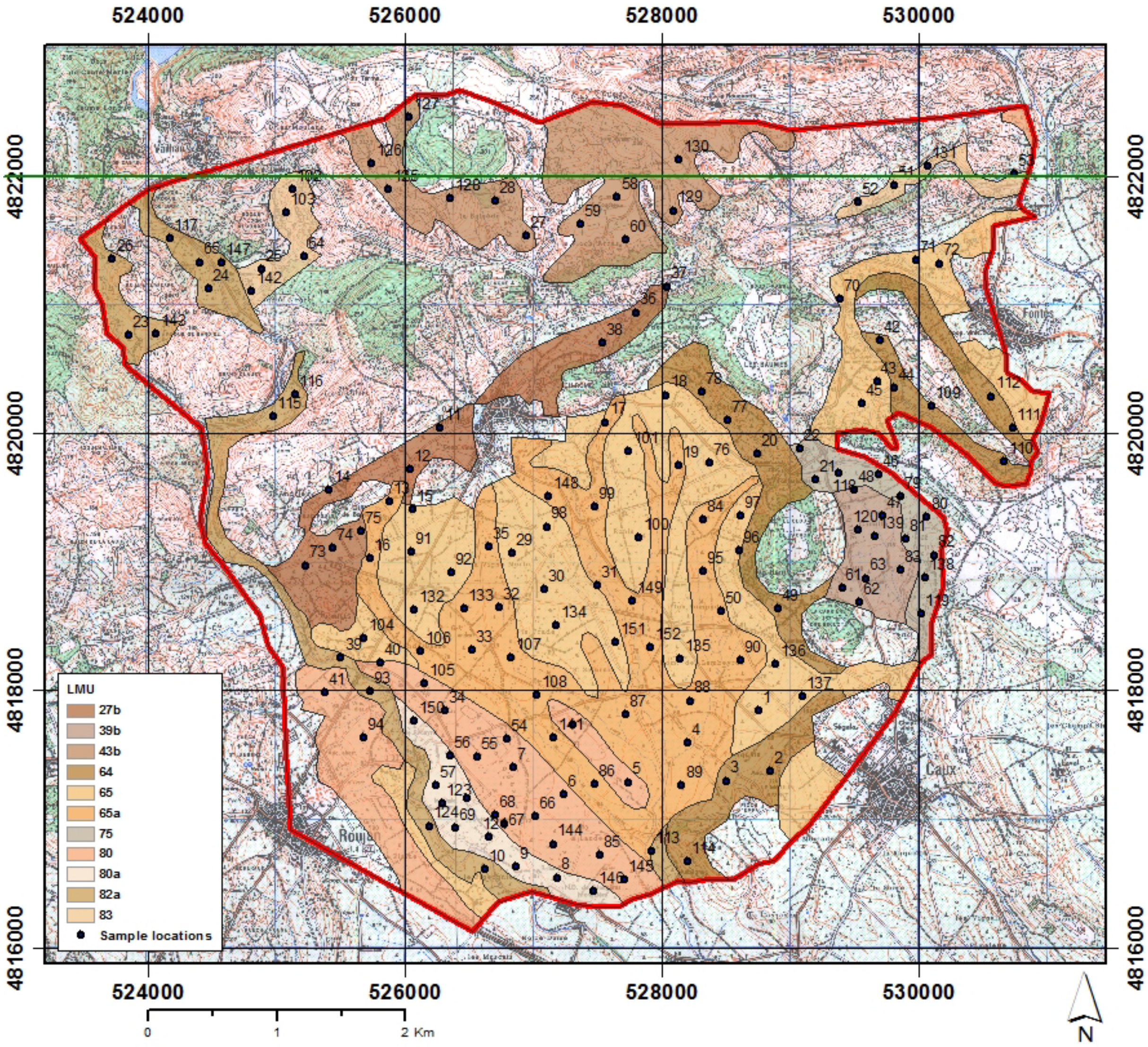


Figure 5.1: Topographic map of the study area showing the sample locations.

The average LQ value is calculated per LMU/LMUS (*section 5.3*). Because the study area is divided into smaller units based on soil type, it is assumed that the physical soil properties of each unit are homogeneous, and that outliers therefore represent measurement errors. A sample is considered an outlier when its value exceeds 2 times the standard deviation of a LMU, and removed from the dataset.

5.3 LQ values

Table 5.1 and *table 5.2* show all LQ values as used in the final suitability assessment. All values are presented as average values per LMU/LMUS. Note that: (1) pH and CEC are only available on LMU scale; (2) average erosion (RUSLE) values vary with each crop type; (3) soil drainage is expressed in TWI values rather than drainage classes (see *table 4.5*); (4) climatic LQ values were not included because of their large diversity, but all values were acquired from the data shown in *table 4.4*.

Because the LQs ‘oxygen availability to roots’ and ‘erosion hazard’ values were determined with the use of models (i.e. TWI and RUSLE), they are presented and discussed separately in *sections 5.3.1* and *5.3.2*.

Table 5.1: *Average LQ values per LMU.*

LMU	TWI	OM	Texture	Stones	Porosity	DBD	$CaCO_3$	Slope	pH	CEC
27b	10,5	4,4	Loam	19,4	36,5	1,60	8,4	10,13	8,1	10
39b	12,2	4,5	Loam	10,6	36,6	1,71	14,8	3,69	7,2	12,7
43b	9,6	6,6	Silt loam	36,4	38,5	1,45	1,3	14,49	7,7	8,1
64	9,9	4,9	Loam	13,8	40,5	1,54	21,3	16,82	8,3	11,2
65	11,1	4,1	Loam	11,6	38,9	1,64	15,7	5,63	8,2	10
65a	12,0	4,1	Loam	13,8	37,7	1,59	14,5	3,15	8,2	10
75	10,7	4,9	Loam	28,0	38,0	1,57	0,2	7,11	8,3	18,8
80	11,4	3,6	Loam	28,2	34,5	1,52	1,8	3,19	6,9	10,4
80a	11,4	4,1	Loam	24,5	35,9	1,62	2,8	3,77	6,9	10,4
82a	11,1	4,6	Loam	25,0	35,8	1,59	2,1	10,07	7,9	12
83	10,6	5,2	Loam	22,8	34,3	1,74	3,3	13,24	7,9	12

Table 5.2: *Average LQ values per LMUS (ns =no sample).*

LMUS	TWI	OM	Texture	Stones	Porosity	DBD	$CaCO_3$	Slope
27b_1	10,5	4,6	Loam	20,0	36,8	1,59	10,5	8,59
27b_2	10,5	4,0	Loam	18,3	36,0	1,62	4,2	12,7
39b_1	12,2	4,5	Loam	10,6	36,6	1,71	14,8	3,69
43b_1	9,6	10,0	Silt loam	39,0	ns	ns	1,6	14,95
43b_2	9,7	4,3	Silt loam	34,2	38,5	1,45	1,1	13,5
64_1	10,0	3,8	Silt loam	10,0	39,7	1,50	26,8	12,94
64_2	9,8	4,9	Loam	11,3	44,7	1,45	20,4	17,86
64_3	11,0	5,0	Loam	18,8	38,6	1,54	24,2	14,8
64_4	9,2	6,0	Loam	15,0	37,4	1,78	11,0	22,85
65_1	ns	ns	ns	ns	ns	ns	ns	ns
65_2	ns	ns	ns	ns	ns	ns	ns	ns
65_3	10,6	4,2	Clay loam	10,0	40,5	1,57	1,4	5,72
65_4	12,0	4,6	Loam	17,5	34,7	1,74	5,2	2,37
65_5	11,0	4,0	Loam	8,0	42,5	1,53	20,6	3,81
65_6	11,4	4,0	Loam	11,0	38,7	1,70	15,3	6,29
65_7	ns	ns	ns	ns	ns	ns	ns	ns
65_8	11,3	4,1	Loam	13,0	38,0	1,71	20,4	4,16
65_9	ns	ns	ns	ns	ns	ns	ns	ns

65_10	10,3	4,0	Silt loam	10,0	38,2	1,60	24,5	10,95
65a_1	12,0	4,1	Loam	13,8	37,7	1,59	14,5	3,15
75_1	10,7	4,9	Loam	28,0	38,0	1,57	0,2	7,11
80_1	11,3	4,1	Silt loam	25,0	36,3	1,27	4,0	2
80_2	11,2	3,4	Silt loam	12,5	37,6	1,60	6,8	4,48
80_3	11,6	3,5	Loam	31,2	33,1	1,54	0,3	2,24
80_4	ns	ns	ns	ns	ns	ns	ns	ns
80a_1	11,4	4,1	Loam	24,5	35,9	1,62	2,8	3,77
82a_1	ns	ns	ns	ns	ns	ns	ns	ns
82a_2	11,2	3,6	Silt loam	26,7	36,8	1,62	4,2	10,04
82a_3	10,4	5,5	Loam	21,7	34,8	1,47	0,3	13,46
82a_4	11,2	5,3	Loam	22,5	34,6	1,62	1,8	7,77
83_1	10,7	5,7	Loam	23,0	34,9	1,74	3,8	13,17
83_2	10,6	4,3	Loam	22,5	33,0	1,74	2,5	13,34

5.3.1 TWI

The 25m DEM used as input for the TWI calculation and the resulting index map, are shown in *figure 5.2a* and *b*. Index values are calculated based on upslope catchment size and slope, where a large upslope catchment and a small slope indicate a poorly drained area (high TWI value) and vice versa. When comparing the DEM with the TWI map this becomes apparent: the flat area in the south displays the highest TWI values, while the steeper area to the north shows lower values.

Figure 5.2c and *d* illustrate the effect of land mapping unit scale on average TWI values. The smaller LMUS scale shows more variation than the LMU scale, and more accurately resembles the continuous TWI map. A clear example of this is unit 64: its average TWI value is 9.9, but the values for its subdivisions range from 9.2 to 11. In order to compare the wetness index values with crop requirements, the average values were expressed as drainage classes, according to *table 4.5*.

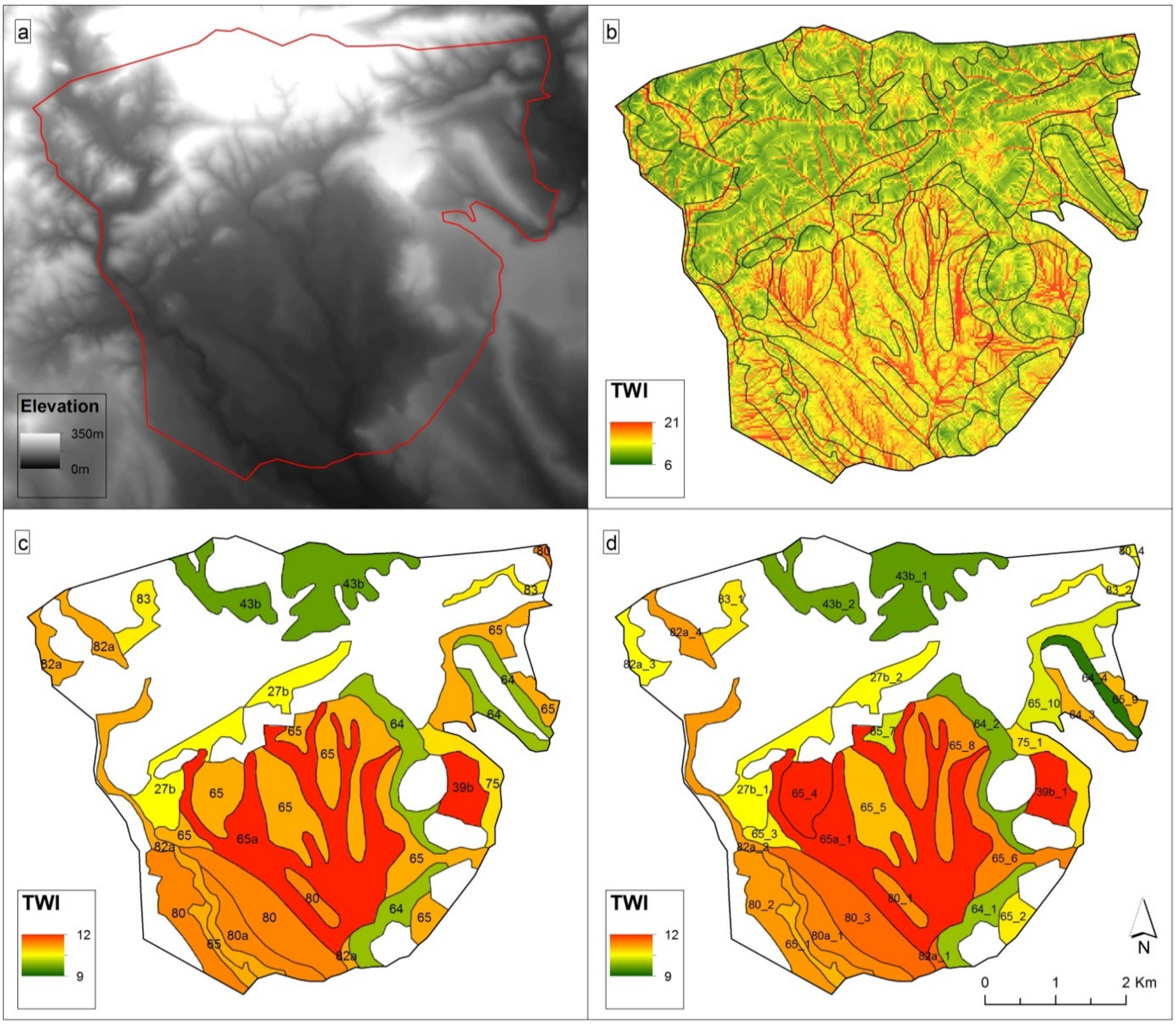
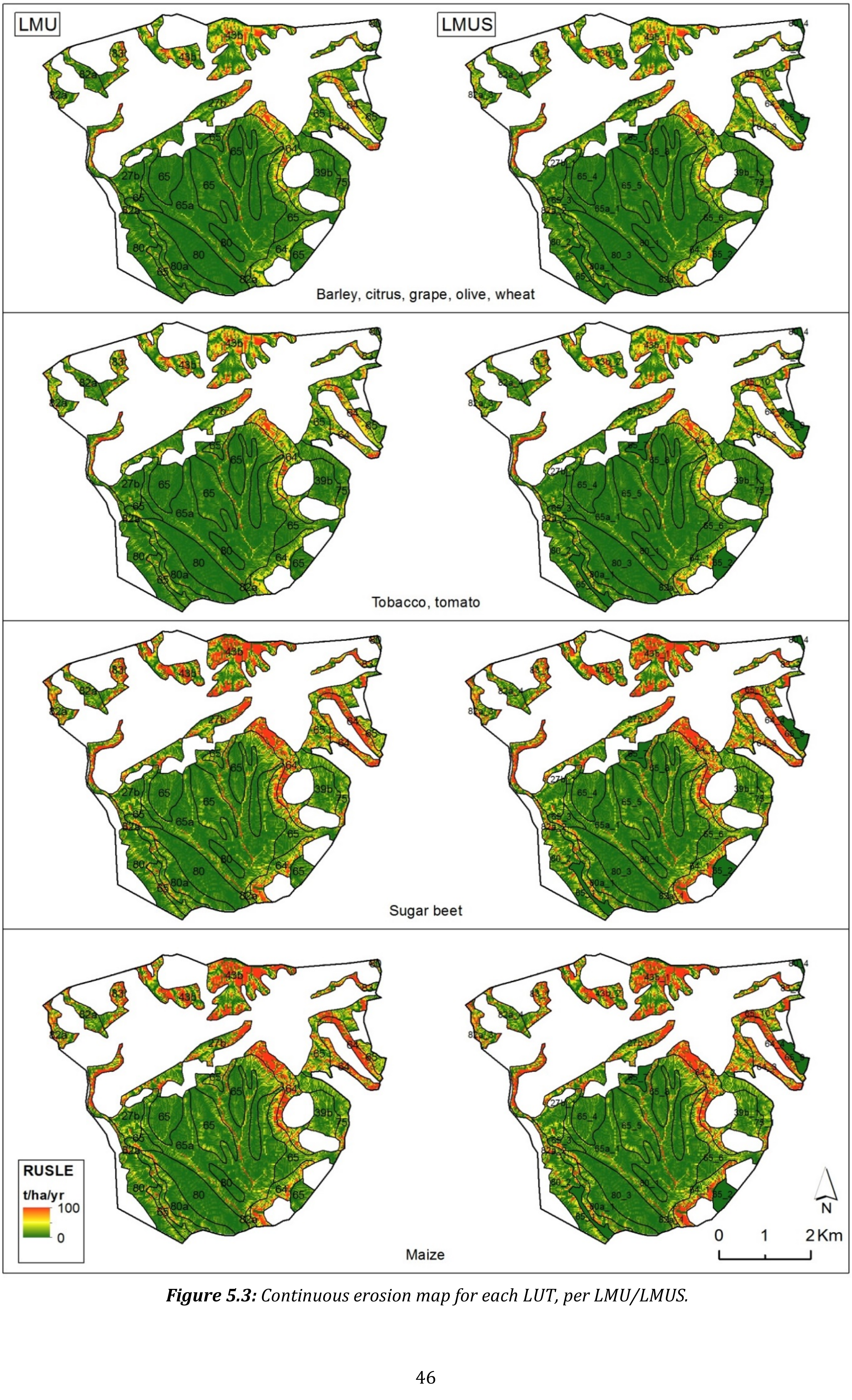


Figure 5.2: *a. shows the 25m DEM used as input; b. shows the topographic wetness index map of the study area; c. shows the average TWI per LMU; d. shows the average TWI per LMUS.*

5.3.2 RUSLE

For each LUT, the erosion hazard was calculated using the RUSLE. To assess the effect of the different crop types on erosion, only the C factor varied for each LUT (note that some LUTs have equal C factors, and thus equal erosion rates); the other factors (e.g. tillage method, or support practices) were kept constant. This resulted in a number of continuous erosion maps, shown in *figure 5.3*. Average soil erosion values were then calculated per LMU/LMUS, and subsequently classified according to *table 4.8*. *Figure 5.4* shows the resulting factor rating maps. *Appendix C* contains tables of the input factors and the average erosion values per LMU/LMUS and LUT. Differences in erosion values between the scale levels are mainly the result of variation in LS factor values, although in some cases the K factor also varies between LMU and LMUS.



Barley, citrus, grape, olive, wheat

Tobacco, tomato

Sugar beet

Maize

Figure 5.3: *Continuous erosion map for each LUT, per LMU/LMUS.*

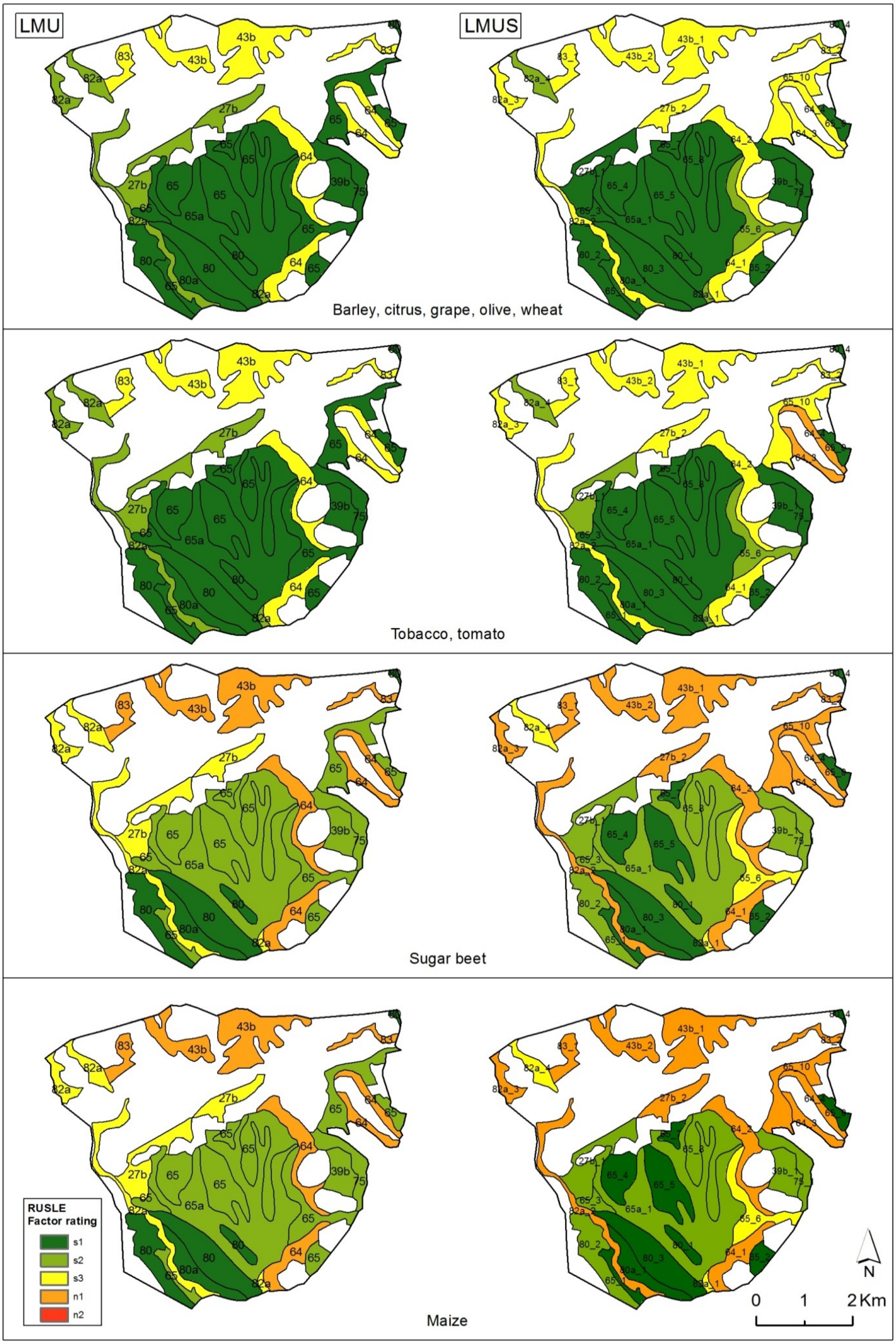


Figure 5.4: *Soil loss factor rating map for each LUT, per LMU/LMUS.*

5.4 Suitability ratings

In the final step of the suitability assessment, the LQ values are compared with the LUR values for each crop type, and each of the diagnostic factors gets assigned a factor rating. The most limiting factor rating (i.e. the lowest) is considered to be the suitability rating of a LMU/LMUS for a specific LUT. *Figure 5.5* to *figure 5.13* show the resulting land suitability maps for each LUT. To distinguish between climatic factors and physical soil properties, and between LMUs and LMUSs, 5 maps are presented per crop type: (a) shows climatic suitability (for whole study area); (b) and (c) show soil suitability per LMU and per LMUS; and (d) and (e) show the combined and overall suitability per LMU and per LMUS. *Table 5.3* shows the average suitability ratings in percentages of the study area, which serves to illustrate the differences in suitability between the scale levels.

Table 5.3: *Suitability in percentage of area per LUT, and per LMU/LMUS.*

	LMU					**LMUS**				
LUT	*S1*	*S2*	*S3*	*N1*	*N2*	*S1*	*S2*	*S3*	*N1*	*N2*
Barley			100					100		
Citrus				44.1	55.9				44.1	55.9
Grape			94.5		5.5			90.3		9.7
Maize				44.1	55.9				44.1	55.9
Olive		16.6	83.4				22.2	77.8		
Sugar beet		15.0	50.4	34.6			15.0	62.4	22.6	
Tobacco				15.0	85.0				15.0	85.0
Tomato				37.8	62.2				37.8	62.2
Wheat		4.0	96.0				6.3	93.7		

The overall land suitability classes and their limiting land qualities are shown in *table 5.4* and *table 5.5*; *table 5.6* and *table 5.7* further specify the number and types of limiting LQs. The following LQ suffixes are used:

- c: temperature regime;
- m: moisture availability;
- w: oxygen to roots;
- n: nutrient availability;
- r: rooting conditions;
- x: soil toxicities;
- q: potential for mechanization;
- e: erosion hazard.

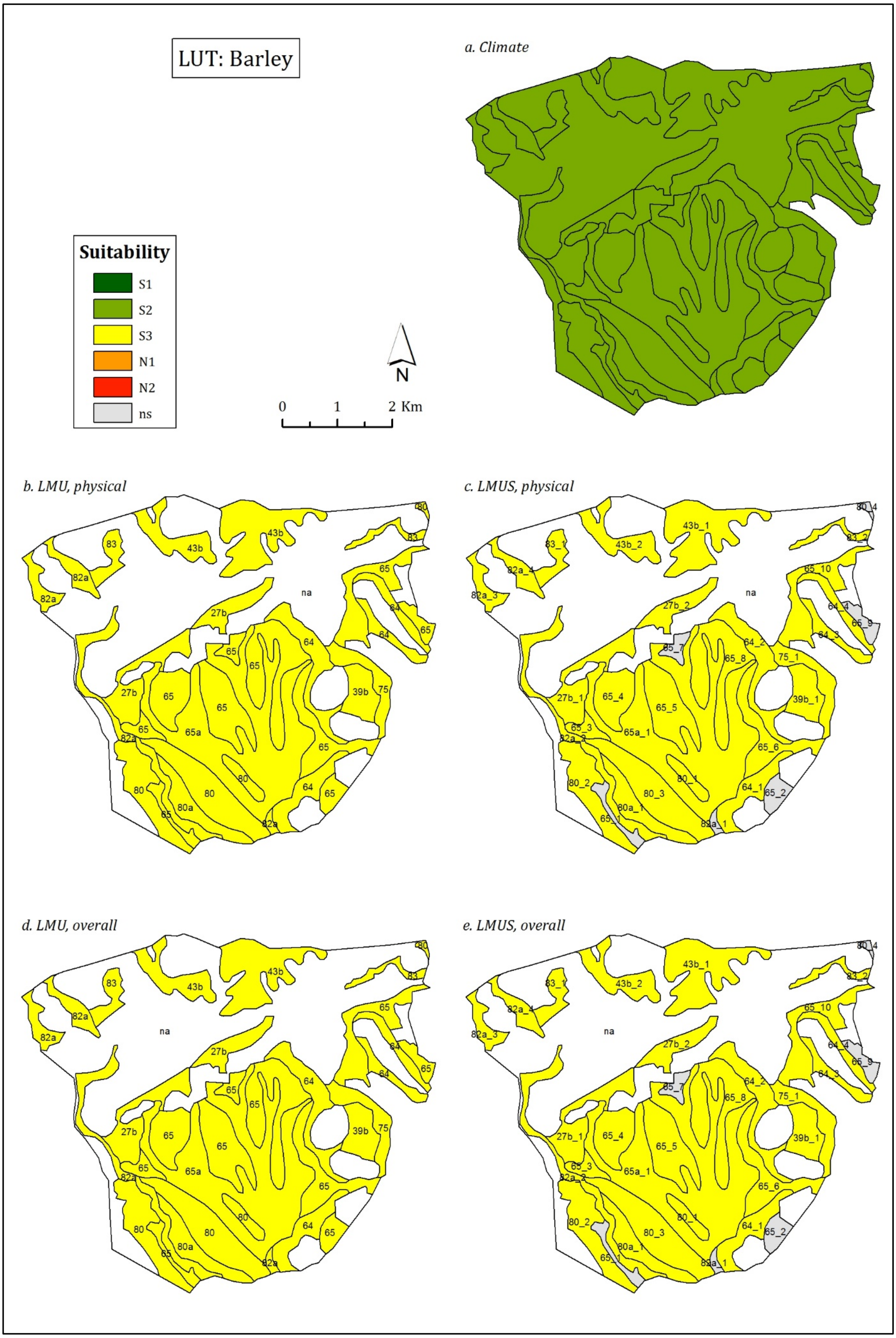


Figure 5.5: *Land suitability maps for barley.*

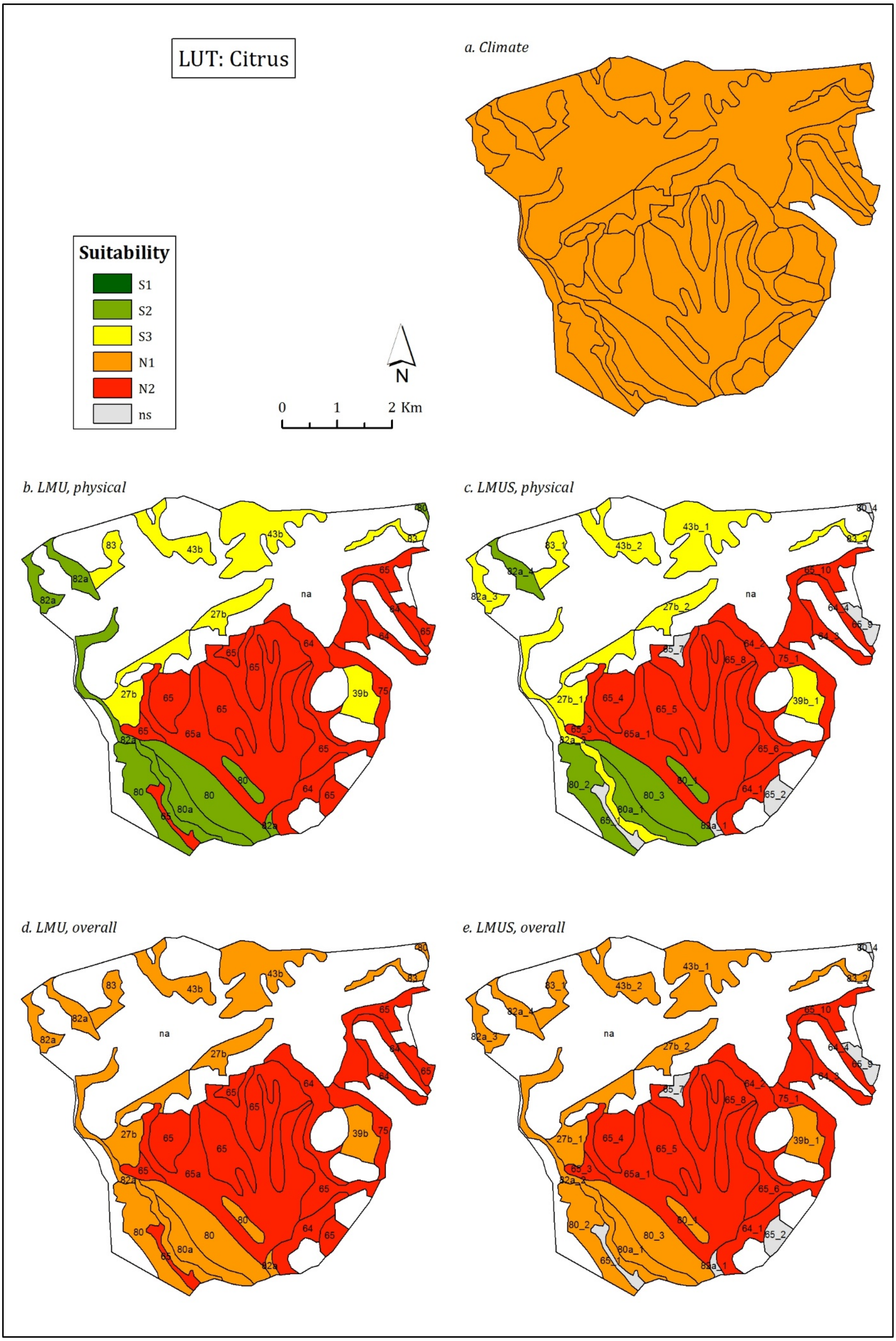


Figure 5.6: *Land suitability maps for citrus.*

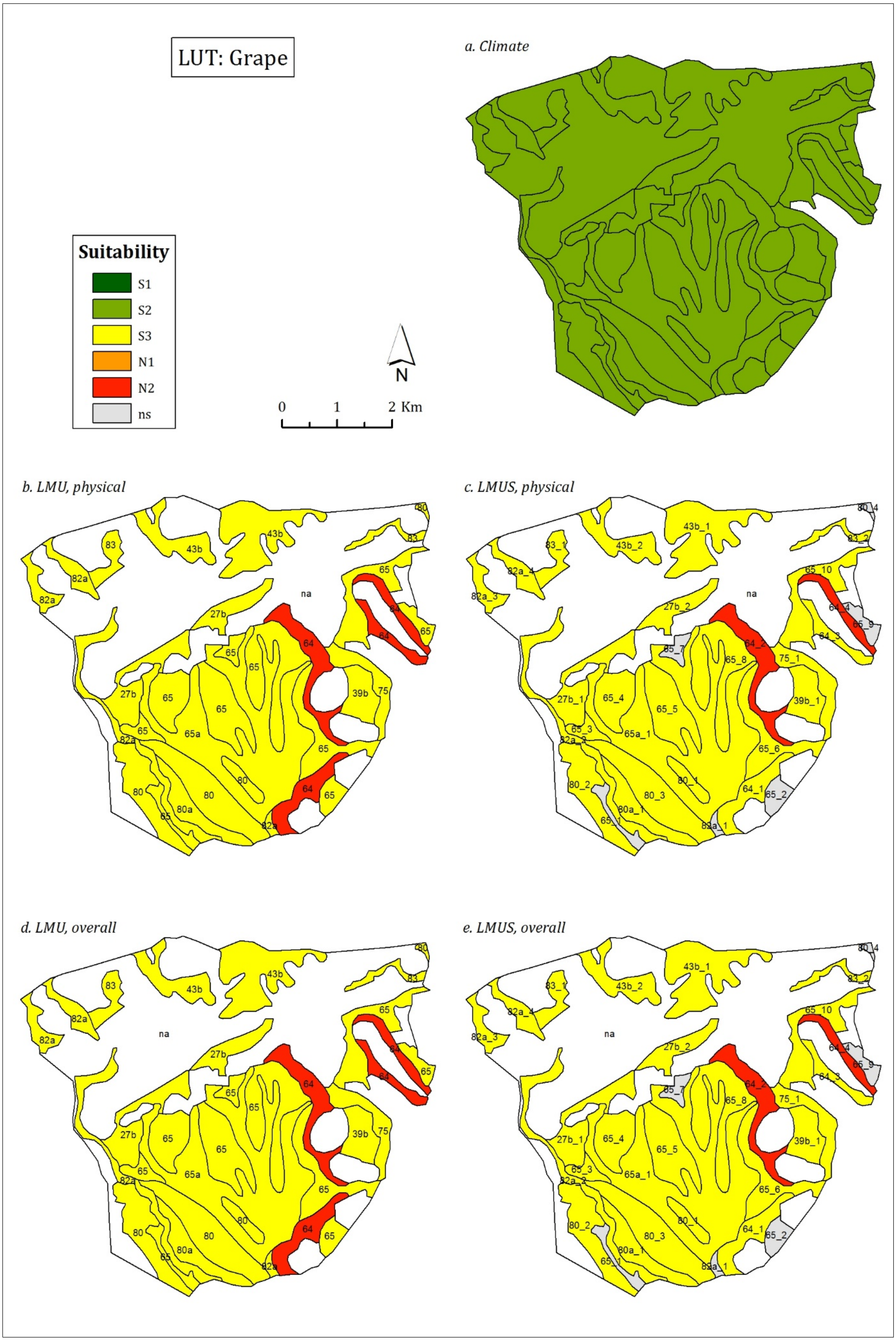


Figure 5.7: *Land suitability maps for grape.*

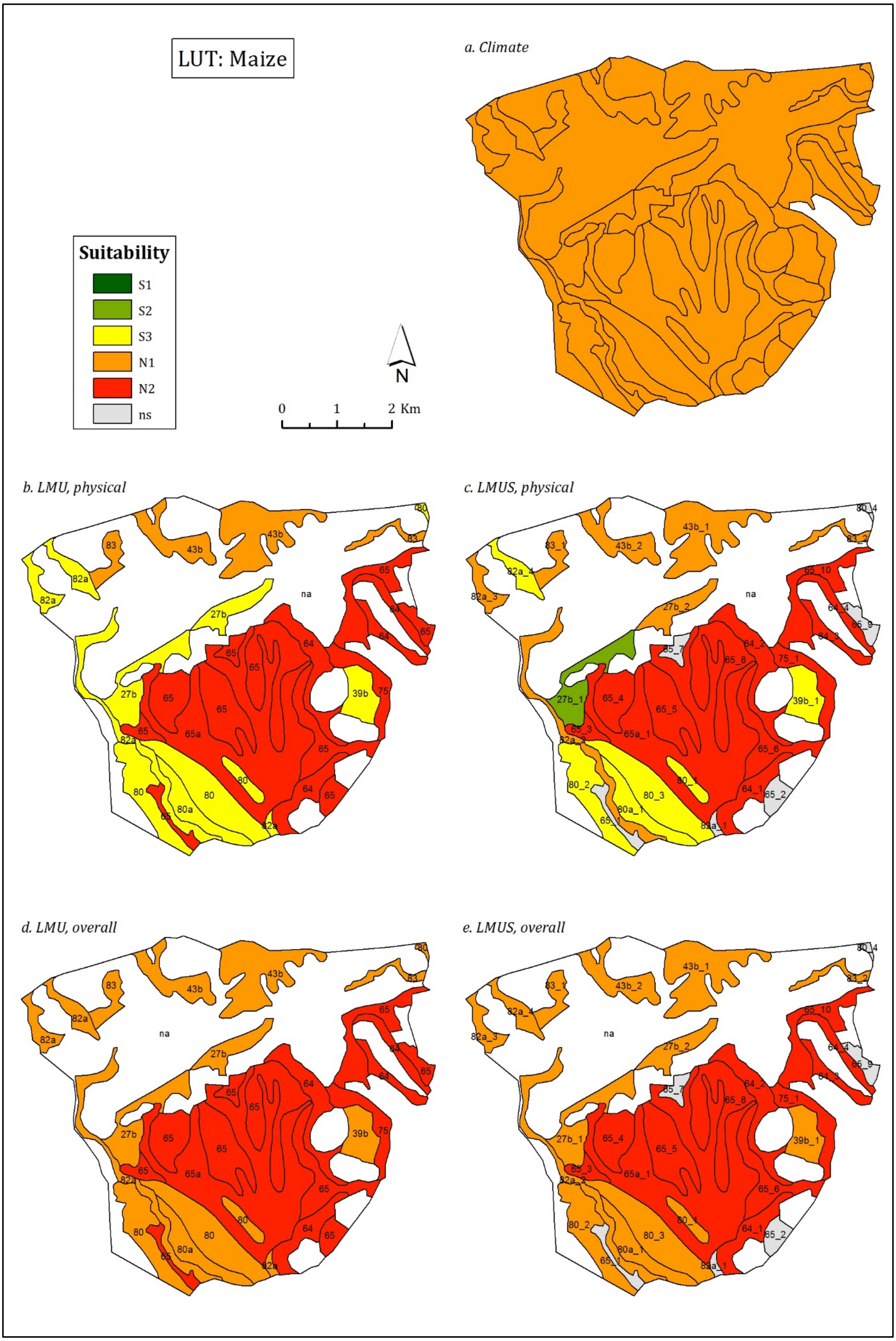


Figure 5.8: Land suitability maps for maize.

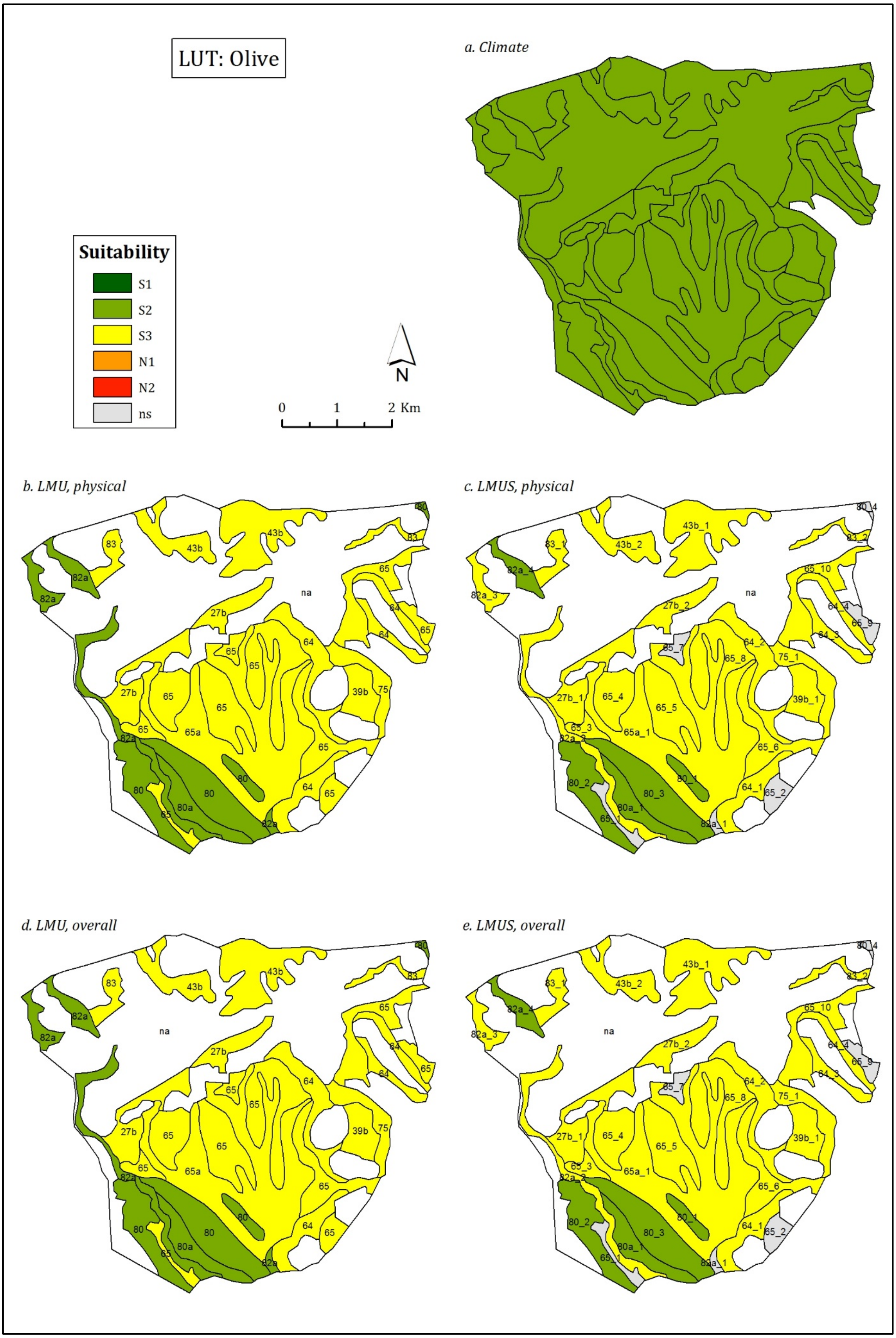


Figure 5.9: *Land suitability maps for olive.*

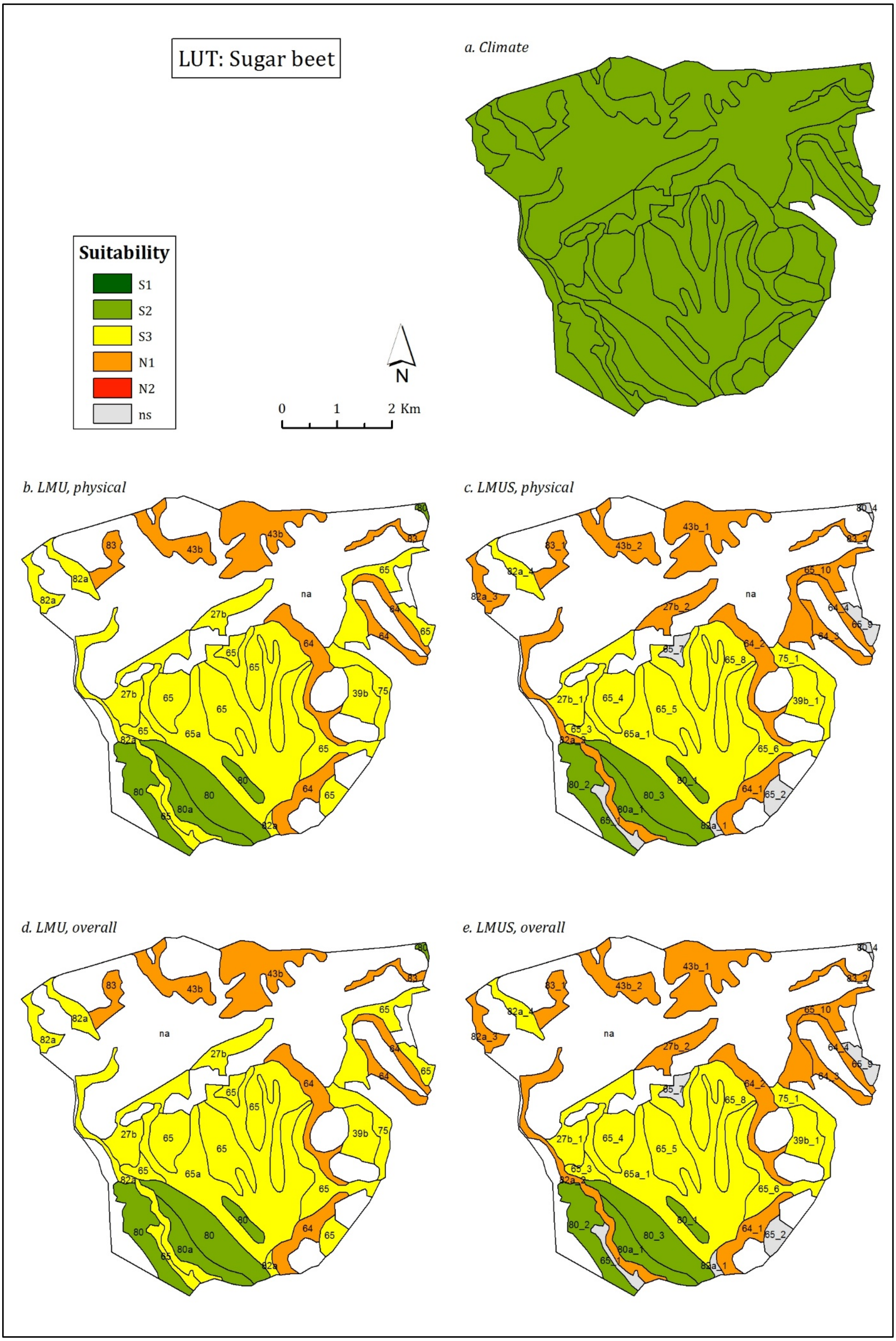


Figure 5.10: *Land suitability maps for sugar beet.*

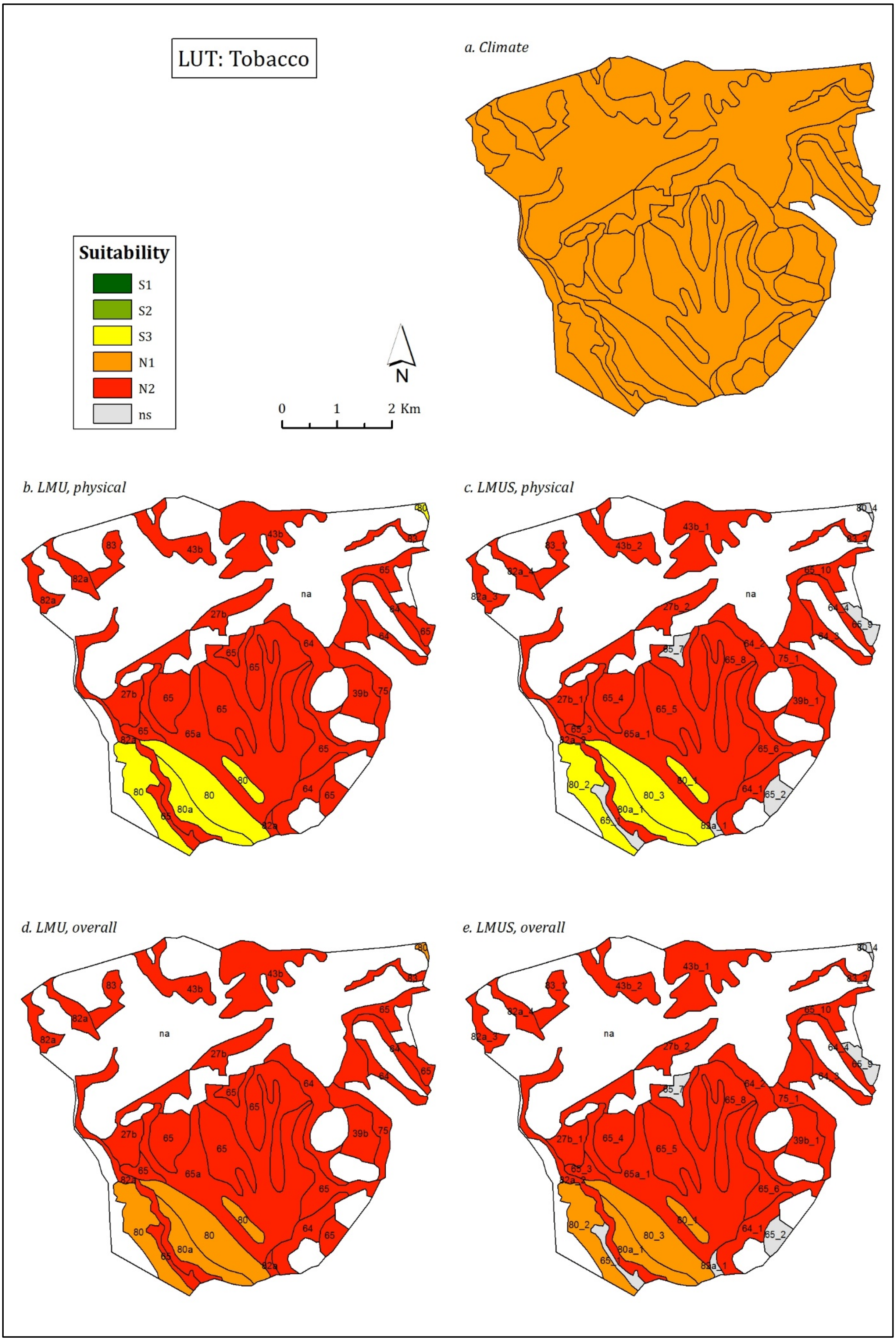


Figure 5.11: *Land suitability maps for tobacco.*

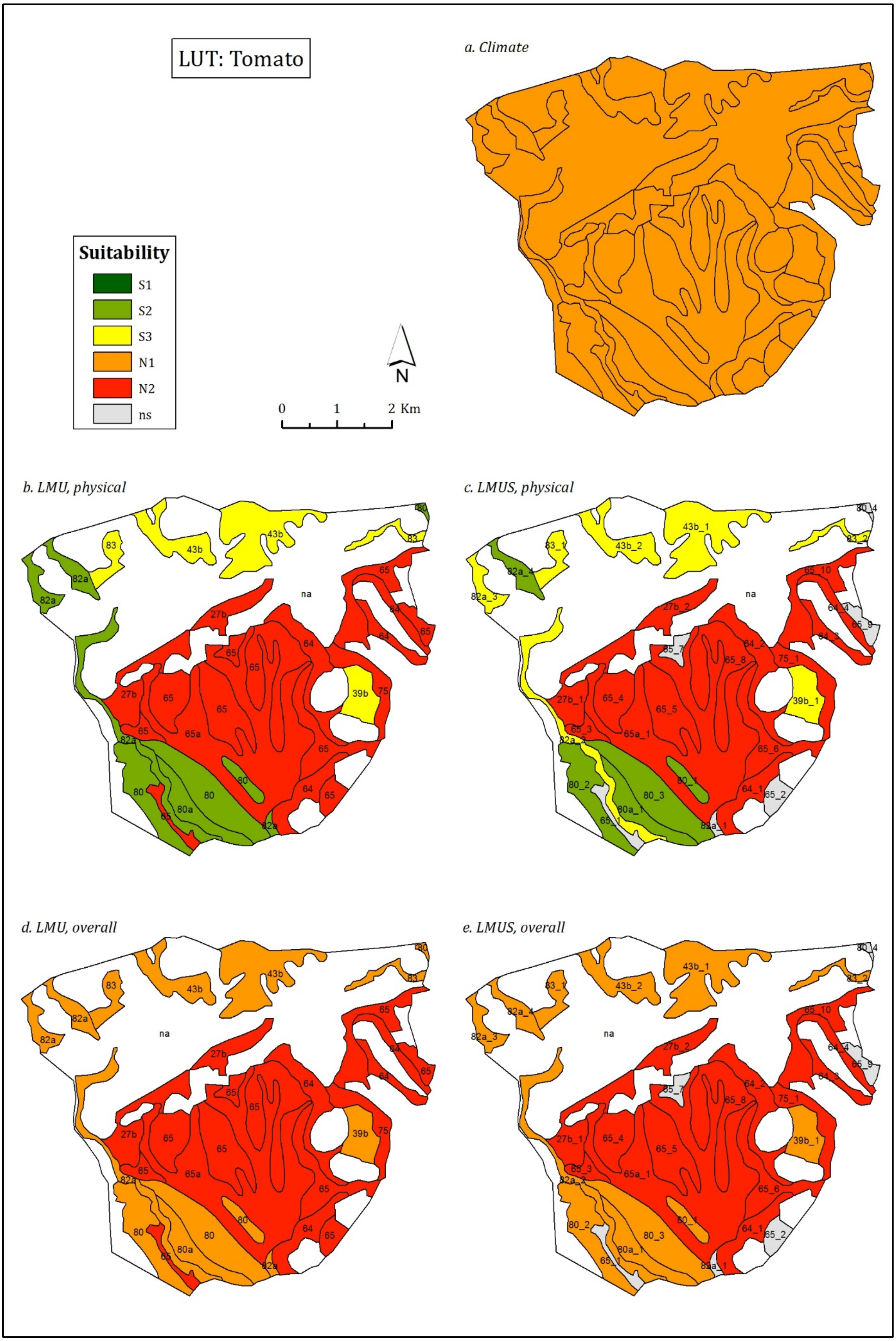


***Figure 5.12:** Land suitability maps for tomato.*

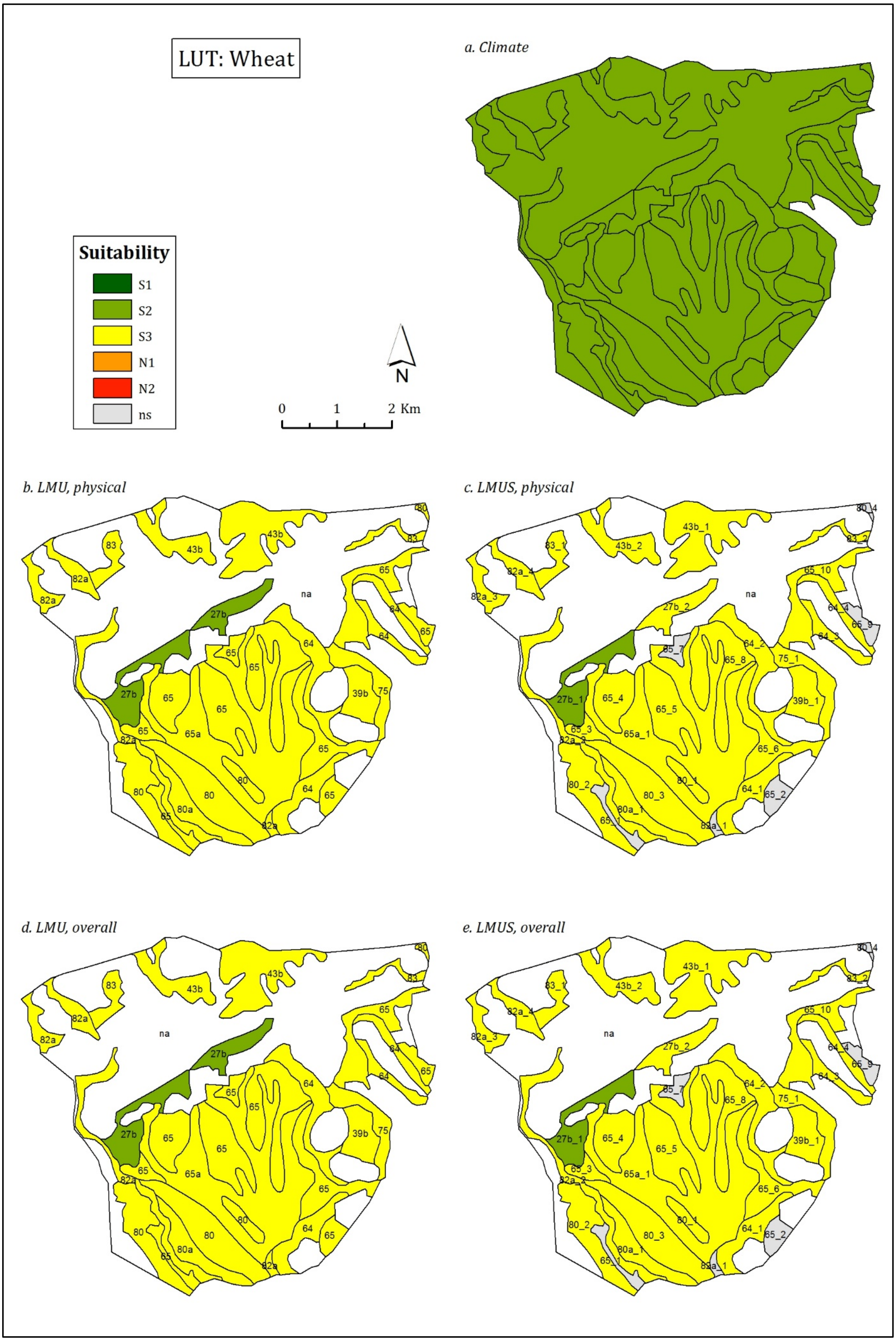


Figure 5.13: Land suitability maps for wheat.

Table 5.4: *Shows suitability and limiting LQs (see table 3.3 for suffix) per LMU for each LUT.*

LMU	Barley	Citrus	Grape	Maize	Olive	Sugar beet	Tobacco	Tomato	Wheat
27b	S3n	N1m	S3q	N1m	S3n	S3ne	N2n	N2n	S2c
39b	S3wr	N1m	S3wr	N1m	S3r	S3r	N2x	N1m	S3wr
43b	S3re	N1m	S3qe	N1me	S3e	N1e	N2n	N1m	S3re
64	S3nqe	N2n	N2q	N2n	S3ne	N1e	N2nx	N2n	S3nqe
65	S3wnr	N2n	S3wnr	N2n	S3nr	S3nr	N2nx	N2n	S3wnr
65a	S3wn	N2n	S3wn	N2n	S3n	S3n	N2nx	N2n	S3wn
75	S3n	N2n	S3n	N2n	S3n	S3n	N2n	N2n	S3n
80	S3w	N1m	S3w	N1m	S2c	S2mwnr	N1m	N1m	S3w
80a	S3w	N1m	S3w	N1m	S2c	S2mwnr	N1m	N1m	S3w
82a	S3w	N1m	S3wq	N1m	S2c	S3e	N2n	N1m	S3w
83	S3re	N1m	S3rqe	N1me	S3re	N1e	N2n	N1m	S3re

Table 5.5: *Shows suitability and limiting LQs (see table 3.3 for suffix) per LMUS for each LUT.*

LMUS	Barley	Citrus	Grape	Maize	Olive	Sugar beet	Tobacco	Tomato	Wheat
27b_1	S3n	N1m	S3q	N1m	S3n	S3n	N2nx	N2n	S2c
27b_2	S3n	N1m	S3qe	N1me	S3ne	N1e	N2n	N2n	S3e
39b_1	S3wr	N1m	S3wr	N1m	S3r	S3r	N2x	N1m	S3wr
43b_1	S3re	N1m	S3qe	N1me	S3e	N1e	N2n	N1m	S3qe
43b_2	S3e	N1m	S3qe	N1me	S3e	N1e	N2n	N1m	S3e
64_1	S3ne	N2nx	S3nqe	N2n	S3ne	N1e	N2nx	N2x	S3ne
64_2	S3nqe	N2n	N2q	N2n	S3ne	N1e	N2nx	N2n	S3nqe
64_3	S3ne	N2n	S3nqe	N2n	S3ne	N1e	N2nxe	N2n	S3ne
64_4	S3nrqe	N2n	N2q	N2n	S3rne	N1e	N2nxe	N2n	S3nrqe
65_1	ns	ns	ns	ns	ns	ns	ns	ns	ns
65_10	S3ne	N2n	S3nqe	N2n	S3ne	N1e	N2nx	N2n	S3ne
65_2	ns	ns	ns	ns	ns	ns	ns	ns	ns
65_3	S3n	N2n	S3n	N2n	S3n	S3n	N2n	N2n	S3n
65_4	S3wnr	N2n	S3wnr	N2n	S3nr	S3nr	N2n	N2n	S3wnr
65_5	S3n	N2n	S3n	N2n	S3n	S3n	N2nx	N2n	S3n
65_6	S3wnr	N2n	S3wnr	N2n	S3nr	S3nre	N2nx	N2n	S3wnr
65_7	ns	ns	ns	ns	ns	ns	ns	ns	ns
65_8	S3wnr	N2n	S3wnr	N2n	S3nr	S3nr	N2nx	N2n	S3wnr
65_9	ns	ns	ns	ns	ns	ns	ns	ns	ns
65a_1	S3wn	N2n	S3wn	N2n	S3n	S3n	N2nx	N2n	S3wnr
75_1	S3n	N2n	S3n	N2n	S3n	S3n	N2n	N2n	S3n
80_1	S3w	N1m	S3w	N1m	S2c	S2mwnr	N1m	N1m	S3w
80_2	S3w	N1m	S3w	N1m	S2c	S2mwnre	N1m	N1m	S3w
80_3	S3w	N1m	S3w	N1m	S2c	S2mwnr	N1m	N1m	S3w
80_4	ns	ns	ns	ns	ns	ns	ns	ns	ns
80a_1	S3w	N1m	S3w	N1m	S2c	S2mwnr	N1m	N1m	S3w
82a_1	ns	ns	ns	ns	ns	ns	ns	ns	ns
82a_2	S3wre	N1m	S3wrqe	N1me	S3re	N1e	N2n	N1m	S3we
82a_3	S3e	N1m	S3qe	N1me	S3e	N1e	N2n	N1m	S3e
82a_4	S3w	N1m	S3w	N1m	S2c	S3e	N2n	N1m	S3w
83_1	S3re	N1m	S3rqe	N1me	S3re	N1e	N2n	N1m	S3re
83_2	S3re	N1m	S3rqe	N1me	S3re	N1e	N2n	N1m	S3re

Table 5.6: *The number of limiting factors per LUT on LMU scale.*

LUT	c	m	w	n	r	x	q	e	Total
Barley			6	5	4		1	3	19
Citrus		7		4					11
Grape			6	3	3		5	2	19
Maize		7		4				2	13
Olive	3			5	3			3	14
Sugar beet		2	2	6	4			5	19
Tobacco		2		8		4			14
Tomato		6		5					11
Wheat	1	6		4	4		1	3	19
Total	4	30	14	44	18	4	7	18	139
Total (%)	2.9	21.6	10.1	31.7	12.9	2.9	5.0	12.9	100

Table 5.7: *The number of limiting factors per LUT on LMUS scale.*

LUT	c	m	w	n	r	x	q	e	Total
Barley			11	14	9		2	11	47
Citrus		14		12		1			27
Grape			11	10	7		13	10	51
Maize		14		12				7	33
Olive	5			14	8			12	39
Sugar beet		4	4	12	8			15	43
Tobacco		4		21		11		2	38
Tomato		12		13		1			26
Wheat	1		11	11	8		3	12	46
Total	6	48	37	119	40	13	18	69	350
Total (%)	1.7	13.7	10.6	34.0	11.4	3.7	5.1	19.7	100

5.5 Present land use

The final result of the classification procedure is a map of the present land use (see *figure 5.14*). The Landsat 7 image used as input is presented in *APPENDIX D*, together with the segmentation results, the training data and the classification trees.

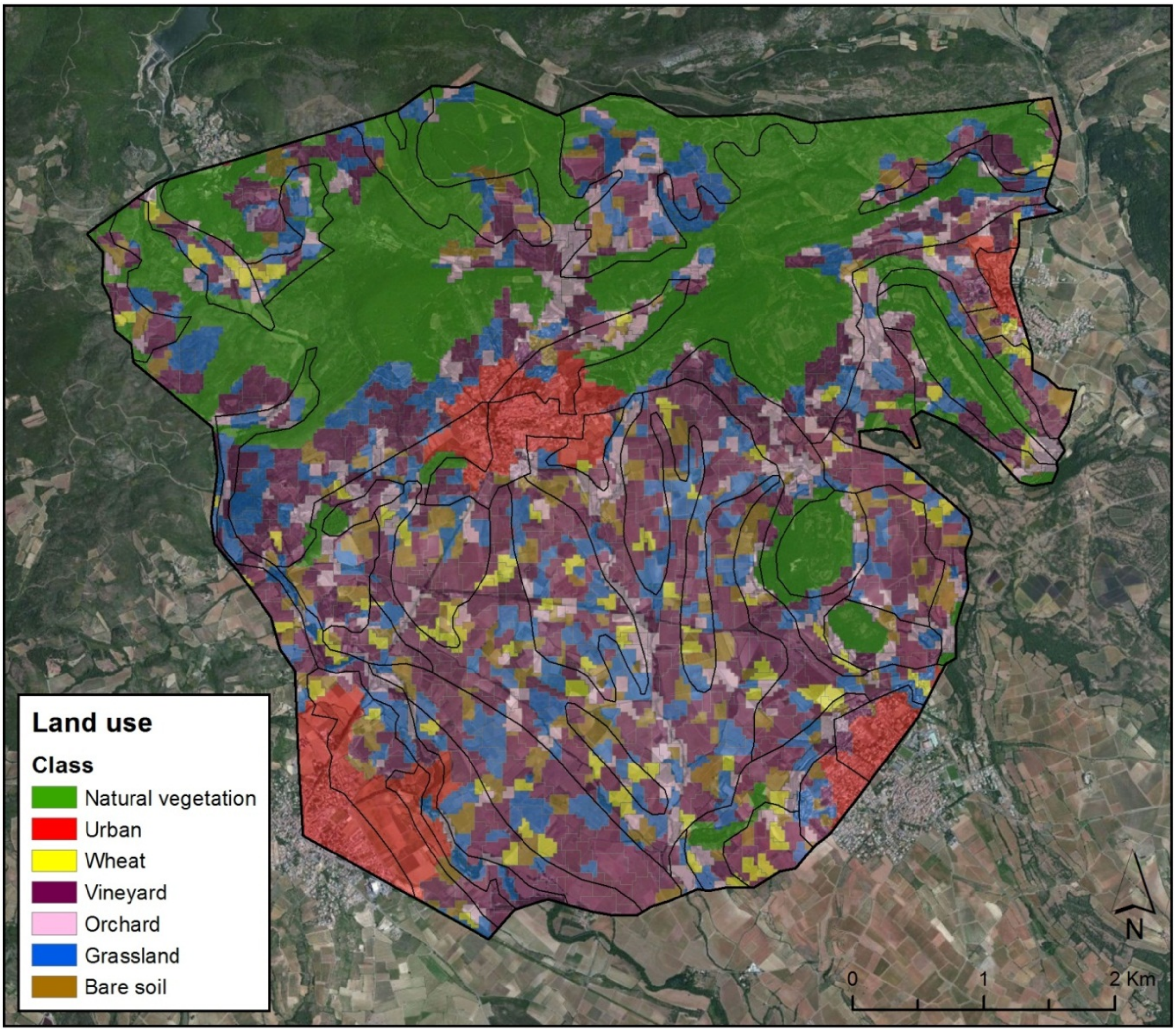


Figure 5.14: *Map of present land use of the study area.*

This map shows the results of both classification levels: two of the three principal land use classes (natural vegetation and urban) are visible, while the third class (agriculture) is further classified into 5 more specific subclasses: wheat, vineyard, orchard (both almond and olive), grassland, and bare soil. The average size of the classified objects (excluding natural vegetation and urban) is approximately 17 pixels (each 30x30m) with a minimum of 1 and a maximum of 74. *Table 5.8* shows the result of the classification in percentages of the area, with the most common land use type being vineyard, comprising 30.5% of the total (or 47% of agricultural) land use.

The first, large scale segmentation of the Landsat 7 image resulted in 519 objects, of which 50 objects were selected as training set for a classification tree. Although the result was excellent and accurately classified the three main units, it was decided to manually adjust the classified objects to improve accuracy of especially the agriculture class. This adjustment was done with use of a 1:25.000 topographic map of the area. The objects classified as agriculture were further segmented into 4160 objects, of which 147 objects were selected as training set. To assess accuracy of this classification, an error matrix was constructed with validation data (71 objects) obtained from the field survey (see *table 5.9*). The matrix shows that the overall accuracy is 52.1%.

Table 5.8: *Area of each land use class. Agricultural subclasses are shown (as % of total and as % of agriculture).*

Land use class	Area (%)	Agricultural land uses	Area (%)	Area of total (%)
Natural vegetation	27.9	Wheat	5.4	3.5
Urban	7.2	Vineyard	47	30.5
Agriculture	64.9	Orchard	13.6	8.8
		Grassland	22.9	14.9
		Bare soil	11	7.2

Table 5.9: *Error matrix for second scale classification.*

	Predicted class						**Producer's accuracy**
Actual class	*Vineyard*	*Orchard*	*Bare soil*	*Grassland*	*Wheat*	*Total*	
Vineyard	23	2	8	5	1	39	59.0
Orchard	1	4		1		6	66.7
Bare soil	2	1	7			10	70.0
Grassland	4		2	1	2	9	11.1
Wheat			4	1	2	7	28.6
Total	30	7	21	8	5	71	
User's accuracy	76.7	57.1	33.3	12.5	40.0		
Overall accuracy	52.1						

Chapter 6

LAND USE RECCOMENDATION REPORT

According to the FAO, the comparison of land use with land should consist of the following stages (FAO, 1983): (1) initial matching of land use requirements with land qualities; (2) interim review and iteration; (3) land improvements; (4) environmental impact; (5) economic and social analysis; (6) review and field check; and (7) land suitability classification. However, the evaluation procedure performed in this study was limited to the initial matching, land improvements, and final land suitability classification. In addition, mainly physical land properties were considered, with the exception of slope as a management, and soil erosion as a conservation factor.

The following section can be seen as the final result of the land evaluation procedure, and entails a land use recommendation report. The report consists of a discussion of the suitability matching results, an overview of recommended land utilization types, a number of suggestions for improvements, and a comparison of recommended with present land use.

6.1 Results of matching

Section 5.4 contains the land suitability maps for each land utilization type, which are the results of the matching procedure. As the maps show, besides the scale difference between LMUs and LMUSs, a distinction was also made between soil and climatic suitability. This was done to illustrate the large effect climate potentially has on suitability, and because it influences all LMUs/LMUSs equally.

Table 6.1: *Rating and percentage of area that is limited by climate suitability per LUT.*

LUT	Climate rating	LMU	LMUS
Barley	s2	0	0
Citrus	n1	44,1	44,1
Grape	s2	0	0
Maize	n1	44,1	44,1
Olive	s2	22,2	16,6
Sugar beet	s2	0	0
Tobacco	n1	15,0	15,0
Tomato	n1	37,8	37,8
Wheat	s2	6,3	4,0

Table 6.1 serves to illustrate the effect of climate on overall suitability rating per crop. Since the simple limitation method is used for matching, and climate is equal for the entire study area, its rating class is by definition the maximum suitability that can be attained for a crop. This means that suitability ratings for, in particular citrus, maize, tobacco, and tomato, are severely limited by climate, which is also reflected in the percentages of area that are indicated as limited. Interesting to note is that these crops are limited even more by physical soil properties: in accordance with *table 5.3* the remaining area has a

suitability of N2. As expected, the climate limitation for these 4 crops mainly concerns the LQ moisture availability (i.e. precipitation), where the lowest suitability rating for the LQ temperature regime is s3 for citrus. This is not surprising because usually citrus, maize, tobacco, and tomato require irrigation to be cultivated successfully in the Mediterranean (see *table 3.5*). The same, however, was assumed for sugar beet, but this is not the case as it has a s2 suitability rating for moisture availability (on a side note, this LQ rating for sugar beet was only based on annual precipitation). Furthermore climate is also limiting the suitability ratings of olive and wheat, although this is the effect of temperature regime rather than moisture availability.

When looking at the suitability ratings as a result of physical soil properties, several points catch the attention. First of all barley, grape, olive, and wheat show uniform suitability values (mainly s3) with little variation between the LMU(S)s. This means that these crops have a relatively wide range of requirements, allowing them to grow on all land mapping units despite differences in LQ values. In combination with their high climate suitability rating, it is probably no coincidence that these crops are mentioned in *chapter 3.3* as the most popular Mediterranean crops.

Secondly, there appears to be a similarity between the LMUs. For example, units 43b, 64, and 83, often show the same suitability class. When looking at their LQ values, one notices that these units are characterized by steep slopes and slope related properties that often prove limiting (e.g. RUSLE values, see *figure 5.4*). This similarity in LMU properties is even more pronounced for units 64, 65, and 65a, and units 80, 80a, 82a, and 83 (if slope is not the limiting factor for 64 and 83). These two combinations have very similar values for example for stone content, porosity, and $CaCO_3$, where in general the latter combination is less limiting for the LUTs under consideration. This similarity between units is not surprising because, although they show enough difference to be classified as separate soil units, they are the result of the same process: i.e. 64, 65, and 65a are all marine deposits and 80, 80a, 82a, and 83 are all fluvial deposits. In future research it should therefore be considered to combine this type of units.

Lastly it should be noted that not only the lack of precipitation limits the suitability of citrus, maize, tobacco, and tomato: they (sugar beet being the exception) are also severely limited by the physical properties of some LMUs (notably 27b, 64, 65 and 65a).

6.2 Recommended land utilization types

The suitability maps and *table 5.3* demonstrate that none of the crop types scored a S1 suitability on any of the mapping units, and only olive, sugar beet, and wheat show a S2 suitability for a small percentage of the study area. For most land units the optimum land suitability rating that can be achieved by crops is S3. Since citrus, maize, tobacco, and tomato all have a maximum suitability class of N1 or lower, they are not suited for cultivation as rain fed crop in this area.

The most suitable crops for each land unit (or the most suitable land units for a crop) can be obtained from the suitability maps in *section 5.4*. In general, the fluvial deposits defined as units 80, 80a, and 82a show the highest suitability ratings per LUT. The physical suitability of these units is never below S3. Fluvial deposit unit 83 forms an exception because of its location on steep slopes, resulting in high potential erosion. *Figure 6.1*, *table 6.2* and *table 6.3* below give overviews of the best LUT per LMU/LMUS.

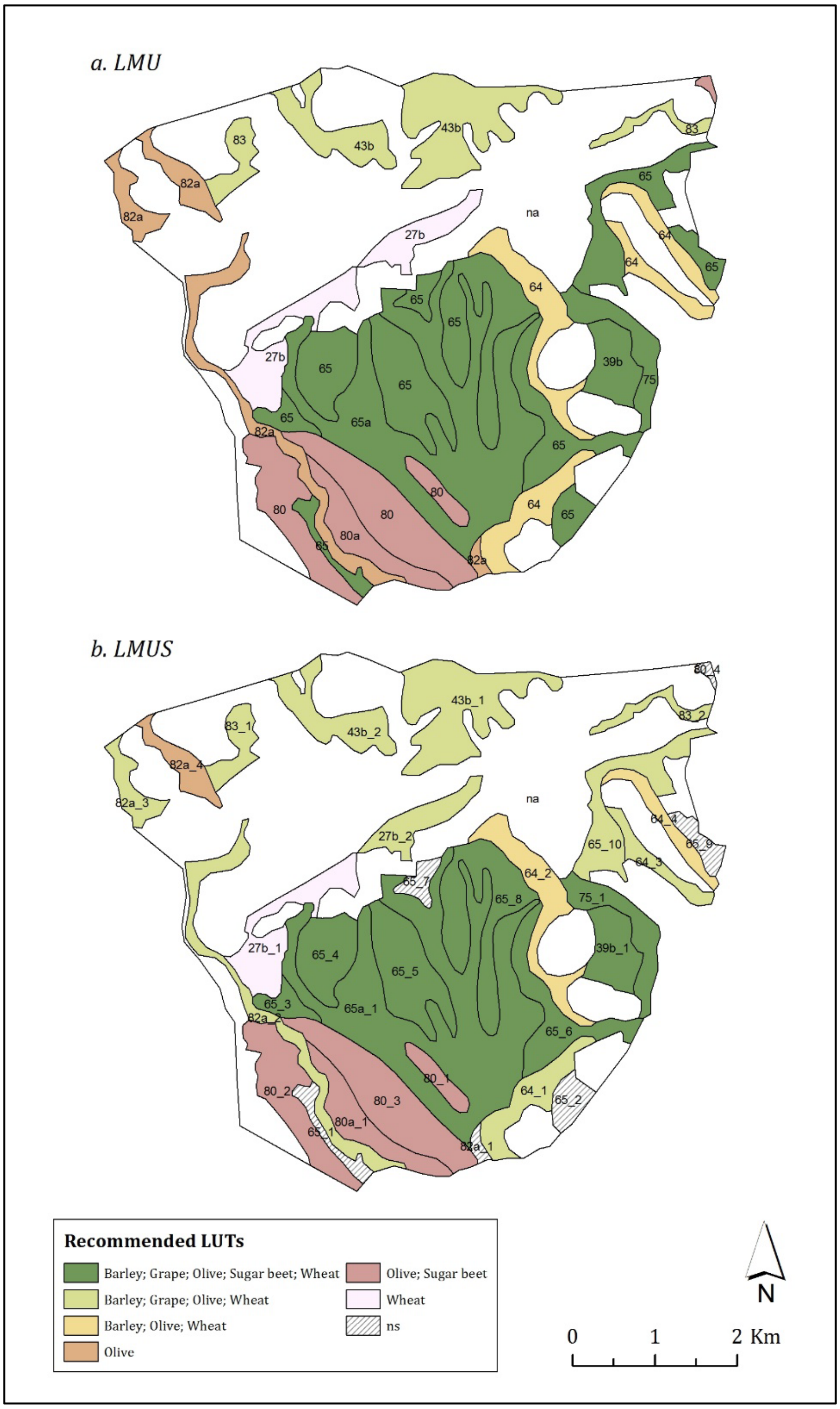


Figure 6.1: *Map a shows recommended crop types per LMU; map b per LMUS.*

Table 6.2: *Optimum crop types for each LMU.*

LMU	S2	S3
27b	Wheat	Barley; Grape; Olive; Sugar beet
39b		Barley; Grape; Olive; Sugar beet; Wheat
43b		Barley; Grape; Olive; Wheat
64		Barley; Olive; Wheat
65		Barley; Grape; Olive; Sugar beet; Wheat
65a		Barley; Grape; Olive; Sugar beet; Wheat
75		Barley; Grape; Olive; Sugar beet; Wheat
80	Olive; Sugar beet	Barley; Grape; Wheat
80a	Olive; Sugar beet	Barley; Grape; Wheat
82a	Olive	Barley; Grape; Olive; Wheat
83		Barley; Grape; Olive; Wheat

Table 6.3: *Optimum crop types for each LMUS.*

LMUS	S2	S3
27b_1	Wheat	Barley; Grape; Olive; Sugar beet
27b_2		Barley; Grape; Olive; Wheat
39b_1		Barley; Grape; Olive; Sugar beet; Wheat
43b_1		Barley; Grape; Olive; Wheat
43b_2		Barley; Grape; Olive; Wheat
64_1		Barley; Grape; Olive; Wheat
64_2		Barley; Olive; Wheat
64_3		Barley; Grape; Olive; Wheat
64_4		Barley; Olive; Wheat
65_10		Barley; Grape; Olive; Wheat
65_3		Barley; Grape; Olive; Sugar beet; Wheat
65_4		Barley; Grape; Olive; Sugar beet; Wheat
65_5		Barley; Grape; Olive; Sugar beet; Wheat
65_6		Barley; Grape; Olive; Sugar beet; Wheat
65_8		Barley; Grape; Olive; Sugar beet; Wheat
65a_1		Barley; Grape; Olive; Sugar beet; Wheat
75_1		Barley; Grape; Olive; Sugar beet; Wheat
80_1	Olive; Sugar beet	Barley; Grape; Wheat
80_2	Olive; Sugar beet	Barley; Grape; Wheat
80_3	Olive; Sugar beet	Barley; Grape; Wheat
80a_1	Olive; Sugar beet	Barley; Grape; Wheat
82a_2		Barley; Grape; Olive; Wheat
82a_3		Barley; Grape; Olive; Wheat
82a_4	Olive	Barley; Grape; Sugar beet; Wheat
83_1		Barley; Grape; Olive; Wheat
83_2		Barley; Grape; Olive; Wheat

6.3 Possible improvements

Table 5.6 and *table 5.7* show the number and percentages of crop limitations. The land qualities: nutrient availability, moisture availability, and erosion hazard are the most common and account for 66.2% of the total number of limitations for LMUs (67.4% for LMUSs). Improving these land qualities will have a positive effect on overall suitability ratings.

The most important limiting quality is nutrient availability, with a share of 31.7% (34% for LMUS) of all limitations. Organic matter content and pH were both employed as diagnostic factors for this LQ. Because the study area consists for a large part of calcareous soils, high pH values are often limiting. A pH of above 8 is considered high for most crops and results in a lower availability of nutrients for the crops. Improving this LQ can be achieved by lowering pH or adding nutrients to the soil. Lowering pH can be done by adding acids to the soil, and increasing nutrient availability by applying phosphorus, iron, copper, and zinc to the soil. Adding anhydrous ammonia seems to be the best solution since it serves as a nitrogen fertilizer and at the same time lowers pH (USDA, 1998).

The second most limiting quality is moisture availability. 21.6% (13.7% for LMUS) of the limitations are the result of the characteristic lack of precipitation during summer in the Mediterranean. Applying irrigation to the area can improve this land quality. However, since irrigation is not a recommendable practice, it should be avoided as much as possible (see *chapter 1*).

With 12.9% (19.7% for LMUS), erosion hazard is also an important limiting factor. As stated by the FAO, the goal of every land evaluation procedure is to minimize land degradation and erosion. There are numerous prevention measures for erosion, for example contour farming and terracing. These measures should be taken especially in areas vulnerable to erosion, i.e. areas with steep slopes.

These proposed improvements will increase the suitability rating of the land for crops. An essential part of implementing improvements is determining if they are cost effective. Obviously the increase of yields and subsequently revenues should outweigh costs of the improvements. This study, however, entails a qualitative evaluation procedure (see *section 3.1.1*), which means that no quantitative estimation of crop yields (both present and after improvements) is made. Furthermore, no economic or social analysis is performed. Since yields and their proceedings are unknown it is difficult to establish whether it is economically viable to improve land qualities. In addition, a social analysis can assess if local farmers are willing and knowledgeable enough to implement the improvements. To produce accurate and useful land improvement advice, it is therefore recommended to perform a qualitative land evaluation with an economic and social analysis.

6.4 Differences between suitability and present land use

The present land use corresponds for a large part with the most suitable crops for this area. According to the land use classification, grape, olive, and wheat make up 66% of agricultural land uses. These crops are deemed marginally suitable for most areas and in some cases even moderately suitable. The remaining 34% of present land use does not concern crop cultivation, but consists of bare soil and grassland.

As alternatives for present land use barley and sugar beet are suggested. Barley is considered marginally suitable on all LMUs, sugar beet has the same and sometimes an even higher suitability. These suitability ratings however, are not higher than the ratings for present land use. Therefore, an economic analysis should prove useful to determine which of these equally suitable land uses is the most profitable.

Chapter 7

DISCUSSION

This chapter will discuss the following topics: LQs and their outliers, remarks on the land cover classification procedure, and a discussion of the differences between LQ values on the LMU and LMUS scale.

7.1 LQs

When dividing the research area into land mapping units based on the soil map, the assumption is made that these units have similar LQ values. The soil map that was used also takes into account topographic factors such as slope and elevation (Bonfils, 1993). Because of this assumption it was decided to remove outlying LQ values from the dataset. Standard deviations were calculated for each LQ and each LMU, when a value exceeded two times the standard deviation it was considered an outlier. Only the diagnostic factors of stone content (contained 3 outliers), organic matter (4), dry bulk density (10), and porosity (10) contained outliers. Some possible causes of outliers per diagnostic factor are discussed below.

Outliers in stone content are probably the result of human activities: to preserve heat, farmers frequently add stones that they remove from cereal fields and grassland to vineyards.

To calculate dry bulk density and porosity the same samples are used, therefore when one of them is an outlier the other is also removed from the dataset. Outliers for these factors are probably the result of disturbances of the soil structure during sampling. The structure needs to remain intact otherwise the sample cannot be completely saturated.

The organic matter outliers are probably the result of contamination of the samples with material such as leaves, roots, or other material that is lost while heating the sample to 450°C.

Gravimetric rings are used to take samples with an intact soil structure to determine DBD and porosity. However, some of the soil units in the study area have a high stone content, which can make it very troublesome to fill the sample rings with an undisturbed sample. As a result it was not possible to acquire an undisturbed gravimetric sample at all of the sample locations. For LMU 43b and 80 no gravimetric samples were taken at half of the locations. With such a decrease in sample size one can question the reliability of the obtained DBD and porosity values for these units. This becomes even more problematic when LMUs are further subdivided into LMUSs.

7.2 Land classification

The land cover classification was performed with the goal to classify the agricultural land use of the study area. The aim is to compare present agricultural land use with the most suitable alternative LUTs according to the land evaluation. The final result has an overall accuracy of 52.1% for agricultural land uses, which is considered to be low. Overall accuracy is especially affected by the confusion of the classes: bare soil & vineyard, and grassland & vineyard. The identification of other classes is much more reliable.

Accuracy of the classification could be improved by using an image with higher resolution and more spectral bands. Agricultural plots in the study area are relatively small and show a lot of variation. When the 30x30 pixels of the Landsat 7 image are joined into objects these easily exceed the size of the agricultural plots under consideration.

Furthermore, agriculture in the study area is dominated by viticulture. Based on field experience, it is assumed that the classification of 47% of the area as vineyard is an underestimation. During the field survey it was difficult to find plots with other land uses. This is expressed in the training and validation sets where objects for orchards, wheat, bare soil, and grassland are underrepresented. To improve the results, more of those objects should be included.

Another difficulty is the abundance of bare soil in the area. For example, vineyards are planted in rows spaced between 1 and 2 meters apart with little soil cover in between. The same goes for orchards, where trees are even further spaced apart. Because of their size each pixel therefore contains a fair amount of bare soil. In addition, the image was acquired in October after the dry summer and harvest period. This means a lot of plots showed remains of crop cover (for example wheat), but were essentially bare. The problem with this is that practically bare training plots are assigned a specific land use class.

Nonetheless, in accordance with the literature (Bonfils, 1993) and field survey observations, the major part of the image is classified as vineyard.

7.3 Differences in scale level (LMU vs. LMUS)

Originally, two levels of land mapping units were recognized for this land evaluation: the whole study area (for climatic properties) and soil units (for physical soil properties). However, some of these soil units are not continuous but consist of several separated components (see *figure 4.2*). During the evaluation procedure it was noticed that average LQ values for these components varied. *Figure 7.1* shows average values of four land qualities on the LMU and LMUS scale to illustrate this variation (note that units 39b, 65a, 75, and 80a are 'single' units, meaning that the LMU and LMUS are identical). Subdivisions of LMU 64 and 65 are examples of units that show a large variation from their parent unit.

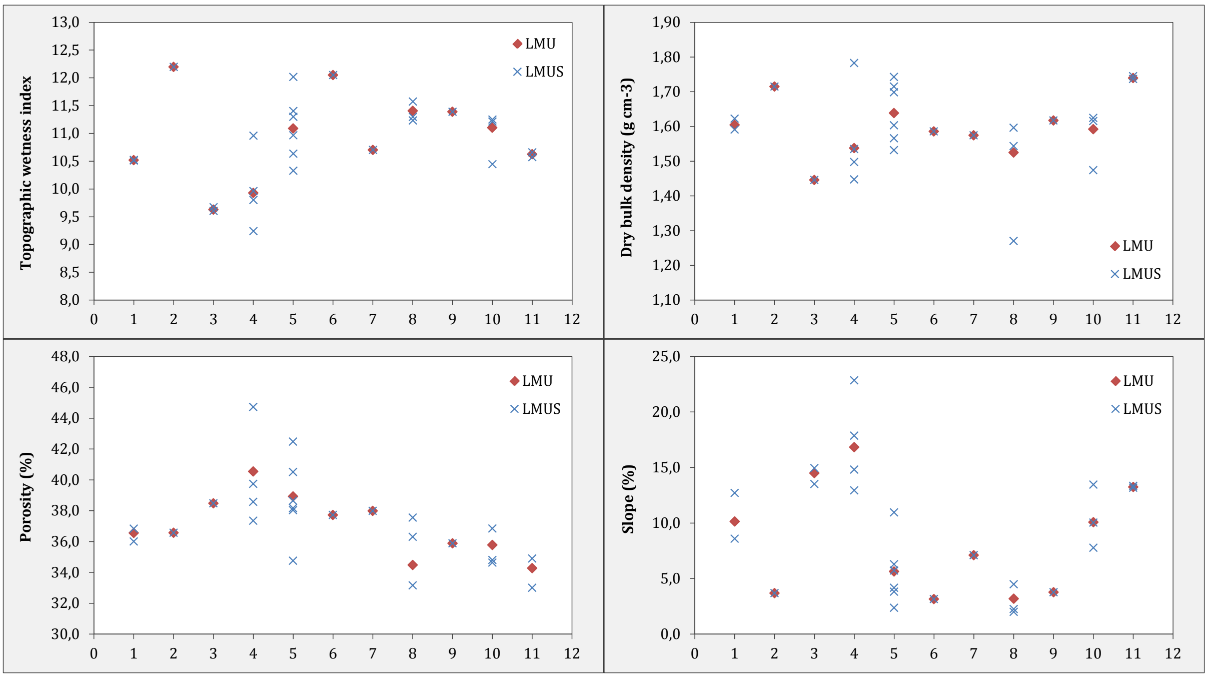


Figure 7.1: *Plots show the average value of each LMU and LMUS for TWI, DBD, porosity and slope (1 = 27b, 2 = 39b, 3 = 43b, 4 = 64, 5 = 65, 6 = 65a, 7 = 75, 8 = 80, 9 = 80a, 10 = 82a, 11 = LMU 83).*

Since the goal of defining LMUs is to create units that are as homogeneous as possible, the subdivided soil units were included as land mapping units (LMUS). The advantage of this, is smaller but more homogeneous units and thus a more reliable suitability result. The downside, however, is that the sample size per LMUS decreases in comparison with the LMU sample size. Furthermore, the field campaign was based on LMUs, with as result that not all LMUSs are equally sampled (e.g. LMUS 80_1 has only 2 samples while 80_3 has 12). This disadvantage does not apply to TWI and RUSLE since they do not use soil samples as input.

Suitability ratings were calculated for both scale levels to evaluate the effect of scale on the final result. *Table 7.1* shows the differences between LMU and LMUS in suitability classes as a measure of area. The table demonstrates that only four of the nine LUTs show a (minor) difference in suitability rating, with only sugar beet showing a difference larger than 10%. Even though the variations in suitability ratings are small, the limiting land qualities of the involved land units were examined to determine the cause of the changes. In total 11 LMUS showed an altered suitability rating, of which all but one were caused by changes in slope and RUSLE values. Because the RUSLE is also partly a function of slope (LS factor), this means that the main reason for changes in suitability between scale levels is variation in slope. So we can say that although LQ values vary per scale level, these differences mostly fall within the range of the LUR rating values and therefore do not affect suitability rating, with as notable exception slope (and RUSLE). In the case of LQs that depend on soil sampling, it is sensible to determine their values on the LMU scale (i.e. soil map units) to keep the sampling size as large as possible. If possible, slope or factors that depend on slope (RUSLE, TWI), should be assessed on a smaller scale to include their effect more accurately.

Table 7.1: *Differences in suitability in percentages of area (LMU – LMUS).*

LUT	S1	S2	S3	N1	N2
Barley	0	0	0	0	0
Citrus	0	0	0	0	0
Grape	0	0	+4,3	0	-4,3
Maize	0	0	0	0	0
Olive	0	-5,6	+5,6	0	0
Sugar beet	0	0	-12,0	+12,0	0
Tobacco	0	0	0	0	0
Tomato	0	0	0	0	0
Wheat	0	-2,3	+2,3	0	0

Chapter 8

CONCLUSIONS

The land evaluation results indicate that the study area in the Peyne catchment in general is marginally suitable (S3) for rain fed agriculture. The most suitable crops are barley, grape, olive, sugar beet, and wheat. Cultivation of citrus, maize, tomato, and tobacco should be avoided because they are severely limited both by climatic and physical soil properties.

The most suitable land mapping units are formed by soil units 80, 80a, and 82a. These fluvial deposits possess the highest physical suitability for each LUT. Because of this, they form the most valuable agricultural units.

The most limiting factors for crop suitability are availability of nutrients, moisture availability, and erosion hazard. Although it is relatively easy to improve these factors, a quantitative and economic analysis should be performed first to ascertain whether these improvements are cost effective.

Performing a land evaluation on the LMU or LMUS scale did not result in large variations in suitability rating, slope and slope related land qualities being the exception. Because slope is a highly varying factor, the smaller LMUS scale is more suited to demonstrating its effects on crop suitability.

The majority of present land use, i.e. grape, olive, and wheat, corresponds with the most suitable land utilization types. Considering their suitability rating, barley and sugar beet are possible alternatives. An economic analysis should be performed to see if they are also profitable alternatives.

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APPENDIX A

Land use requirement tables

Legends for requirement tables

Both texture and drainage are expressed in classes. In the LUR tables these are denoted by numbers. The tables below show the numbers and their associated classes.

Table A.1: *Shows texture class and associated number and abbreviation.*

No.	Texture class	Abb.
1	Gravel	G
2	Coarse sand	CS
3	Medium sand	MS
4	Fine sand	FS
5	Loamy sand	LS
6	Sandy loam	SL
7	Loam	L
8	Sandy clay loam	SCL
9	Silt loam	SiL
10	Silt	Si
11	Clay loam	CL
12	Silty clay loam	SiCL
13	Sandy clay	SC
14	Koalinitic clay	KC
15	Silty clay	SiC
16	Clay	C
17	Montmorillonitic clay, structured	MCs
18	Montmorillonitic clay, massive	MCm

Table A.2: *Shows drainage class and associated number and abbreviation.*

No.	Drainage class	Abb.
1	Excessively well drained	E
2	Somehat excessively drained	SE
3	Well drained	W
4	Moderately well drained	MW
5	Imperfectly drained	I
6	Poorly drained	P
7	Very poorly drained	VP

A.3: Barley

Length growing period (days): 90 - 240 Dormancy: Dec/Jan/Feb
Start growing period/End growing period: Nov/Jun

LUR/LQ	s1	s2	s3	n1	n2	Source
2. Temperature regime (c)						
Mean T growing season (°C)	15-20	10-15 / 20-23	5-10	-	<5 / >23	Hees et al. (1987)
Mean T vegetative stage (Mar)(°C)	6-18	4-6 / 18-24	2-4 / 24-28	-	<2 / >28	Sys et al. (1993)
Mean T flowering stage (Apr)(°C)	12-26	10-12 / 26-32	8-10 / 32-36	-	<8 / >36	Sys et al. (1993)
Mean T ripening stage (May/Jun)(°C)	14-30	12-14 / 30-36	10-12 / 36-42	-	<10 / >42	Sys et al. (1993)
3. Moisture availability (m)						
Annual precipitation (mm)	500-1000	350-500 / 1000-1500	200-350 / 1500-2000	<200 / >2000	-	FAO (2007)
Precipitation growing season (mm)	300-1100	200-300 / 1100-1300	150-200 / 1300-1500	<150 / >1500	-	Sys et al. (1993)
Monthly precipitation vegetative stage (Mar)(mm)	15-95	10-15 / 95-120	5-10 / >120	<5	-	Sys et al. (1993)
Monthly precipitation flowering stage (Apr)(mm)	20-90	10-20 / 90-120	<10 / >120	-	-	Sys et al. (1993)
4. Oxygen availability to roots (w)						
Soil drainage class	3-5	-	2-3 / 5-6	-	<2 / >6	Hees et al. (1987)
5. Nutrient availability (n)						
pH	6-7,5	5,5-5,9 / 7,5-8	5,2-5,5 / 8-8,5	-	<5,2 / >8,5	Hees et al. (1987)
Organic matter (%)	>0,4	<0,4	-	-	-	Sys et al. (1993)
6. Nutrient retention (n)						
Cation Exchange Capacity (meq/100 gr)	>16	<16	-	-	-	Sys et al. (1993)
7. Rooting conditions (r)						
Texture (class)	7-14	14-18	6-7	-	<6 / >18	Hees et al. (1987)
Stones (%)	0-15	15-35	35-55	-	>55	Sys et al. (1993)
14, Soil toxicities (x)						
CaCO3 (%)	0-30	30-40	40-60	-	>60	Sys et al. (1993)
17, Potential for mechanization (q)						
Slope (%)	0-8	8-16	16-24	24-30	>30	Sys et al. (1993)
24, Erosion hazard (e)						
RUSLE (t ha^{-1} yr^{-1})	0-12	12-25	25-50	50-100	>100	Hees et al. (1987)

A.4: Citrus

Length growing period (days): 365
Start growing period/End growing period: Jan/Dec

LUR/LQ	s1	s2	s3	n1	n2	Source
2. Temperature regime (c)						
Mean annual T (°C)	19-33	16-19 / 33-36	13-16 / 36-39	-	<13 / >39	Sys et al. (1993)
Mean T growing season (°C)	23-30	18-23	13-18 / 30-35	-	<13 / >35	Hees et al. (1987)
No. of months with mean T > 38 °C	0-3	3-5	5-7	-	>7	Sys et al. (1993)
No. of months with mean T < 13 °C	0-3	3-5	5-7	-	>7	Sys et al. (1993)
Absolute min T (°C)	>-4	-4--7,5	-7,5--9,5	-	<-9,5	Sys et al. (1993)
Mean T in 2 months after harvest (Mar/Apr)	8-18	6-8 / 18-20	4-6 / 20-25	-	<4 / >25	Sys et al. (1993)
3. Moisture availability (m)						
Annual precipitation (mm)	>1200	1000-1200	800-1000	<800	-	Sys et al. (1993)
No. of dry months (P < 0.5 PET)	0-4	4-6	6-7	-	>7	Sys et al. (1993)
4. Oxygen availability to roots (w)						
Soil drainage class	3-4	4-6	2-3	-	<2 / >6	Hees et al. (1987)
5. Nutrient availability (n)						
pH	5,5-7	7-8	5,2-5,5 / 8-8,2	-	<5,2 / >8,2	Hees et al. (1987)
Organic matter (%)	>0,8	<0,8	-	-	-	Sys et al. (1993)
6. Nutrient retention (n)						
Cation Exchange Capacity (meq/100 gr)	>16	<16	-	-	-	Sys et al. (1993)
7. Rooting conditions (r)						
Texture (class)	5-8	8-15	3-5 / 15-16	-	<3 / >16	Hees et al. (1987)
Stones (%)	0-15	15-35	35-55	-	>55	Sys et al. (1993)
14, Soil toxicities (x)						
CaCO3 (%)	0-5	5-10	10-25	-	>25	Sys et al. (1993)
17, Potential for mechanization (q)						
Slope (%)	0-8	8-16	16-30	30-50	>50	Sys et al. (1993)
24, Erosion hazard (e)						
RUSLE (t ha^{-1} yr^{-1})	0-12	12-25	25-50	50-100	>100	Hees et al. (1987)

A.5: Grape

Length growing period (days): 160 - 205
Start growing period/End growing period: Mar/Sep

LUR/LQ	s1	s2	s3	n1	n2	Source
2. Temperature regime (c)						
Mean T growing season (°C)	20-25	15-20 / 25-30	-	-	<15 / >30	Hees et al. (1987)
3. Moisture availability (m)						
Annual precipitation (mm)	700-850	550-700 / 850-1025	400-550 / 1025-1200	<400 / >1200	-	FAO (2007)
4. Oxygen availability to roots (w)						
Soil drainage class	3-4	4-5	2-3 / 5-6	-	<2 / >6	Hees et al. (1987)
5. Nutrient availability (n)						
pH	6-8,2	-	5,2-6 / 8,2-8,5	-	<5,2 / >8,5	Ye et al. (2004)
Organic matter (%)	>0,4	<0,4	-	-	-	Ye et al. (2004)
6. Nutrient retention (n)						
Cation Exchange Capacity (meq/100 gr)	>16	<16	-	-	-	Ye et al. (2004)
7. Rooting conditions (r)						
Texture (class)	6-16	3-6	2-3 / 16-17	-	<2 / >17	Hees et al. (1987)
Stones (%)	0-35	35-55	55-75	-	>75	Sys et al. (1993)
14, Soil toxicities (x)						
CaCO3 (%)	0-30	30-40	40-60	-	>60	Ye et al. (2004)
17, Potential for mechanization (q)						
Slope (%)	0-4	4-8	8-16	-	>16	Sys et al. (1993)
24, Erosion hazard (e)						
RUSLE (t ha^{-1} yr^{-1})	0-12	12-25	25-50	50-100	>100	Hees et al. (1987)

A.6: Maize

Length growing period (days): 90 - 130
Start growing period/End growing period: May/Sep

LUR/LQ	s1	s2	s3	n1	n2	Source
2. Temperature regime (c)						
Mean T growing season (°C)	18-32	16-18 / 32-35	14-16 / 35-40	-	<14 / >40	Sys et al. (1993)
Mean T vegetative stage (Mar)(°C)	12-24	9-12 / 24-28	7-9 / 28-30	-	<7 / >30	Sys et al. (1993)
3. Moisture availability (m)						
Annual precipitation (mm)	600-1200	500-600 / 1200-1500	400-500 / 1500-1800	<400 / >1800	-	FAO (2007)
Precipitation growing season (mm)	500-1200	400-500 / 1200-1600	300-400 / >1600	<300	-	Sys et al. (1993)
Precipitation 1st month GS (mm)	100-295	75-100 / 295-400	60-75 / 400-475	<60 / >475	-	Sys et al. (1993)
Precipitation 2nd month GS (mm)	150-310	120-150 / 310-400	70-120 / 400-475	<70 / >475	-	Sys et al. (1993)
Precipitation 3rd month GS (mm)	150-310	120-150 / 310-400	70-120 / 400-475	<70 / >475	-	Sys et al. (1993)
Precipitation 4th month GS (mm)	100-285	80-100 / 285-400	60-80 / 400-475	<60 / >475	-	Sys et al. (1993)
4. Oxygen availability to roots (w)						
Soil drainage class	3-5	-	2-3 / 5-6	-	<2 / >6	Hees et al. (1987)
5. Nutrient availability (n)						
pH	6-7	5,5-6 / 7-8,2	5,2-5,5	-	<5,2 / >8,2	Hees et al. (1987)
Organic matter (%)	>0,4	<0,4	-	-	-	Sys et al. (1993)
6. Nutrient retention (n)						
Cation Exchange Capacity (meq/100 gr)	>16	<16	-	-	-	Sys et al. (1993)
7. Rooting conditions (r)						
Texture (class)	7-14	14-17	4-7 / 17-18	-	<4 / >18	Hees et al. (1987)
Stones (%)	0-15	15-35	35-55	-	>55	Sys et al. (1993)
14, Soil toxicities (x)						
CaCO3 (%)	0-15	15-25	25-35	-	>35	Sys et al. (1993)
17, Potential for mechanization (q)						
Slope (%)	0-8	8-16	16-30	30-50	>50	Sys et al. (1993)
24, Erosion hazard (e)						
RUSLE (t ha^{-1} yr^{-1})	0-12	12-25	25-50	50-100	>100	Hees et al. (1987)

A.7: Olive

Length growing period (days): 210 - 270
Start growing period/End growing period: Mar/Nov

LUR/LQ	s1	s2	s3	n1	n2	Source
2. Temperature regime (c)						
Mean T growing season (°C)	20-25	15-20 / 25-30	30-35	-	<15 / >35	Hees et al. (1987)
Mean annual T (°C)	15-22	14-15 / 22-24	13-14 / 24-26	-	<13 / >26	Sys et al. (1993)
Average absolute min T of coldest month (°C)	-4-2	-6--4 / 2-4	-8--6 / 4-6	-	<-8 / >6	Sys et al. (1993)
3. Moisture availability (m)						
Annual precipitation (mm)	400-700	300-400 / 700-950	200-300 / 950-1200	<200 / >1200	-	FAO (2007)
Monthly prec during sclerification of stone (Aug)	>20	<20	-	-	-	Sys et al. (1993)
Monthly prec during sclerification of stone (Sep)	>15	<15	-	-	-	Sys et al. (1993)
4. Oxygen availability to roots (w)						
Soil drainage class	3-4	<3 / >4	-	-	-	Hees et al. (1987)
5. Nutrient availability (n)						
pH	6-7,5	5,5-6 / 7,5-8	5-5,5 / 8-8,5	-	<5 / >8,5	FAO (2007)/Sys et al. (1993)
Organic matter (%)	>0,8	0,4-0,8	<0,4	-	-	Sys et al. (1993)
6. Nutrient retention (n)						
Cation Exchange Capacity (meq/100 gr)	>16	<16	-	-	-	Sys et al. (1993)
7. Rooting conditions (r)						
Texture (class)	3-9	9-16	2-3	-	<2 / >16	Hees et al. (1987)
Stones (%)	0-35	35-55	55-75	-	>75	Sys et al. (1993)
14, Soil toxicities (x)						
CaCO3 (%)	0-101	-	-	-	-	Sys et al. (1993)
17, Potential for mechanization (q)						
Slope (%)	0-16	16-30	30-50	-	>50	Sys et al. (1993)
24, Erosion hazard (e)						
RUSLE (t ha^{-1} yr^{-1})	0-12	12-25	25-50	50-100	>100	Hees et al. (1987)

A.8: Sugar beet

Length growing period (days): 60 - 140
Start growing period/End growing period: May/Sep

LUR/LQ	s1	s2	s3	n1	n2	Source
2. Temperature regime (c)						
Mean T growing season (°C)	18-22	14-18 / 22-26	10-14 / 26-30	-	<10 / >30	Hees et al. (1987)
Absolute min T initial stage (May)(°C)	>-6	-8--6	-10--8	-	<-10	Sys et al. (1985)
Average daily max T coldest month (°C)	11-21	11-12 / >21	10-11	-	<10	Sys et al. (1985)
3. Moisture availability (m)						
Annual precipitation (mm)	600-800	550-600 / 800-900	500-550 / 900-1000	<500 / >1000	-	FAO (2007)
4. Oxygen availability to roots (w)						
Soil drainage class	3-4	<3 / >4	-	-	-	Hees et al. (1987)
5. Nutrient availability (n)						
pH	6-7	7-8	5,8-6 / 8-8,5	-	<5,8 / >8,5	Hees et al. (1987)
Organic matter (%)	>0,4	<0,4	-	-	-	Sys et al. (1985)
6. Nutrient retention (n)						
Cation Exchange Capacity (meq/100 gr)	>16	<16	-	-	-	Sys et al. (1985)
7. Rooting conditions (r)						
Texture (class)	6-13	13-16	5-6 / 16-17	-	<5 / >17	Hees et al. (1987)
Stones (%)	0-15	15-35	35-55	-	>55	Sys et al. (1985)
14, Soil toxicities (x)						
CaCO3 (%)	0-30	30-40	40-60	-	>60	Sys et al. (1985)
17, Potential for mechanization (q)						
Slope (%)	0-8	8-16	16-30	30-50	>50	Sys et al. (1985)
24, Erosion hazard (e)						
RUSLE (t ha^{-1} yr^{-1})	0-12	12-25	25-50	50-100	>100	Hees et al. (1987)

A.9: Tobacco

Length growing period (days): 70 - 150
Start growing period/End growing period: May/Sep

LUR/LQ	s1	s2	s3	n1	n2	Source
2. Temperature regime (c)						
Mean T growing season (°C)	20-30	15-20 / 30-32	32-35	-	<15 / >35	Hees et al. (1987)
3. Moisture availability (m)						
Annual precipitation (mm)	500-750	425-500 / 750-1875	350-425 / 1875-3000	<350 / >3000	-	FAO (2007)
Precipitation growing season (mm)	600-1200	500-600 / 1200-1400	400-500 / >1400	<400	-	Sys et al. (1993)
4. Oxygen availability to roots (w)						
Soil drainage class	3-5	-	2-3 / 5-6	-	<2 / >6	Hees et al. (1987)
5. Nutrient availability (n)						
pH	5,5-6,5	5-5,5 / 6,5-7,5	-	-	<5 / >7,5	Hees et al. (1987)
Organic matter (%)	>1,2	0,8-1,2	<0,8	-	-	Sys et al. (1993)
6. Nutrient retention (n)						
Cation Exchange Capacity (meq/100 gr)	>16	<16	-	-	-	Sys et al. (1993)
7. Rooting conditions (r)						
Texture (class)	3-13	13-16	-	-	<3 / >16	Hees et al. (1987)
Stones (%)	0-15	15-35	35-55	-	>55	Sys et al. (1993)
14, Soil toxicities (x)						
CaCO3 (%)	0-2	2-5	5-10	-	>10	Sys et al. (1993)
17, Potential for mechanization (q)						
Slope (%)	0-8	8-16	16-30	30-50	>50	Sys et al. (1993)
24, Erosion hazard (e)						
RUSLE (t ha^{-1} yr^{-1})	0-12	12-25	25-50	50-100	>100	Hees et al. (1987)

A.10: Tomato

Length growing period (days): 70 - 150
Start growing period/End growing period: May/Sep

LUR/LQ	s1	s2	s3	n1	n2	Source
2. Temperature regime (c)						
Mean T growing season (°C)	18-25	15-18 / 25-27	27-28	-	<15 / >28	Hees et al. (1987)
Mean T germinstion (°C)	16-30	12-16 / 30-32	10-12 / 32-35	-	<10 / >35	Sys et al. (1993)
Mean T yield forming period (Jul/Aug)(°C)	16-22	14-16 / 22-27	12-14 / 27-32	-	<12 / >32	Sys et al. (1993)
3. Moisture availability (m)						
Annual precipitation (mm)	600-1300	500-600 / 1300-1550	400-500 / 1550-1800	<400 / >1800	-	FAO (2007)
Precipitation growing season (mm)	400-700	300-400 / 700-800	200-300 / >800	<200	-	Sys et al. (1993)
4. Oxygen availability to roots (w)						
Soil drainage class	3-5	5-6	-	-	<2 / >6	Hees et al. (1987)
5. Nutrient availability (n)						
pH	5-7	4,5-5 / 7-8	4-4,5	-	<4 / >8	Hees et al. (1987)
Organic matter (%)	>1,2	0,8-1,2	<0,8	-	-	Sys et al. (1993)
6. Nutrient retention (n)						
Cation Exchange Capacity (meq/100 gr)	>16	<16	-	-	-	Sys et al. (1993)
7. Rooting conditions (r)						
Texture (class)	7-13	5-7 / 13-16	4-5 / 16-17	-	<4 / >17	Hees et al. (1987)
Stones (%)	0-15	15-35	35-55	-	>55	Sys et al. (1993)
14, Soil toxicities (x)						
CaCO3 (%)	0-5	5-10	10-25	-	>25	Sys et al. (1993)
17, Potential for mechanization (q)						
Slope (%)	0-8	8-16	16-30	30-50	>50	Sys et al. (1993)
24, Erosion hazard (e)						
RUSLE (t ha^{-1} yr^{-1})	0-12	12-25	25-50	50-100	>100	Hees et al. (1987)

A.11: Wheat

Length growing period (days): 90 - 250
Start growing period/End growing period: Nov/Jun
Dormancy: Dec/Jan/Feb

LUR/LQ	s1	s2	s3	n1	n2	Source
2. Temperature regime (c)						
Mean T growing season (°C)	12-23	10-12 / 23-25	8-10 / 25-30	-	<8 / >30	Sys et al. (1993)
Mean T vegetative stage (Mar)(°C)	6-18	4-6 / 18-24	2-4 / 24-28	-	<2 / >28	Sys et al. (1993)
Mean T flowering stage (Apr)(°C)	12-26	10-12 / 26-32	8-10 / 32-36	-	<8 / >36	Sys et al. (1993)
Mean T ripening stage (May/Jun)(°C)	14-30	12-14 / 30-36	10-12 / 36-42	-	<10 / >42	Sys et al. (1993)
3. Moisture availability (m)						
Annual precipitation (mm)	750-900	525-750 / 900-1250	300-525 / 1250-1600	<300 / >1600	-	FAO (2007)
Precipitation growing season (mm)	350-1250	250-350 / 1000-1250	200-250 / 1500-1750	<200 / >1750	-	Sys et al. (1993)
Monthly precipitation vegetative stage (Mar)	20-120	12-20 / >120	8-12	<8	-	Sys et al. (1993)
Monthly precipitation flowering stage (Apr)	30-120	15-30 / >120	10-15	<10	-	Sys et al. (1993)
4. Oxygen availability to roots (w)						
Soil drainage class	3-5	-	2-3 / 5-6	-	<2 / >6	Hees et al. (1987)
5. Nutrient availability (n)						
pH	6-8,2	-	5,2-6 / 8,2-8,5	-	<5,2 / >8,5	Hees et al. (1987)
Organic matter (%)	>0,4	<0,4	-	-	-	Sys et al. (1993)
6. Nutrient retention (n)						
Cation Exchange Capacity (meq/100 gr)	>16	<16	-	-	-	Sys et al. (1993)
7. Rooting conditions (r)						
Texture (class)	7-14	14-18	6-7	-	<6 / >18	Hees et al. (1987)
Stones (%)	0-15	15-35	35-55	-	>55	Sys et al. (1993)
14, Soil toxicities (x)						
CaCO3 (%)	0-30	30-40	40-60	-	>60	Sys et al. (1993)
17, Potential for mechanization (q)						
Slope (%)	0-8	8-16	16-30	-	>30	Sys et al. (1993)
24, Erosion hazard (e)						
RUSLE (t ha^{-1} yr^{-1})	0-12	12-25	25-50	50-100	>100	Hees et al. (1987)

APPENDIX B

Sample locations

Legends for sample locations table

Land use is expressed in classes. In the sample locations table these are denoted by a letter. Land use class and associated letter are shown in the table below. Outlying sample values are highlighted.

Table B.1: Abbreviations used in soil sample table.

Sample properties	Abb.
Sample number	No.
Land mapping unit	LMU
X-coordinate (WGS 84; UTM 31N)	X
Y-coordinate (WGS 84; UTM 31N)	Y
Land use (class)	LU
Depth of soil sample (cm)	Depth
Organic matter content (%)	OM
Texture (class)	Texture
Stones (%)	Ston.
Porosity (%)	Por.
Dry bulk density (g cm^{-3})	DBD
Calcium carbonate content (%)	$CaCO_3$

Table B.2: *Land use class and associated letter.*

Land use	LU
Vineyard	A
Olive grove	B
Bare soil	C
Wheat	D
Natural vegetation	E
Almond grove	F

Outlier

ns = no sample

Table B.3: *Soil samples taken during field campaign and their properties.*

No.	LMU	X	Y	LU	Depth	OM	Texture	Ston.	Por.	DBD	$CaCO_3$
1	65	528751	4817838	A	10	3.8	Loam	10	26.7	1.61	-
2	64	528844	4817367	D	15	3.6	Silt loam	5	34.4	1.52	-
3	64	528502	4817294	C	10	3.6	Silt loam	5	40.0	1.49	-
4	65a	528201	4817587	A	15	4.7	Loamy sand	10	35.7	1.43	-
5	80	527738	4817283	A	15	5.1	Silt loam	20	36.3	1.27	-
6	80	527234	4817188	D	ns	3.5	Silt loam	40	ns	ns	-
7	80	526844	4817401	C	20	2.6	Loamy sand	35	30.6	1.43	0.6
8	80a	527184	4816540	A	10	2.9	Loam	20	37.5	1.46	2.1
9	80a	526864	4816629	A	15	3.7	Silt loam	35	33.0	1.27	8.8
10	82a	526630	4816608	A	10	3.5	Silt loam	40	31.4	1.30	-
11	27b	526275	4820038	D	ns	3.9	Loam	40	ns	ns	-
12	27b	526046	4819717	E	20	5.4	Loam	5	36.8	1.47	11.0
13	65a	525879	4819471	B	ns	4.6	Silt loam	45	ns	ns	-
14	27b	525416	4819559	A	ns	4.1	Clay loam	20	ns	ns	2.4
15	65	526064	4819407	A	ns	2.5	Silt loam	25	ns	ns	0.7
16	65a	525736	4819029	A	10	3.4	Silt loam	20	34.3	1.38	-
17	65a	527565	4820085	D	5	4.2	Silt loam	25	37.0	1.48	-
18	65	528037	4820296	A	5	4.0	Loam	10	42.5	1.24	-
19	65a	528131	4819753	A	15	4.0	Loam	20	38.7	1.54	-
20	64	528742	4819839	A	20	5.2	Clay loam	15	39.5	1.41	-
21	75	529201	4819640	A	5	5.0	Loam	30	43.8	1.39	-
22	75	529077	4819879	A	5	2.9	Clay loam	30	39.0	1.27	-
23	82a	523852	4820767		10	6.1	Loam	15	35.4	1.49	-
24	82a	524479	4821123	B	15	5.1	Loam	10	33.3	1.60	1.2
25	83	524887	4821276	D	10	3.3	Loam	10	39.7	1.46	1.8
26	82a	523729	4821358	D	20	4.4	Silt loam	20	34.2	1.46	0.1
27	43b	526945	4821540	C	15	8.1	Loam	45	40.6	1.19	-
28	43b	526704	4821805	A	10	5.5	Loam	40	40.4	1.31	3.0
29	65	526840	4819063	D	15	2.6	Loam	5	45.7	1.50	-
30	65	527092	4818786	D	10	4.5	Loam	5	42.5	1.20	-
31	65a	527499	4818813	E	5	3.6	Loam	5	40.3	1.49	-
32	65a	526732	4818640	D	10	5.7	Loam	10	36.5	1.58	27.2
33	65a	526526	4818317	C	15	4.9	Loam	15	38.1	1.47	0.1
34	80	526313	4817842	A	15	4.6	Loam	30	33.5	1.57	0.0
35	65a	526654	4819118	D	10	3.9	Silt loam	5	39.5	1.52	29.0
36	27b	527803	4820939	A	20	3.7	Loam	15	31.7	1.66	-
37	27b	528040	4821140	A	10	4.3	Loam	25	36.9	1.61	1.2
38	27b	527540	4820700	A	15	3.8	Loam	15	35.1	1.60	7.1
39	82a	525506	4818255	A	20	3.5	Silt loam	20	39.2	1.55	-
40	80	525813	4818216	C	25	5.1	Loam	20	41.7	1.28	-
41	80	525380	4817978	A	15	3.5	Silt loam	15	39.1	1.40	-
43	64	529699	4820723	A	5	5.3	Silt loam	15	47.2	1.12	-
44	65	529681	4820399	A	10	4.8	Loam	10	38.0	1.65	-
45	64	529811	4820349	E	5	4.8	Loam	20	39.0	1.37	27.3

No.	LMU	X	Y	LU	Depth	OM	Texture	Ston.	Por.	DBD	$CaCO_3$
46	65	529558	4820232	D	5	4.2	Loam	15	41.0	1.40	-
47	75	529688	4819683	A	15	7.5	Clay loam	35	35.6	1.14	0.2
48	39b	529715	4819356	A	10	ns	Silt loam	10	35.6	1.69	-
49	39b	529499	4819554	A	10	3.3	Silt loam	15	36.2	1.51	-
51	64	528903	4818636	D	5	6.8	Loam	15	48.0	1.46	-
53	65a	528464	4818610	A	10	5.9	Silt loam	5	49.5	1.52	15.8
54	83	529810	4821928	A	10	4.7	Silt loam	25	34.8	1.63	2.4
55	83	529524	4821798	A	10	4.5	Loam	15	31.2	1.86	2.6
56	83	530746	4822019	A	ns	3.6	Loam	20	ns	ns	-
57	80	526794	4817616	A	5	4.0	Loam	15	26.6	1.85	0.7
58	80	526570	4817481	A	ns	3.6	Loam	30	ns	ns	-
59	80a	526351	4817486	A	10	4.0	Loam	20	34.5	1.55	0.1
60	80a	526243	4817262	A	15	5.2	Loam	15	35.5	1.67	-
61	43b	527655	4821839	A	ns	7.6	Clay loam	40	ns	ns	-
62	43b	527367	4821625	C	ns	ns	Loam	30	ns	ns	4.0
63	43b	527724	4821509	A	ns	8.7	Loam	45	ns	ns	-
64	39b	529408	4818799	M	10	3.8	Loam	5	41.6	1.68	14.9
65	39b	529537	4818686	M	15	4.5	Loam	5	36.2	1.77	22.1
66	39b	529592	4818870	A	10	4.6	Loam	5	41.4	1.69	10.8
67	83	525217	4821379	F	10	6.2	Loam	30	33.3	1.76	-
68	82a	524410	4821330	L	ns	5.5	Loam	35	ns	ns	-
69	80	527022	4817021	D	ns	2.6	Loam	35	ns	ns	-
70	80	526780	4816961	C	10	3.1	Loam	30	33.2	1.52	-
71	80	526704	4817031	A	ns	4.6	Loam	40	ns	ns	0.1
72	80a	526399	4816928	A	10	3.8	Loam	30	36.2	1.65	-
73	65	529389	4821047	A	10	3.0	Silt loam	5	37.2	1.73	-
74	65	529979	4821348	A	10	4.0	Silt loam	10	35.2	1.73	21.2
75	65	530161	4821320	B	10	4.0	Silt loam	10	39.4	1.50	27.8
77	27b	525228	4818971	D	15	5.3	Loam	20	35.7	1.72	19.2
78	27b	525443	4819102	N	10	4.9	Clay loam	10	36.9	1.63	-
79	27b	525662	4819233	A	10	3.9	Loam	25	37.9	1.53	9.4
80	65	528373	4819773	A	10	3.9	Loam	5	41.7	1.61	24.5
81	64	528518	4820099	A	10	3.7	Loam	10	43.2	1.53	-
82	64	528311	4820324	D	5	4.1	Loam	5	48.2	1.40	20.4
83	75	529859	4819512	A	10	5.0	Loam	30	40.5	1.62	-
84	75	530065	4819346	A	10	3.9	Loam	30	38.1	1.65	-
85	75	529897	4819179	A	10	4.5	Loam	20	46.1	1.41	-
86	75	530117	4819051		10	7.2	Silt loam	25	38.4	1.90	0.1
87	39b	529859	4818936	A	10	5.1	Silt loam	5	30.4	1.96	20.5
88	65a	528324	4819324	D	15	2.7	Silt loam	5	37.9	1.68	13.4
89	80	527520	4816718	C	ns	3.7	Loam	40	ns	ns	0.1
90	65a	527476	4817269	A	ns	3.3	Loam	30	ns	ns	-
91	65a	527725	4817809	L	10	3.1	Silt loam	5	36.1	1.68	13.4
92	65a	528220	4817916	A	20	4.3	Loam	5	37.1	1.66	-
93	65a	528157	4817261	A	10	3.2	Loam	5	45.3	1.53	4.5

No.	LMU	X	Y	LU	Depth	OM	Texture	Ston.	Por.	DBD	$CaCO_3$
94	65a	528615	4818232	L	10	7.2	Loam	5	50.4	1.43	13.0
95	65	526058	4819077	A	15	3.7	Loam	20	33.1	1.77	-
96	65	526363	4818918	A	10	4.9	Loam	15	28.1	1.91	9.6
97	82a	525729	4817994	C	15	2.5	Clay loam	30	32.7	1.76	0.2
98	80	525685	4817628	A	10	3.2	Loam	10	36.0	1.80	6.8
99	65a	528326	4818925	L	20	4.2	Loam	10	38.9	1.70	-
100	65	528603	4819084	E	10	3.8	Loam	10	40.2	1.65	-
101	65	528614	4819355	C	10	4.3	Loam	15	36.8	1.69	18.4
102	65	527104	4819272	A	15	3.7	Loam	5	37.9	1.67	-
103	65a	527476	4819431	A	15	3.6	Loam	30	37.2	1.65	9.0
104	65	527825	4819188	A	15	3.5	Loam	10	38.8	1.76	11.3
105	65	527743	4819862	A	ns	5.0	Loam	35	ns	ns	-
106	83	525127	4821897	B	15	6.3	Loam	20	34.3	1.82	4.1
107	83	525077	4821718	D	15	7.0	Loam	20	32.3	1.91	5.4
108	65	525683	4818407	A	5	4.2	Clay loam	10	40.5	1.57	1.4
109	80	526158	4818056	A	ns	2.0	Silt loam	30	ns	ns	-
110	65a	526125	4818299	A	10	4.0	Silt loam	5	40.8	1.60	19.6
111	65a	526831	4818253	A	15	4.7	Loam	5	40.8	1.54	-
112	65a	527032	4817961	D	10	4.2	Loam	20	38.4	1.64	-
113	64	530096	4820210	B	15	5.6	Loam	25	33.9	1.90	-
114	64	530668	4819777		10	4.5	Clay loam	15	34.2	1.75	21.0
115	64	530737	4820041	A	10	5.6	Loam	10	32.4	1.98	11.0
116	64	530567	4820286	D	10	6.5	Clay loam	20	42.3	1.59	-
117	82a	527924	4816748	A	ns	4.0	Loam	35	ns	ns	-
118	64	528202	4816663	D	20	4.3	Loam	20	44.8	1.49	26.8
120	82a	524980	4820127	A	15	3.3	Clay loam	30	37.5	1.56	-
121	82a	525145	4820301		10	5.1	Clay loam	25	39.1	1.67	-
122	82a	524174	4821520	A	10	4.4	Loam	25	33.6	1.58	2.4
123	75	529381	4819687	A	ns	3.9	Loam	40	ns	ns	0.2
124	75	530020	4818594	A	10	3.3	Loam	20	27.1	1.98	-
125	39b	529526	4819250	A	15	4.2	Loam	15	34.6	1.70	5.7
126	80a	526655	4816853	L	10	4.8	Loam	20	36.2	1.76	0.1
127	80a	526487	4817162	A	ns	4.3	Clay loam	35	ns	ns	-
128	80a	526290	4817116	A	10	4.4	Clay loam	20	43.4	1.56	5.4
129	82a	526195	4816942	A	10	ns	Silt loam	15	35.7	1.59	8.3
130	43b	525875	4821900	E	ns	3.2	Silt loam	40	ns	ns	0.1
131	43b	525742	4822099	E	30	3.7	Silt loam	30	39.8	1.43	0.2
132	43b	526035	4822461	D	10	1.9	Silt loam	25	32.8	1.70	-
133	43b	526359	4821830	C	20	3.6	Silt loam	25	38.8	1.61	-
134	43b	528088	4821732	A	ns	10.1	Silt loam	40	ns	ns	0.4
135	43b	528133	4822127	E	ns	13.5	Silt loam	40	ns	ns	0.3
137	83	530068	4822079	A	ns	ns	Loam	30	ns	ns	-
138	65	526076	4818627	A	10	5.0	Loam	10	36.4	1.72	-
139	65a	526464	4818631	A	15	3.6	Loam	20	31.3	1.65	-
140	65	527180	4818507	L	15	5.7	Loam	20	43.8	1.51	20.6

No.	LMU	X	Y	LU	Depth	OM	Texture	Ston.	Por.	DBD	$CaCO_3$
141	65	528147	4818239	A	10	4.2	Loam	5	33.6	1.78	25.4
142	65	528887	4818203	A	10	4.9	Loam	15	35.7	1.88	12.1
143	65	529095	4817952	L	10	3.4	Loam	5	41.9	1.58	-
144	75	530047	4818874	A	15	5.3	Clay loam	20	33.2	1.82	-
145	39b	529657	4819194	A	ns	5.6	Loam	25	ns	ns	-
146	80	527311	4817733	C	ns	3.1	Loam	30	ns	ns	4.0
147	65a	527160	4817632	A	ns	5.2	Loam	30	ns	ns	-
148	83	524809	4821109	C	ns	5.9	Loam	35	ns	ns	-
149	82a	524068	4820769	A	ns	5.9	Loam	30	ns	ns	0.5
150	80	527157	4816802	A	ns	2.8	Silt loam	35	ns	ns	-
151	80	527707	4816524	A	10	3.9	Loam	25	33.3	1.62	-
152	80a	527472	4816436	A	10	3.8	Loam	30	38.3	1.55	-
153	82a	524577	4821322	L	10	6.1	Loam	20	37.0	1.67	-
154	65a	527122	4819506	A	10	2.9	Silt loam	15	34.2	1.68	-
155	65a	527775	4818696	A	15	5.1	Loam	5	34.3	1.74	-
156	80a	526074	4817763	L	15	4.2	Loam	20	33.0	1.69	0.1
157	65	527645	4818376	A	15	3.9	Loam	5	42.5	1.45	-
158	65a	527913	4818335	A	10	4.1	Loam	5	39.6	1.66	-

APPENDIX C

RUSLE input factors and results

Input factors RUSLE

Table C.1: *C-factor per LUT.*

LUT	C factor
Barley	0,2
Citrus	0,2
Grape	0,2
Maize	0,42
Olive	0,2
Sugar beet	0,41
Tobacco	0,22
Tomato	0,22
Wheat	0,2

Table C.2: *Input factors per LMU.*

LMU	LS factor	R factor	K factor	P factor
27b	2,11	218,5	0,26	0,75
39b	0,77	218,5	0,26	0,75
43b	2,94	218,5	0,37	0,75
64	4,34	218,5	0,26	0,75
65	1,08	218,5	0,26	0,75
65a	0,72	218,5	0,26	0,75
75	1,24	218,5	0,26	0,75
80	0,48	218,5	0,26	0,75
80a	0,60	218,5	0,26	0,75
82a	2,64	218,5	0,26	0,75
83	4,07	218,5	0,26	0,75

Table C.3: *Input factors per LMUS.*

LMUS	LS factor	R factor	K factor	P factor
27b_1	1,39	218,5	0,26	0,75
27b_2	3,32	218,5	0,26	0,75
39b_1	0,77	218,5	0,26	0,75
43b_1	3,08	218,5	0,37	0,75
43b_2	2,64	218,5	0,37	0,75
64_1	2,44	218,5	0,37	0,75
64_2	4,89	218,5	0,26	0,75
64_3	5,43	218,5	0,26	0,75
64_4	5,38	218,5	0,26	0,75
65_1	ns	ns	ns	ns
65_10	2,30	218,5	0,37	0,75
65_2	ns	ns	ns	ns
65_3	0,87	218,5	0,28	0,75
65_4	0,33	218,5	0,26	0,75
65_5	0,44	218,5	0,26	0,75
65_6	1,46	218,5	0,26	0,75
65_7	ns	ns	ns	ns
65_8	0,83	218,5	0,26	0,75
65_9	ns	ns	ns	ns
65a_1	0,72	218,5	0,26	0,75
75_1	1,24	218,5	0,26	0,75
80_1	0,15	218,5	0,37	0,75
80_2	0,78	218,5	0,37	0,75
80_3	0,26	218,5	0,26	0,75
80_4	ns	ns	ns	ns
80a_1	0,60	218,5	0,26	0,75
82a_1	1,58	218,5	0,26	0,75
82a_2	2,86	218,5	0,37	0,75
82a_3	3,17	218,5	0,26	0,75
82a_4	1,81	218,5	0,26	0,75
83_1	3,92	218,5	0,26	0,75
83_2	4,30	218,5	0,26	0,75

Output RUSLE per LUT and per LMU(S)

Table C.4: *Soil loss (t ha^{-1} yr^{-1}) of different crops per LMU.*

LMU	Barley	Citrus	Grape	Maize	Olive	Sugar beet	Tobacco	Tomato	Wheat
27b	18,0	18,0	18,0	37,8	18,0	36,9	19,8	19,8	18,0
39b	6,6	6,6	6,6	13,8	6,6	13,5	7,3	7,3	6,6
43b	35,6	35,6	35,6	74,8	35,6	73,0	39,2	39,2	35,6
64	37,0	37,0	37,0	77,7	37,0	75,8	40,7	40,7	37,0
65	9,2	9,2	9,2	19,3	9,2	18,8	10,1	10,1	9,2
65a	6,2	6,2	6,2	13,0	6,2	12,6	6,8	6,8	6,2
75	10,5	10,5	10,5	22,1	10,5	21,6	11,6	11,6	10,5
80	4,1	4,1	4,1	8,5	4,1	8,3	4,5	4,5	4,1
80a	5,2	5,2	5,2	10,8	5,2	10,6	5,7	5,7	5,2
82a	22,5	22,5	22,5	47,2	22,5	46,1	24,7	24,7	22,5
83	34,7	34,7	34,7	72,8	34,7	71,1	38,1	38,1	34,7

Table C.5: *Soil loss (t ha^{-1} yr^{-1}) of different crops per LMUS.*

LMUS	Barley	Citrus	Grape	Maize	Olive	Sugar beet	Tobacco	Tomato	Wheat
27b_1	11,8	11,8	11,8	24,9	11,8	24,3	13,0	13,0	11,8
27b_2	28,3	28,3	28,3	59,5	28,3	58,1	31,2	31,2	28,3
39b_1	6,6	6,6	6,6	13,8	6,6	13,5	7,3	7,3	6,6
43b_1	37,3	37,3	37,3	78,4	37,3	76,5	41,1	41,1	37,3
43b_2	32,0	32,0	32,0	67,2	32,0	65,6	35,2	35,2	32,0
64_1	29,6	29,6	29,6	62,1	29,6	60,6	32,5	32,5	29,6
64_2	41,7	41,7	41,7	87,5	41,7	85,4	45,8	45,8	41,7
64_3	46,2	46,2	46,2	97,1	46,2	94,8	50,9	50,9	46,2
64_4	45,8	45,8	45,8	96,2	45,8	94,0	50,4	50,4	45,8
65_1	ns	ns	ns	ns	ns	ns	ns	ns	ns
65_10	27,9	27,9	27,9	58,7	27,9	57,3	30,7	30,7	27,9
65_2	ns	ns	ns	ns	ns	ns	ns	ns	ns
65_3	8,0	8,0	8,0	16,8	8,0	16,4	8,8	8,8	8,0
65_4	2,8	2,8	2,8	5,9	2,8	5,8	3,1	3,1	2,8
65_5	3,8	3,8	3,8	7,9	3,8	7,7	4,2	4,2	3,8
65_6	12,5	12,5	12,5	26,2	12,5	25,6	13,7	13,7	12,5
65_7	ns	ns	ns	ns	ns	ns	ns	ns	ns
65_8	7,1	7,1	7,1	14,9	7,1	14,5	7,8	7,8	7,1
65_9	ns	ns	ns	ns	ns	ns	ns	ns	ns
65a_1	6,2	6,2	6,2	13,0	6,2	12,6	6,8	6,8	6,2
75_1	10,5	10,5	10,5	22,1	10,5	21,6	11,6	11,6	10,5
80_1	1,9	1,9	1,9	3,9	1,9	3,8	2,0	2,0	1,9
80_2	9,4	9,4	9,4	19,8	9,4	19,3	10,4	10,4	9,4
80_3	2,3	2,3	2,3	4,7	2,3	4,6	2,5	2,5	2,3
80_4	ns	ns	ns	ns	ns	ns	ns	ns	ns
80a_1	5,2	5,2	5,2	10,8	5,2	10,6	5,7	5,7	5,2
82a_1	13,5	13,5	13,5	28,3	13,5	27,6	14,8	14,8	13,5
82a_2	34,7	34,7	34,7	72,8	34,7	71,0	38,1	38,1	34,7
82a_3	27,0	27,0	27,0	56,8	27,0	55,4	29,8	29,8	27,0
82a_4	15,4	15,4	15,4	32,3	15,4	31,6	16,9	16,9	15,4
83_1	33,4	33,4	33,4	70,1	33,4	68,5	36,7	36,7	33,4
83_2	36,7	36,7	36,7	77,0	36,7	75,2	40,3	40,3	36,7

APPENDIX D

Present land use classification

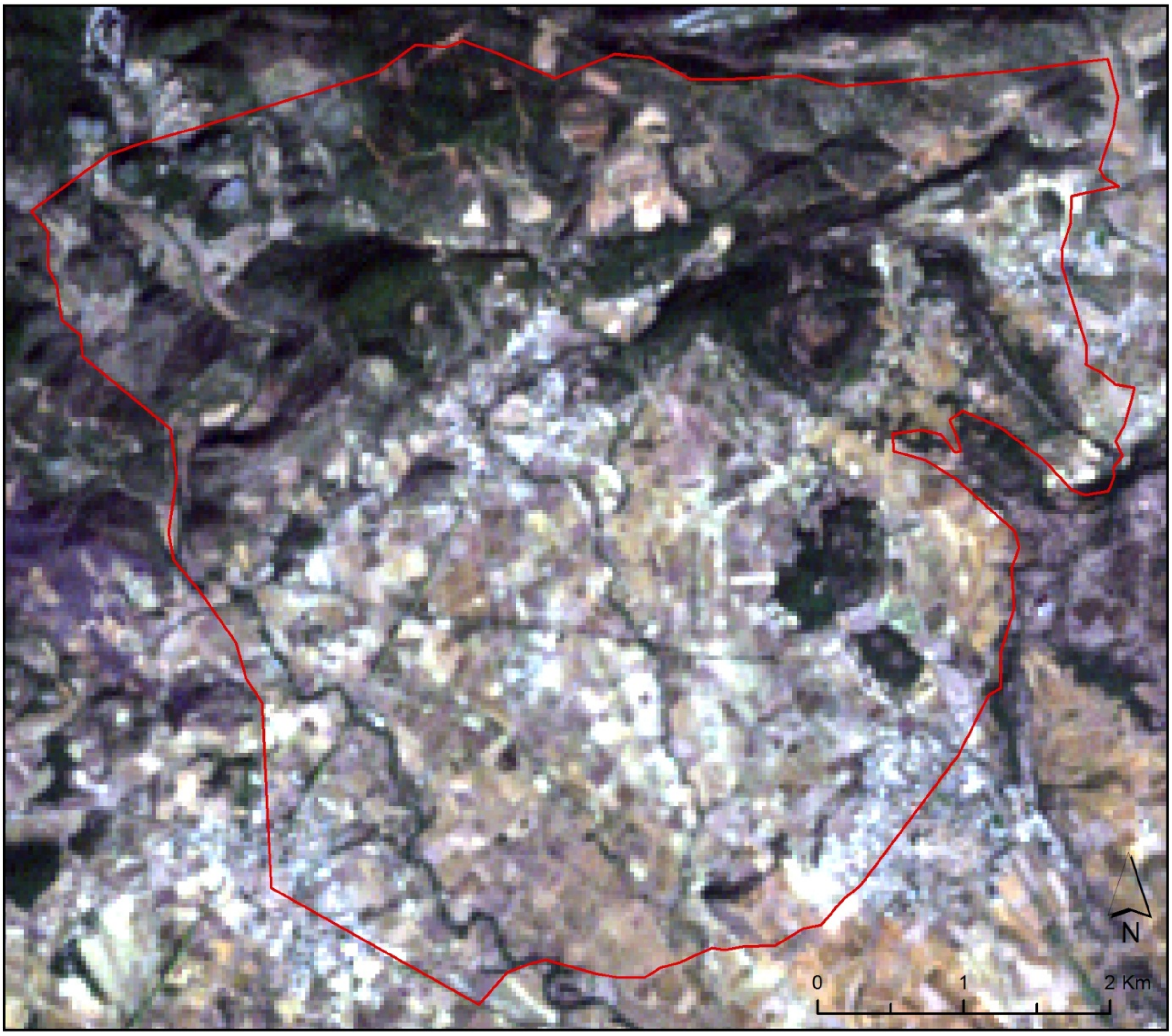

Figure D.1: *Landsat 7 image of study area, acquired: 12-10-2011 (R: band 3; G: band 2; B: band 1).*

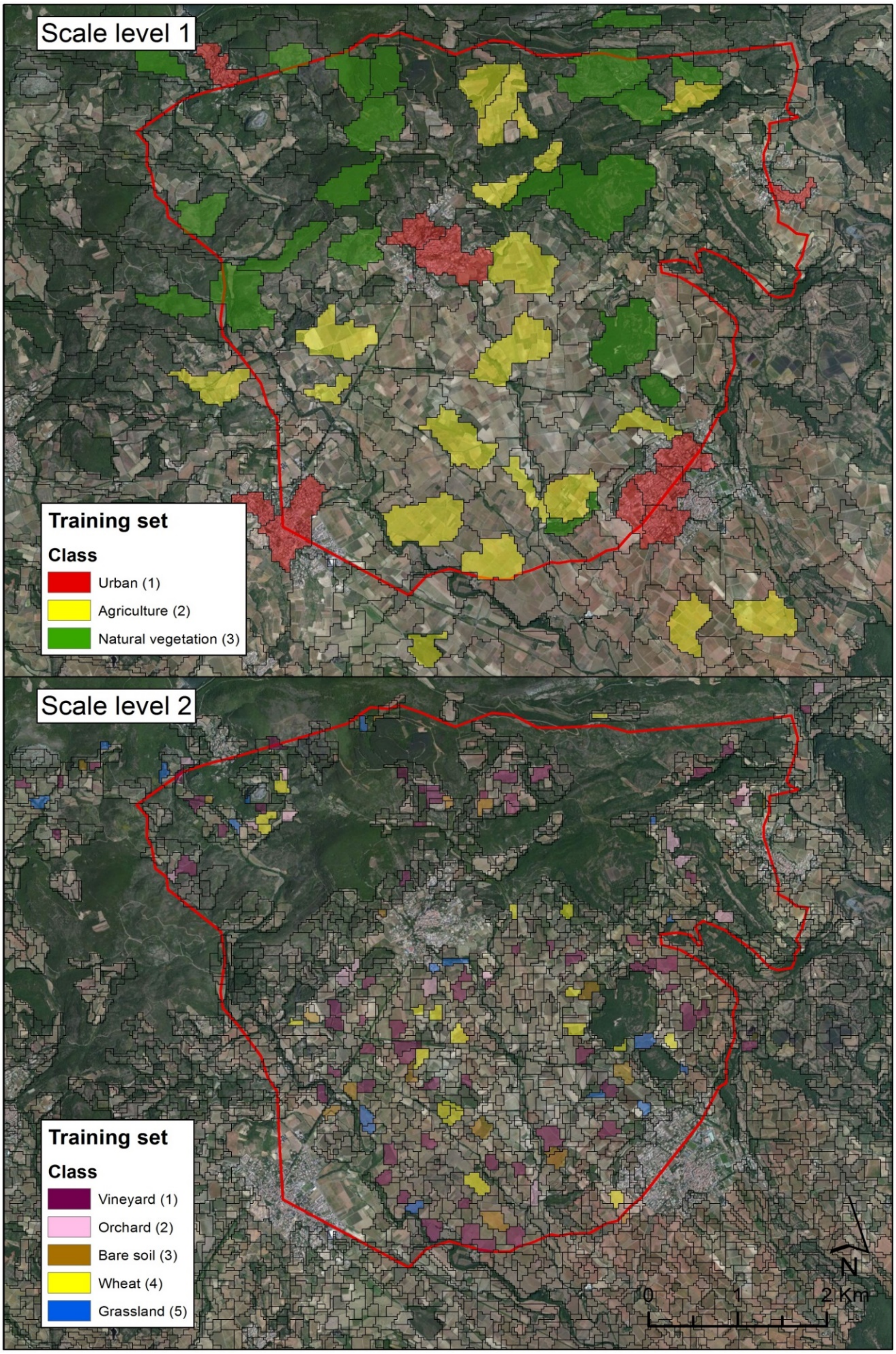

Figure D.2: *Manually selected training sets for both scale levels.*

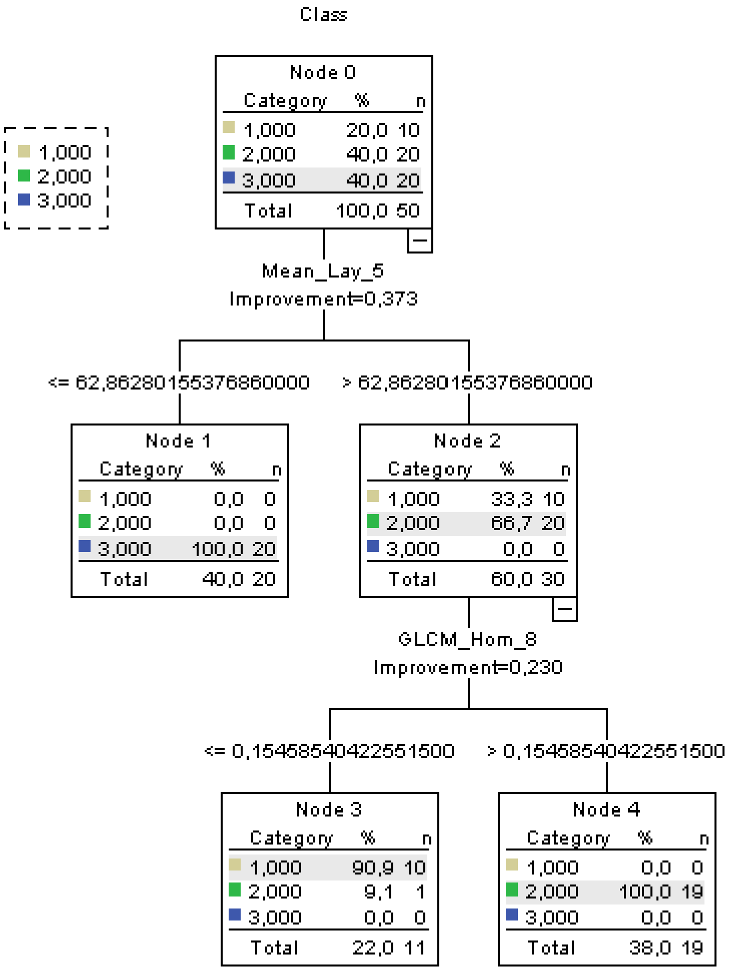

Figure D.3: *Decision tree level 1 (SPSS 19 output).*

Table D.1: *Accuracy table of decision tree level 1 (SPSS 19 output).*

	Predicted			
Observed	1	2	3	Percent Correct
1	10	0	0	100%
2	1	19	0	95,0%
3	0	0	20	100%
Overall Percentage	22,0%	38,0%	40%	98,0%

Growing Method: CRT

Dependent Variable: Class

***Figure D.4:** Decision tree level 2 (SPSS 19 output).*

Table D.2: *Accuracy table of decision tree level 2 (SPSS 19 output).*

	Predicted					
Observed	1	2	3	4	5	Percent Correct
1	66	0	1	3	0	94,3%
2	2	12	1	5	0	60%
3	2	0	15	3	0	75,0%
4	5	0	1	13	1	65,0%
5	2	0	4	3	8	47,1%
Overall Percentage	52,4%	8,2%	15,0%	18,4%	6,1%	77,6%

Growing Method: CRT

Dependent Variable: Class_L2