Recommendations for establishing Action Programmes under Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources

Contract number N° 07 0307/2010/580551/ETU/B1

Part A

Review and further differentiation of pedo-climatic zones in Europe

Final Report

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Consortium

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ABSTRACT

Recommendations for establishing Action Programmes under Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources. Review and further differentiation of pedo-climatic zones in Europe: Alterra, Wageningen-UR, Wageningen. 91 pages.; 12 figs.; 9 tables.; 51 refs.

This report provides a review and further differentiation of the four existing environmental zones so far used within the context of the Nitrate Directive.

Based on the review, the pedo-climatic zones have been based on two separated layers of information. The first layer of information is the environmental stratification: the Environmental Zones (EnZs). The second layer of information deals with the surface run-off risk potential and nitrate leaching risk potential, which are based on a combination of land, soil and climate factors (ie. pedo-climatic information). These two layers of information have been combined into two maps, showing the surface run-off risk potential and nitrate leaching risk potential for each EnZs, respectively.

The first layer consists of 13 different Environmental zones, which have been distinguished on climatic differences (precipitation, temperature, altitude and latitude). The second layer was based upon the soil properties as defined in the European Soil data base. Together, climate and soil properties determine the risks of surface run off and leaching of nutrients. In each environmental zone three different risk classes have been defined based upon soil texture, soil organic matter, soil depth and slopes precipitation and temperature.

Keywords:, Nitrate Directive, N leaching, N run off, climate, soil, texture, organic matter, soil depth, slope, pedo-Climatic zones

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Administrative summary

Contract number N° 07 0307/2010/580551/ETU/B1
The contract *"Recommendations for establishing Action Programmes under Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources" (*ENV.B.1/ETU/2010/0063) started on 22 December 2010

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Executive Summary

This Final Report presents the results of the study "Recommendations for establishing Action Programmes under Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources" (Contract N° 07 0307/2010/580551/ETU/B1). The general objective of this study is 'to build further on the study of ERM (2001), to cover EU-27 and take into account the most recent relevant scientific and technical data on nitrogen emissions, agricultural practices and environmental and climatic conditions'. The outcome of this study should provide useful inputs for a better implementation of the Nitrates Directive across the whole EU-27.

The study consists of four parts:
Part A: Review and further differentiation of the pedo-climatic zones in Europe: definition of pedo-climatic (sub) zones
Part B: Detailed analysis of the link between farming practices and the risks for leaching/run off towards waters and eutrophication processes
Part C: Detailed analysis of the processes in the soil (surface and subsoil) that influence nutrient leaching and run off that could lead to pollution of waters and eutrophication processes
Part D: Recommendations for the measures referred to in Annex II and Annex III of the Nitrates Directive, differentiated for each pedo-climatic (sub) zone.

The study reported in this Part A Report presents a review of the study of ERM (2001) and a proposal for a further differentiation of pedo-climatic zones in Europe.

In line with the context of the Nitrates Directive, i.e. prevention of pollution of groundwater and surface waters by nitrates from agriculture and preventing and decreasing eutrophication , three general (main) criteria for pedo-climatic zoning have been defined:

- Crop growth potential. The demand for nutrients and (irrigation) water, and the demand for pest and disease control depend on the crop growth potential. Hence, crop growth potential is an important determinant for the demand for nitrogen and phosphorus by the growing crops, and indirectly for the leaching of nitrogen and phosphorus to groundwater and surface waters.
- Surface runoff of N and P to surface waters, which may lead to eutrophication and nutrient pollution of waters which are used for human consumption. Surface runoff is used here as a collective term for overland flow, run-off and shallow lateral flow. Eutrophication is understood as the enrichment of surface waters by phosphates and nitrates. These nutrients typically promote the growth of algae. As the algae die and decompose, they provide high levels of organic matter and the decomposing organisms deplete the water of available oxygen, causing the death of other organisms, such as fish. Also, algae produce H_2S emissions when they decompose, which is a toxic gas for animals and humans. Eutrophication is

a natural process, but human activity greatly speeds up the process, as it is source of a great nutrient load to waters.

- Downward leaching of N from agricultural sources, which directly leads to groundwater pollution by nitrates. Nitrate-rich groundwater aquifers cannot be used as source for drinking water. Moreover, the nitrate-rich groundwater may seep into surface waters in lower lying areas after some time and thereby contribute to the enrichment of these waters with nitrates. Hence, downward N leaching may lead to pollution of groundwater and surface waters. The source-pathway-receptor linkage can be highly complex, also because the traveling pathway of the groundwater may be very lengthy, and the traveling time of the groundwater before it seeps into surface waters may take decades.

Based on the review, the pedo-climatic zones have been based on two separated layers of information. The first layer of information is the environmental stratification: the Environmental Zones (EnZs). The second layer of information deals with the surface run-off risk potential and nitrate leaching risk potential, which are based on a combination of land, soil and climate factors (ie. pedo-climatic information). These two layers of information have been combined into two maps, showing the surface run-off risk potential and nitrate leaching risk potential for each EnZs, respectively.

Table S1 briefly describes the 13 distinguished EnZs. Climate data for each of the EnZs are presented in Annex 1. These zones have been derived using a statistical sound technique, which has been published in peer-reviewed literature. In principal, a further differentiation could be made for each of the EnZs, but this would strongly increase the number of pedo-climatic regions and would be less manageable. Figure S1 shows a map of the Environmental Zones (EnZs) in Europe.

Table S1. The 13 Environmental Zones (EnZs) as the first layer of information for pedo-climatic zonation in Europe.

Nr	Environmental Zone	Main locations and characteristics
1	Alpine North (ALN)	Scandinavian mountains; these have been named Alpine north, because they show environmental conditions as the Alps on a higher latitude, but in lower mountains.
2	Alpine South (ALS)	The high mountains of central and southern Europe that show the environmental conditions of high mountains. Also small Alpine patches are found in mountain areas in Pyrenees and Carpathians.
3	Atlantic North (ATN)	The area under influence of the Atlantic ocean and the North sea, humid with rather low temperatures in summer and winter, but not extremely cold.
4	Atlantic Central (ATC)	The area with moderate climate where the average winter temperature does not go far below 0°C and the average summer temperatures are relatively low. This is a main agricultural production zone in EU-27.
5	Boreal (BOR)	The environmental zone covering the lowlands of Scandinavia
6	Continental (CON)	The part of Europe with an environment of warm summers and rather cold winters. This is a main agricultural production zone in EU-27.
7	Lusitenean (LUS)	The southern Atlantic area from western France to Lisbon. Here, summers are rather warm and sometimes dry, while winters are mild and humid. This is a main agricultural production zone in EU-27.
8	Mediterranean North (MDN)	The Mediterranean north represents the major part of the Mediterranean climate zone with Cork Oak, fruit plantations and Olive groves
9	Mediterranean Mountains (MDM)	These mountains are influenced by both the Mediterranean and mountain climates.
10	Mediterranean South (MDS)	This zone represents the typical Mediterranean climate that is shared with northern Africa, short precipitation periods in winter and long hot, dry summers.
11	Nemoral (NEM	The zone covering the southern part of Scandinavia, the Baltic states and Belarus. This is a main agricultural production zone in EU-27.
12	Pannonian (PAN)	This is the most steppic part of Europe, with cold winters and dry hot summers. Most precipitation is found in spring.
13	Anatolian (ANA)	Represents the steppes of Turkey, a Mediterranean steppic environment.

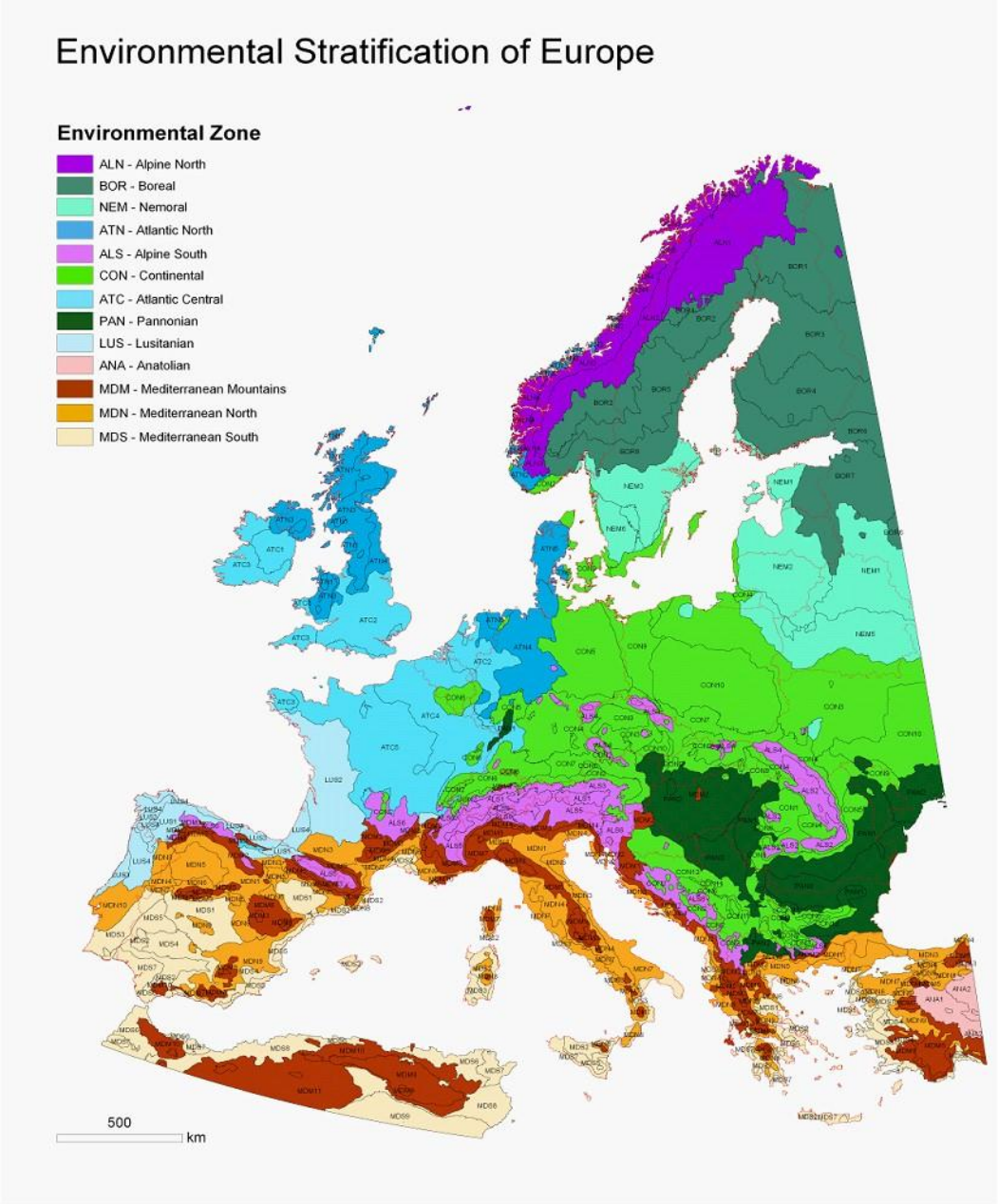


Figure S1. The Environmental Stratification of Europe (EnZs) (Metzger 2005).

The second layer of information is based on soil-related factors, which basically overlay the EnZs. The soil-related risk areas hold for all EnZs. Important soil-related factors have been summarized in Table S2 here below.

Table S2. Soil-related factors that determine the surface runoff risk potential and the leaching risk potential in Environmental Zones.(see also part B of this Report)

Nr	Soil factor	Characteristics, classes and potential risks
1	Slope	Slope determines the risk for overland flow; the risk increases with increasing slope. Flat: 0 to 2%; negligible risk Rolling: 2 to 8%; moderate risk Sloping: 8 to 15%; high risk Moderately steep: 15 to 25 %; very high risk Steep (>25%); extremely high risk
2	Depth	Soil depth determines the crop growth potential and drainage characteristics. Shallow (< 40 cm); very high risk, especially when karst in subsoil Moderate (40-80 cm); high risk, especially when karst in subsoil Deep (80-120 cm); moderate risk Very deep (> 120 cm); low risk
3	Texture	Soil texture determines water and nutrient retention capacity, structure, and hydrological conductivity Heavy clay (clay > 35%); relatively high risk for overland flow Loamy-clay (≤35% clay and < 65% sand); relatively low risk Coarse (> 65% sand and <8% clay); relatively high risk for downward leaching
4	Structure	Soil structure determines root growth, hydrological conductivity, drainage, vulnerability to erosion. no slaking and cracking; low risk to overland flow and preferential flow slaking soils; high risk to overland flow cracking soils; high risk to preferential flow
5	Organic matter	Soil organic matter content determines nitrogen supply and nitrate removal through denitrification Peat soils; >15% organic matter in top 40 cm; high risk for denitrification and mineralization Organic-rich soils; 5 - 15%: moderate risk for denitrification and mineralization Organic-low soils; <5%: low risk for denitrification and mineralization
6	Cover	Soil cover determines evapotranspiration and the vulnerability to erosion. Bare soil: no green cover for >1 month per year; high risk for runoff and leaching Soils with green cover for more than 11 month per year; low risk for runoff and leaching
7	Frost	Soils with frozen soil layers have very low water infiltration rate and hydrological conductivity: no frost in soil; low risk for runoff and leaching frozen top soil and/or frozen subsoil, including soils with snow cover; high risk for runoff and leaching;
8	Buffering	Buffering indicates the presence of terraces, tree-lines, buffer zones, riparian zones. no buffering; no opportunity for retention of leached nutrients and soil buffering; opportunity for retention of leached nutrients and soil

The map of the Environmental Zones (EnZs) has been combined with the map of the utilized agricultural area and with maps indicating the land, soil and climate factors that determine the surface runoff risk potential and the leaching risk potential. This combination has resulted in a pedo-climatic zoning that show the surface runoff risk potential (Figure S2) and the leaching risk potential (Figure S3) for utilized agricultural land within the Environmental Zones. Three classes have been distinguished for the surface runoff risk potential and the leaching risk potential: low, medium and high.

Note that there are uncertainties related to the maps of utilized agricultural area and the soil and geomorphological maps underlying the surface runoff risk potential (Figure S2) and the leaching risk potential (Figure S3). Hence, these maps have to be used with care, especially when used at a regional scale.

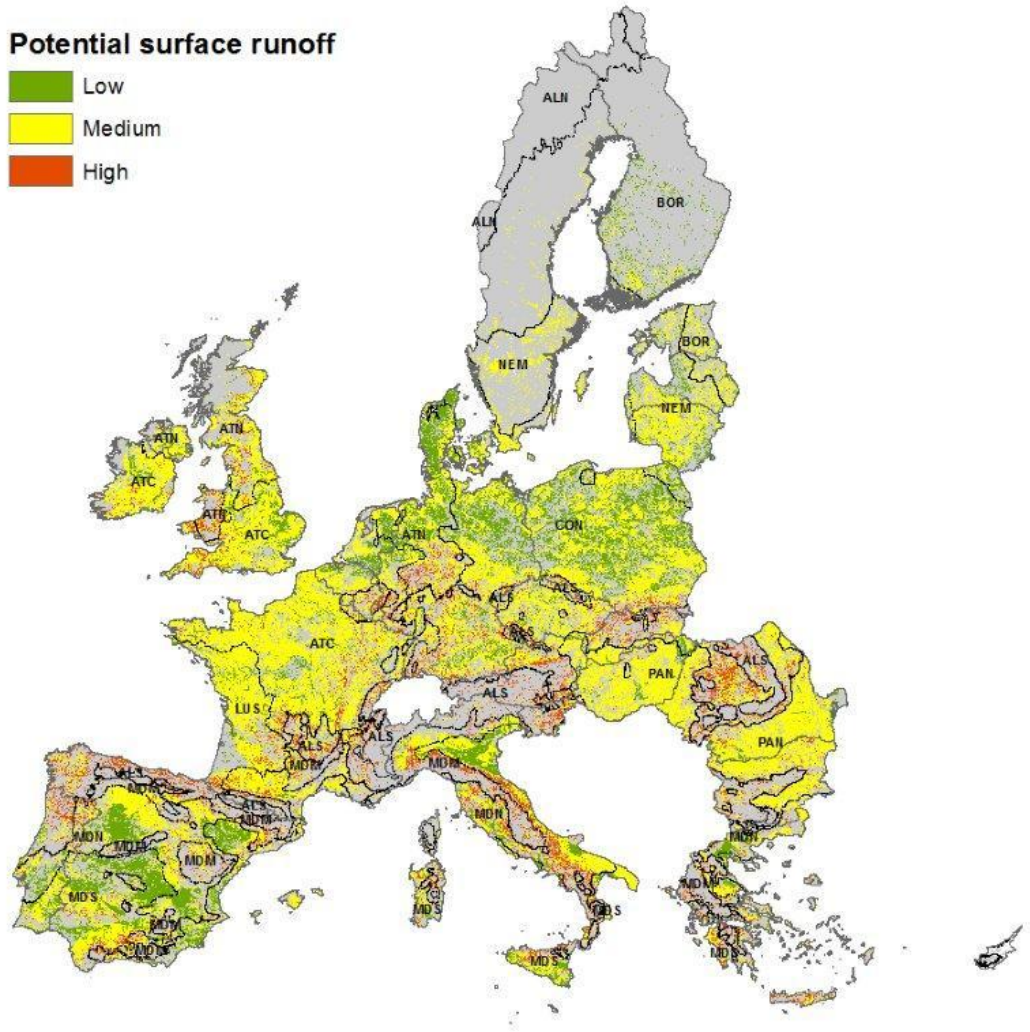


Figure S2. Map showing the surface runoff risk potential for agricultural land within the Environmental Zones in the EU-27. Abbreviations of the Environmental Zones are explained in Figure S1 and Table S1. Note that grey areas indicate non-agricultural areas.

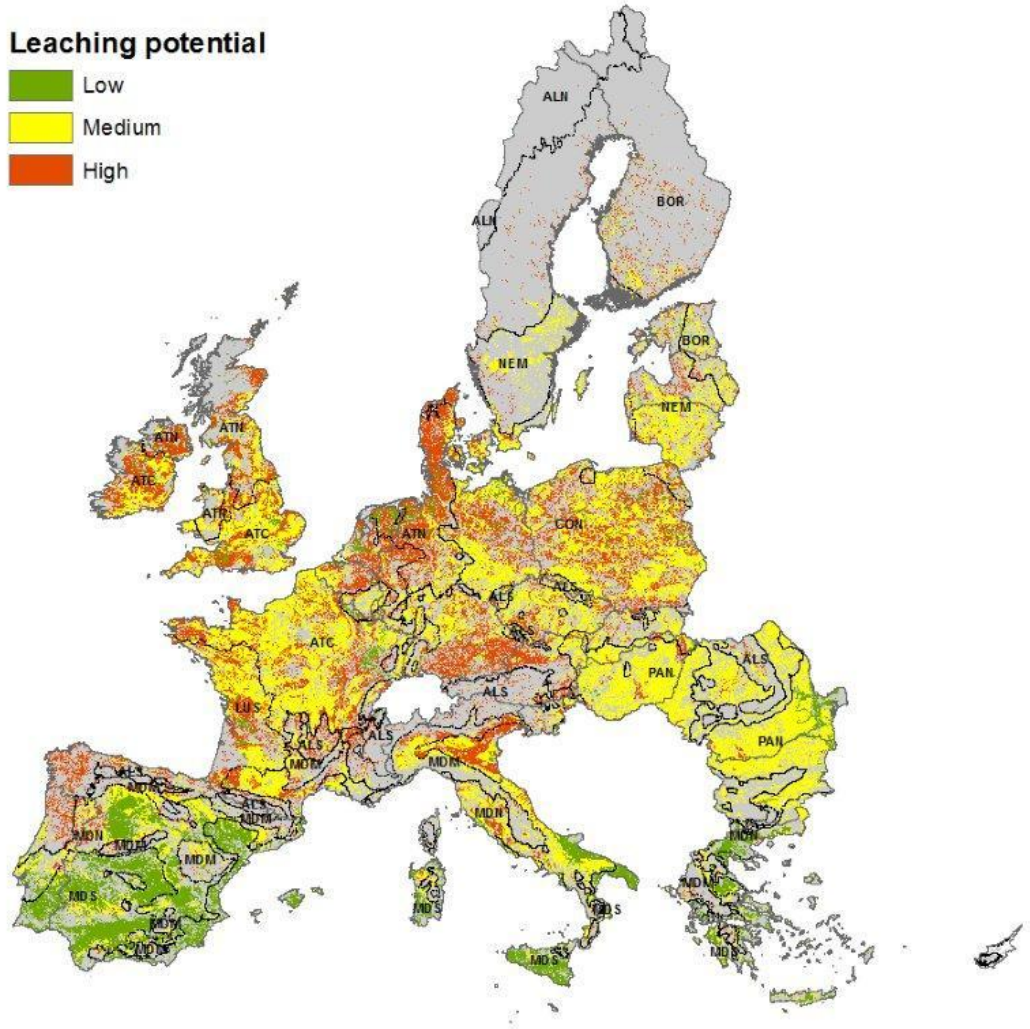


Figure S3. Map showing the leaching risk potential for agricultural land within the Environmental Zones in the EU-27. Abbreviations of the Environmental Zones are explained in Figure S1 and Table S1. Note that grey areas indicate non-agricultural areas.

1 Introduction

The objective of Council Directive 91/676/EEC of 12 December 1991 (Nitrates Directive; concerning the protection of waters against pollution caused by nitrates from agricultural sources) is "*to reduce water pollution caused or induced by nitrates from agricultural sources and to prevent further such pollution*". The Nitrates Directive requires Member States to:

- Monitor ground- and surface waters with regard to nitrate concentration and trophic status;
- Designate Nitrate Vulnerable Zones (NVZs), i.e. all land draining into waters that are affected by nitrate pollution and/or eutrophication or that could be affected if action is not taken;
- Establish a Code of Good Agricultural Practice (CGAP) to be implemented by all farmers throughout the country on a voluntary basis. The CGAP should include, as a minimum, measures identified in Annex II of the Nitrates Directive;
- Establish Action Programme(s) (APs), which should be implemented on a obligatory basis by all farms located within NVZs. Member States can choose not to designate NVZs and to apply the APs throughout the whole country. The APs should include, as a minimum, all measures prescribed in the CGAP, as well as measures identified in Annex III of the Nitrates Directive;
- Review their NVZs and their APs at least every four years and make amendments if necessary.

In 2001, the European Commission has carried out a study[1] aimed at assessing Action Programmes established at that time in the EU-15 and aimed at enunciating main principles which should guide the establishment of measures, taking into account agronomic concepts, pedo-climatic zones and local conditions. The EU has in the meantime been enlarged, meaning that new states with different climatologic, environmental and agronomic characteristics have joined. Also, following discussions with Member States, the Commission identified the need for a reference document containing a strong and detailed scientific base for the establishment of action programmes.

In December 2010, the European Commission, Directorate-General Environment, awarded a contract to a consortium led by Alterra to deliver the work outlined in the tender DG ENV.B.1/ETU/2010/0063 "*Recommendations for establishing Action Programmes under Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources*". The general objective of this study is *'to build further on the study of ERM (2001), to cover EU-27 and take into account the most recent relevant scientific and technical data on nitrogen emissions, agricultural practices and environmental and climatic conditions'*. The outcome of this study should provide useful inputs for a better implementation of the Nitrates Directive across the whole EU-27.

[1] Assessment of Action Programmes Established by Member States under Directive 91/676/EEC (2001) Environmental Resources Management Report EUROPEAN COMMISSION - DG ENVIRONMENT, 85 p

The study consisted of four parts:
Part A: Review and further differentiation of the pedo-climatic zones in Europe: definition of pedo-climatic (sub) zones
Part B: Detailed analysis of the link between farming practices and the risks for leaching/run off towards waters and eutrophication processes
Part C: Detailed analysis of the processes in the soil (surface and subsoil) that influence nutrient leaching and run off that could lead to pollution of waters and eutrophication processes
Part D: Recommendations for the measures referred to in Annex II and Annex III of the Nitrates Directive, differentiated for each pedo-climatic (sub) zone.

This report (part A) deals with defining pedo-climatic zones. The measures referred to in Annexes II and III of the Nitrates Directive are summarized in box 1 below.

Box 1. Measures referred to in Annexes II and III of the Nitrates Directive
Annexes II and III of the Nitrates Directive set out a list of measures, which have to be included in the Code of Good Agricultural Practices (Annex II) and the Action Programme (Annex II and III). In particular, the Action Programmes must contain at least provisions relating to:
1) periods when the land application of certain types of fertilizer is prohibited or inappropriate;
2) the capacity and construction of storage vessels for livestock manures, including measures to prevent water pollution by run-off and seepage into the groundwater and surface water of liquids containing livestock manures and effluents from stored plant materials such as silage;
3) the land application of fertilizer to steeply sloping ground;
4) the land application of fertilizer to water-saturated, flooded, frozen or snow-covered ground;
5) the conditions for land application of fertilizer near water courses;
6) procedures for the land application, including rate and uniformity of spreading, of both chemical fertilizer and livestock manure, that will maintain nutrient losses to water at an acceptable level;
7) limitation of the land application of fertilizers, consistent with good agricultural practice and taking into account the characteristics of the vulnerable zone concerned, in particular: (a) soil conditions, soil type and slope; (b) climatic conditions, rainfall and irrigation; (c) land use and agricultural practices, including crop rotation systems; and to be based on a balance between: (i) the foreseeable nitrogen requirements of the crops, and (ii) the nitrogen supply to the crops from the soil and from fertilization corresponding to:
- the amount of nitrogen present in the soil at the moment when the crop starts to use it to a significant degree (outstanding amounts at the end of winter),
- the supply of nitrogen through the net mineralization of the reserves of organic nitrogen in the soil,
- additions of nitrogen compounds from livestock manure,
- additions of nitrogen compounds from chemical and other fertilizers.
8) the amount of livestock manure applied to the land each year, including by the animals themselves, which shall not contain more than 170 kg N per hectare.

Additional measures that can be taken are:

9) land use management, including the use of crop rotation systems and the proportion of the land area devoted to permanent crops relative to annual tillage crops;
10) the maintenance of a minimum quantity of vegetation cover during (rainy) periods that will take up the nitrogen from the soil that could otherwise cause nitrate pollution of water;
11) the establishment of fertilizer plans on a farm-by-farm basis and the keeping of records on fertilizer use;
12) the prevention of water pollution from run-off and the downward water movement beyond the reach of crop roots in irrigation systems.

2 Towards further differentiation of pedo-climatic zones

2.1 Introduction

The background of the study "Recommendations for establishing Action Programmes under Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources" refers to the need for a reference document containing a strong and detailed scientific base for the establishment of Action Programmes. Also, the enlargements of the European Union in 2004 and 2007 require an update of the previous ERM study carried out in 2001. Evidently, the new Member States have different climatologic, environmental and agronomic characteristics, which should be considered in the guidance for establishing Action Programmes.

A main underlying assumption of the aforementioned reference document for the establishment of Action Programs (APs) is that the guidance is more accurate and precise for a further differentiated pedo-climatic zoning than for a less differentiated zoning as in the case of the aforementioned ERM study. This assumption is based on the facts that climatic conditions, soil conditions and farming practices differ greatly across EU-27 and at the same time have a huge influence on nitrogen utilization and on the risk of nitrate leaching. The assumption refers also to the fact that site-specific nutrient management is superior in general to 'blanket recommendations'. Also, the measures of Annexes II and III of the Nitrates Directive are most effective when adjusted to farm- and field-specific conditions.

Evidently, the detail sought for a reference document for the establishment of APs has to be a compromise of a pedo-climatic zonation which is sufficiently differentiated to be meaningful and at the same time sufficiently coarse to be manageable from a policy point of view. This compromise is difficult to indicate beforehand.

2.2 Concept and approach

The context of a 'further differentiation' of pedo-climatic zones is the Nitrates Directive, which aims to prevent and reduce pollution of waters by nitrates from agriculture. Since prevention of eutrophication is also an important aim of the Nitrates Directive and since eutrophication is also largely due to pollution with phosphate, this study considers both nitrates and phosphate.

The risks of the leaching and run off of nitrates and phosphate from agricultural land is a function of (i) climatic conditions, (ii) soil and relief conditions and (iii) farming practices. Evidently, the first two factors are not or very difficult to alter; basically these conditions have to be accepted more or less as they are. Farming practices have a large effect on losses of nitrates and phosphate, as discussed also in the report part

B, and these farming conditions can be adjusted to the locally prevailing climatic and soil conditions, so as to minimize the risk of leaching and run off.

The major routes of pollution of waters by nitrates and phosphate are leaching and run off, and hence, the aim is to stratify areas according to their risk of leaching and run off, as affected by climatic conditions and soil and relief conditions. Climatic conditions are perceived here as a combination of the means and variances of rainfall, temperature and photosynthetic radiation, which affect the length of the growing season, the potential crop yield as well as the rainfall surplus and the risks of the leaching of nitrates and phosphate. Climatic conditions vary greatly in space and time, and it must be noted that annual mean climatic conditions show large variations. Conversely, the intrinsic soil and relief conditions (pedological conditions) do not vary over time, but show huge spatial variations, often also within a farm and field. Further, the spatial variations of pedological conditions are more or less independent also of climatic conditions. As a consequence, pedo-climatic stratification, i.e. using both climate and pedological variables for identifying and delineating (homogeneous) strata that differ in the risks of leaching and run off is not easy; it will have to be based on some assumptions.

A sequential approach has been adopted for the differentiation of the pedo-climatic zones in Europe. Firstly, a climatic or environmental stratification has been made, using state-of-the-art procedures. Secondly, a pedological stratification was made, based on an extensive literature review (see also part B report), and geared towards the risk of nitrate and phosphate leaching and run-off. Thirdly, these two stratifications were combined so as to arrive to a pedo-climatic zonation.

The risks of leaching and run off also depend on evapotranspiration and nutrient uptake by the growing crops. Therefore, potential crop growth stratification has been used as an additional stratification approach. Potential crop growth was determined using forage as a model crop for animal farming and (winter) wheat as a model crop for arable and horticultural farming. A distinction was made between irrigated (no water limitation) and non-irrigation (possible water limited) crop yields.

2.3 Outline

The next chapters firstly provide comprehensive reviews of the stratification approaches for pedo-climatic zones according to the aforementioned ERM study and the broader literature. The chapters thereafter present the 'further differentiation of the pedo-climatic zones in Europe' as developed in the current study.

- Chapter 3 provides a comprehensive review of the ERM study.
- Chapter 4 provides a comprehensive review of the literature about climate and environmental stratification.
- Chapter 5 provides a comprehensive review of the literature about pedological stratification.
- Chapter 6 provides a comprehensive review of the literature about potential crop growth stratification.

- Chapter 7 presents the criteria used to identify areas with a high risk of leaching and run off within the climatic and pedological stratification.
- Chapter 8 presents the resulting pedo-climatic stratification.

3 Review of ERM study

3.1 Introduction

The ERM study focused mainly on climatic zoning and less on pedological zoning. For each of the four regions identified in that study, maps showing the days with snow cover, annual precipitation and temperature have been presented[2]. Here we briefly review the description of the climatic zoning of the ERM study and the nitrate pollution risks.

3.2 Climatic zoning

In the ERM study, the European Union (EU-15) has been divided into 4 climatic zones, (i) Boreal region, (ii) Atlantic region, (iii) Central European region, and (iv)Mediterranean region. These regions are briefly introduced below.

3.2.1 Boreal region

The Boreal region includes Finland, the northern two thirds of the area of Sweden and the northern part of Norway. The average temperature in the Boreal region is around 15º C. Rainfall is relatively low and on average, rarely exceeds 500 mm/year, except in mountainous regions. Generally, most of the rainfall occurs in late summer.

The whole of Finland, with exception of the coastal areas, is covered by snow for about half of the year. Similarly, the Gulf of Bothnia is frozen for a period varying between four and six months per year. In Northern Sweden, the ground may also be snow-covered for periods of over six months.

3.2.2 Atlantic region

Countries and regions belonging to this zone are Ireland, the United Kingdom, Denmark, the Netherlands, north-western Germany, northern Belgium, western-central France and north-western Spain and Portugal. This region is also strongly influenced by the relatively warm temperature of the coastal seas and nearby Atlantic Ocean during the winter. Generally, the average temperature ranges between winter and summer are relatively small. The summer means usually range between 15 and 20ºc and the winter mean ranges between 1 and 7ºC.

Rainfall occurs throughout the year with minor maxima in autumn and winter. Nevertheless it varies considerably from place to place. Due to the relatively low temperature, evapotranspiration is also relatively low. In the western mountainous

[2] The ERM-study also included an assessment of the Action Programmes (APs) established by Member States. This part is not dealt with within the context of the present study.

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regions (e.g. Scandinavia and Scotland), the rainfall is much higher (>3,000 mm/year). In the most southern part of the Atlantic climatic region (south-western France and north-western Spain and Portugal), precipitation can be very high in the winter, but with very little frost and snow.

3.2.3 Central European region

This climatic zone covers central-eastern France, northern Italy, Germany (with the exception of the north-western region), Luxembourg and Austria.

There is a gradient for higher winter temperature in the West and lowest winter temperature in the East. The temperatures in the winter usually vary between -1 and -5ºC. The winter month may also be characterized by several months of continuous freezing, snow and frozen rivers. The summer months are relatively hot and often also relatively dry, with mean temperatures that vary between 18 and 26ºC.

The average rainfall is low and decreases eastwards. Usually rainfall does not amount to more than about 600 mm/year. Precipitation occurs throughout the year, although largely as snow in the winter. There are no dry seasons as such. There is a small maximum in the summer which increases eastwards.

3.2.4 Mediterranean region

The Mediterranean climatic region comprises Central and southern Spain, southern Portugal, southern France, Italy and Greece. The climate is characterized by dry summers with periods of droughts and high mean summer temperature (average temperature of 21ºC). The winters are usually mild and moist with average temperature of 6ºC. Rainfall is confined to winters and distributed on irregular basis (storms) in autumn, winter and spring. Rainfall decreases eastwards. The driest parts are the interior land masses. There are, however, large variations within this region. Precipitation varies between 300 - 500 mm in the South-east of the Mediterranean (South-east and central Spain, South-east Italy and eastern Greece). The higher parts of the Mediterranean region (400-1000 m altitude) are more humid. Sunshine is often continuous during the summer period.

The ERM study acknowledges that there can be a significant variation in climatic conditions within the four distinguished zones, and hence in crop production potential and in the vulnerability to nitrate leaching. Moreover, the ERM-study does not explicitly consider spatial variations in soil conditions, morphology and hydrology as possible factors for defining climatic zones that may influence crop production potential and vulnerability to nitrate leaching.

3.3 Nitrate pollution risks

In the ERM study, the 'nitrate pollution risk' at any specific location has been defined as a combination of the probability of high nitrate levels occurring in (or on)

the soil and inadequate soil protection against erosion, runoff and leaching (such as bare soils in winter) combined with the vulnerability of local waters to pollution. The 'nitrate pollution risk' is influenced by the following factors:

- a large positive nitrogen balance in the soil;
- certain identifiable agricultural practices (e.g. the application of excessive inorganic fertiliser, ploughing of grassland in autumn, etc);
- low levels of crop growth and therefore limited nitrogen uptake or crops with low (e.g. cereals) and negative (leguminous) N demand;
- certain environmental factors such as high soil temperature and high soil organic matter content which favour the natural formation of nitrates by mineralisation.

In the ERM study, the influence of climate on nitrate leaching has been summarized as follows:

- temperature and moisture regimes influence the probability of high soil nitrate levels occurring by affecting microbial activity;
- fluctuations in temperature affect the occurrence of surface run-off by causing freezing in winter with the potential for snow cover;
- the interaction of patterns of rainfall and temperature influences the amount of net precipitation and therefore the amount of water draining through the topsoil;
- frozen soils and snow cover limit nutrient movement into the soil and greatly increase the risk of nutrients being carried to surface waters by runoff.

Finally, the following soil-hydrology related factors have been identified by ERM as contributing to the vulnerability to nitrate leaching:

- the vulnerability of the topsoil to surface run-off;
- texture and infiltration capacity;
- slope, and heavy impermeable soils (in fact, from an agronomic point of view, slopes of 3-5% can already be considered as significant in terms of erosion, runoff and subsurface drainage);
- the vulnerability of the topsoil to the leaching of nitrates down the horizon/profile to below the root zone;
- coarse textured soils, when rainfall is high and evapo-transpiration is low;
- the rate of groundwater recharge is high;
- the unsaturated zone above the groundwater is relatively shallow;
- the composition of the unsaturated zone (including top soil) is coarse;
- the aquifer shows good permeability (e.g. igneous and metamorphic rocks with well-developed fissure systems, alluvial/sandy zones, etc.).

4 Review of literature on climatic and environmental stratification

4.1 Climatic stratification

Climate usually encompasses the statistics of solar radiation, day length, temperature, humidity, atmospheric pressure, wind, rainfall, and other meteorological elemental measurements in a given region over long periods (http://amsglossary.allenpress.com/glossary/search?id=climate1). The classical period considered to be reliable in statistical terms is 30 years, as defined by the World Meteorological Organization (WMO). Climate can be contrasted to weather, which is the present condition of these elements and their variations over shorter periods. The climate of a location is affected by its latitude, terrain, and altitude, as well as nearby oceans and their currents. Climates can be classified according to the average and the typical ranges of different variables, most commonly temperature and precipitation.

There are several ways to classify climates into similar regimes. Modern climate classification methods can be broadly divided into (i) *genetic* methods, which focus on the causes of climate, and (ii) *empiric* methods, which focus on the effects of climate. Examples of genetic classification include methods based on the relative frequency of different air mass types or locations within synoptic weather disturbances. Examples of empiric classifications include climate zones defined by plant hardiness and evapotranspiration, or more generally, zones associated with certain biomes (i.e. geographically and climatically defined eco-systems). A common shortcoming of these classification schemes is that they produce distinct boundaries between the zones they define, rather than the gradual transition of climate properties more common in nature.

The classification scheme, originally developed by Wladimir Köppen, is used most commonly. The Köppen classification depends on average monthly values of temperature and precipitation. The system is based on the concept that native vegetation is the best expression of climate. Thus, climate zone boundaries have been selected with vegetation distribution in mind. It combines average annual and monthly temperatures and precipitation, and the seasonality of precipitation. The Thornthwaite system in use since 1948, incorporates evapotranspiration along with temperature and precipitation information. The Bergeron and Spatial Synoptic Classification systems focus on the origin of air masses that define the climate of a region.

In a global and continental context, climate is the main determinant of ecosystem and environmental patterns (Walter & Lieth, 1964; Odum, 1983; Klijn & De Haes, 1994; Godron, 1994), and climatically similar areas can be interpreted as having similar potentials to support ecosystems and agricultural production (Klijn & De Haes, 1994; Paruelo *et al.*, 1995; Metzger *et al.*, 2005). Broad climate classifications, as

expressions of the environment, were first developed by the ancient Greeks (Sanderson, 1999), but saw a proliferation in the late 19th and first half of the 20th century when scientists sought to explain the diversity in vegetation and soils they encountered on their travels (Von Humboldt, 1867; Köppen, 1900; Holdridge, 1947; Thornthwaite, 1948). More recently, bioclimaticbiome classifications have been used to underpin dynamic global vegetation models (Prentice *et al.*, 1992; Sitch *et al.*, 2003). However, these classifications provide limited regional detail by distinguishing only 10-30 classes globally, and with generally coarse spatial resolutions. More detailed approaches to distinguish global ecoregions (Bailey, 1998; Olson *et al.*, 2001) rely heavily on expert judgement for interpreting class divisions, making it difficult to ensure reliability across the world (Lugo *et al.*, 1999; Metzger *et al.*, 2005).

In the last decade there has been a growing urgency for linking climatic information to other environmental data, required to respond to the need for European coherent policy in the field of environment including climate change, nitrate pollution and biodiversity decline (Parr *et al.*, 2003; MA 2005; Pereira & Cooper, 2006; Scholes *et al.*, 2008; Mooney *et al.*, 2009; Metzger *et al.*, 2010; Pereira *et al.*, 2010). Progress in these fields is essential to improve future assessments and policy targets relating to the stock and change of European and global ecosystem resources and biodiversity (Scholes *et al.*, 2008), including the recently launched Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES; Larigauderie & Mooney, 2010) and the United Nations Convention on Biological Diversity (CBD) Aichi targets (Nayar, 2010).

A consistent classification, or stratification[3], of land into relatively homogenous strata provides a valuable spatial framework for comparison and analysis of environmental and ecological data across large heterogeneous areas (Paruelo *et al.*, 1995; Lugo *et al.*, 1999; Mcmahon *et al.*, 2001; Leathwick *et al.*, 2003; Metzger *et al.*, 2005). Consistency can be assured by using statistical methods. The resulting stratifications are reproducible and, as far as possible, independent of personal bias (Leathwick *et al.*, 2003; Jongman *et al.*, 2006). This is of particular importance where large-scale continuous gradients are involved over large distances. No clear boundaries between zones are present in such cases, but statistical methods may provide a way out (Metzger *et al.,* 2005). Multivariate clustering of climate data has proved to be successful in creating more detailed stratifications in many parts of the world e.g. in Great Britain (Bunce *et al.,* 1996a; Bunce *et al.,* 1996b), Europe (Metzger *et al.*, 2005; Jongman *et al.*, 2006) New Zealand (Leathwick *et al.*, 2003) and Senegal (Tappan *et al.*, 2004)). These datasets have been also used for stratified random sampling of ecological resources (Firbank *et al.*, 2003; Bunce *et al.*, 2008), the selection of representative study sites (Palma *et al.*, 2007), and summary reporting of trends and impacts (Thuiller *et al.*, 2005; Metzger *et al.*, 2008b). The stratifications are also flexible, and can be adapted for specific analyses or objectives (Hazeu *et al.*, 2010).

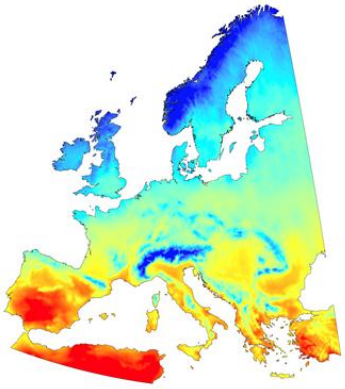
[3] Following Metzger et al (2011) when classes are not meant as descriptive units, but specifically designed to divide gradients into relatively homogeneous subpopulations we prefer to use the statistical term *stratification*.

4.2 Environmental stratification

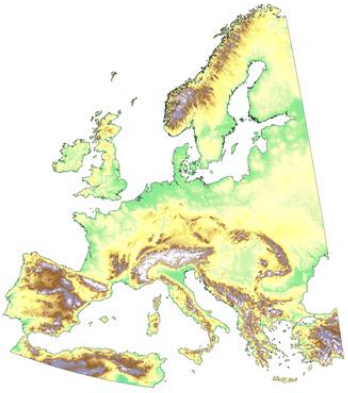
Environmental stratification differs from climatic stratification by using environmental strata that include more than simply climate characteristics. Climate affects life on earth, but life also affects climate. Climate determines the spatial distribution of snow cover, vegetation, biomes, water bodies, soil formation, agricultural production, nutrient cycling, nitrate leaching risk, and so on. Conversely, the distribution of snow, vegetation, water bodies, agriculture affects climate. Hence, there are strong linkages and interactions between climate and the environment. As a result, there has been a search for ways and procedures to identify such environmental strata that go beyond simply climate characteristics.

The need for statistical environmental stratification was first recognized by field ecologists at the Institute of Terrestrial Ecology (ITE) [now Centre for Ecology and Hydrology (CEH)] in the UK in the 1970s. These scientists realized that strategic stratified random sampling was the only feasible way of assessing ecological resources, and enabling monitoring schemes to be developed for large, heterogeneous areas (Bunce et al., 1996a,b,c; Haines-Young et al., 2000; Firbank et al., 2003). Sheail & Bunce (2003) have recently described the history and development of environmental classification and strategic ecological survey in the UK. Several other countries and regions have also adopted quantitative classifications as the basis for survey, monitoring and management, e.g. Australia (Mackey et al., 1988), Spain (Regato et al., 1999), Austria (Wrbka et al., 1999), New Zealand (Leathwick et al., 2003a,b), and Senegal (Tappan et al., 2004).

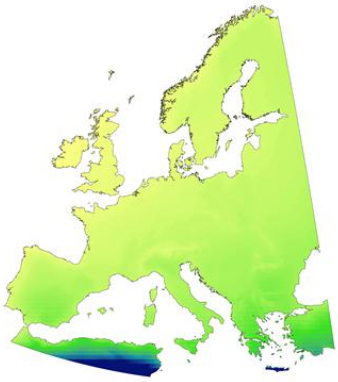
Environmental stratification provides a context within which analyses of dynamic change can be made in the same way as climatic stratification. It is essential that the environmental stratification has a sufficiently fine resolution and that it is derived statistically in a same way as climatic stratification (see previous paragraph). In order to place environmental information into a European context, it is necessary to use standardized methods of synthesizing environmental data into strata that allow objective aggregation. The development of a statistical classification of environmental conditions is the first step in the production of a tool for deriving stratified random samples because it allows areas and situations to be compared in a reproducible way (Bunce et al., 1996a). On a continental scale, e.g. data comparisons and scenario building for the European Union (EU), a stratification of land into more or less homogeneous regions provides a valuable framework because statistical inference requires sample data to be representative of a defined population (Cochran, 1977). Within a stratum changes or effects can, as far as possible, be analysed separately from environmental heterogeneity by using standard statistical procedures (Bunce et al., 1996a; Cochran, 1977).



Climate
- minimum temperature
- maximum temperature
- precipitation
- sunshine



Geomorphology
(substitutes)
- altitude
- slope



Oceanicity
- annual temperature range divided by latitude



Northing
- latitude

Figure 1 The four major layers of the Environmental Stratification in Europe (see text).

Two earlier European statistical environmental stratifications have been produced. In the first, Jones & Bunce (1985) defined eleven classes on a 50 × 50 km grid for Europe. More than a decade later, improved data availability, software and computing power allowed the classification of 64 classes on a 0.5 °grid (approximately 50 × 50 km) (Bunce et al., 1996d). At this resolution, some of the grid cells are relatively heterogeneous for climate and altitude. For example, the grid cell with the Picos de Europa in the Cantabrian Mountains in north-western Spain contains an elevation range from sea level to mountain summits at an altitude of 2500 m, with associated contrasting climate regimes. The earlier classifications were therefore too coarse to be used for monitoring programmes for land use change and for developing detailed scenarios.

The second one relates to the Environmental Stratification of Europe (EnS), which has 84 strata Combined in 13 Environmental Zones (EnZ) with a 1 km^2 resolution (Metzger et al 2005). Main parameters considered for this stratification are (Figure 1): Climate, Geomorphology, Oceanity, and Northing.

The stratification is based on statistical clustering, which has become a tool that is now available for European environmental applications. All together the clustering results in 13 different environmental zones. Figure 2 shows a map of the environmental zones across Europe. The relative areas of Member States in the environmental zones are presented in Table 1. Each of the zones is further characterized below in Tables 2 and 3, respectively, summarizes the location of these areas, their relative areas within the EU and some predominant climatic properties. Figures 3 and 4, respectively, show the average precipitation and temperature in each zone. A detailed description of the 13 Environmental Zones is given in Annex I.

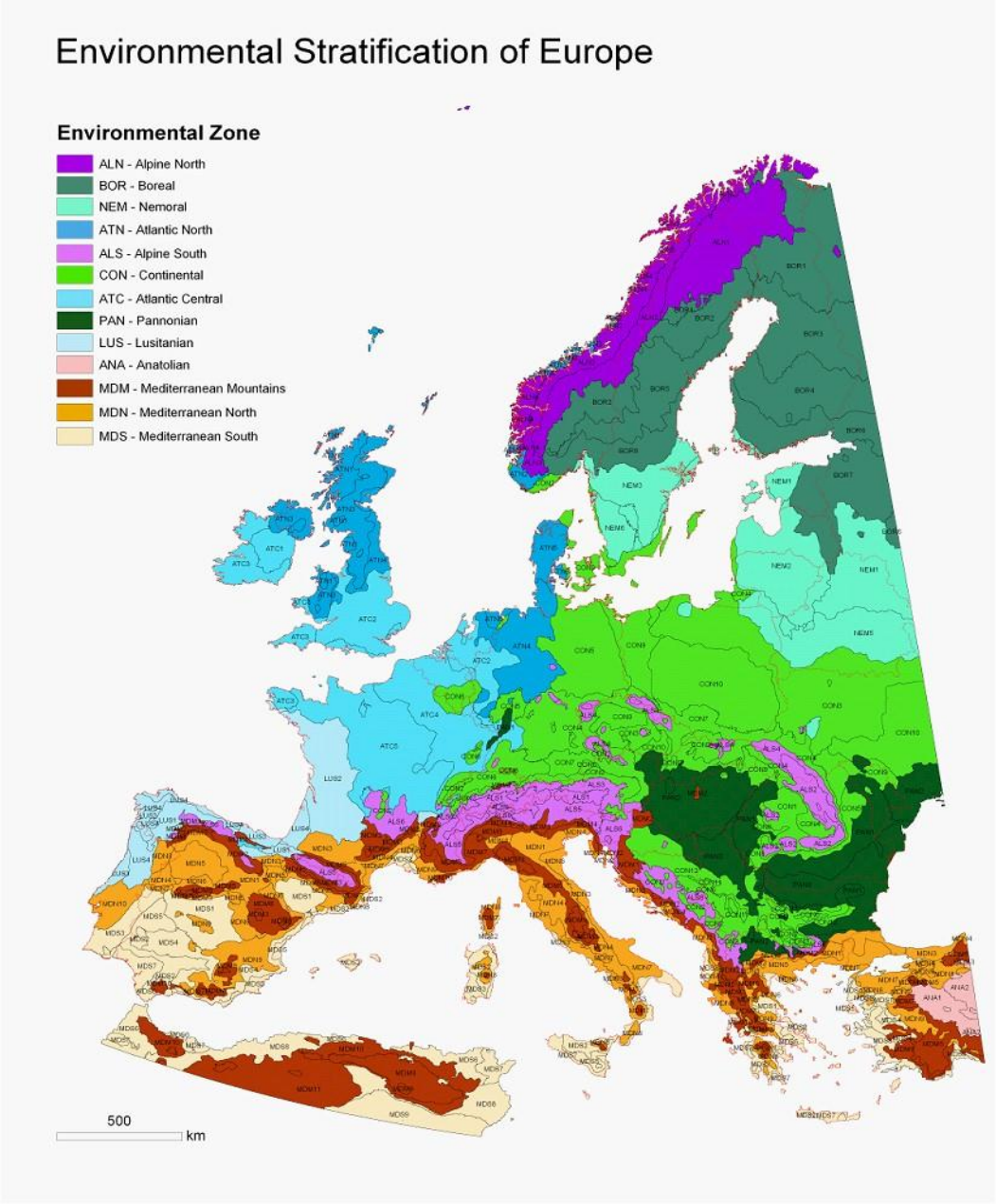


Figure 2. The Environmental Stratification of Europe (Metzger 2005).

Table 1 . Percentage cover of the 13 Environmental Zones (EnZs) per country

		Environmental zones (EnZs)											
	Country	ALN	BOR	NEM	ATN	ALS	CON	ATC	PAN	LUS	MDM	MDN	MDS
FI	Finland	7.8	90.9	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N	Norway	63.6	28.6	1.2	4.9	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0
SE	Sweden	22.3	48.2	25.3	0.0	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0
EW	Estonia	0.0	52.3	47.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LV	Latvia	0.0	29.7	67.5	0.0	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0
LT	Lithuania	0.0	0.0	97.9	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0
BY	Belarus	0.0	0.9	84.0	0.0	0.0	15.1	0.0	0.0	0.0	0.0	0.0	0.0
CH	Switzerland	0.0	0.0	0.0	0.0	52.2	44.5	1.3	0.0	0.0	2.1	0.0	0.0
UK	UK	0.0	0.0	0.0	58.6	0.0	0.0	41.4	0.0	0.0	0.0	0.0	0.0
FL	Lichtenstein	0.0	0.0	0.0	0.0	37.9	62.1	0.0	0.0	0.0	0.0	0.0	0.0
AT	Austria	0.0	0.0	0.0	0.0	46.3	41.9	0.0	11.6	0.0	0.2	0.0	0.0
DK	Denmark	0.0	0.0	0.0	65.8	0.0	34.2	0.0	0.0	0.0	0.0	0.0	0.0
CZ	Czech Republic	0.0	0.0	0.0	0.0	15.6	82.3	0.0	2.1	0.0	0.0	0.0	0.0
DE	Germany	0.0	0.0	0.0	23.8	2.0	63.0	10.2	1.0	0.0	0.0	0.0	0.0
PL	Poland	0.1	0.0	5.3	0.0	1.8	92.8	0.0	0.0	0.0	0.0	0.0	0.0
NL	Netherlands	0.0	0.0	0.0	30.1	0.0	1.5	68.4	0.0	0.0	0.0	0.0	0.0
SK	Slovakia	0.5	0.0	0.0	0.0	5.9	70.3	0.0	23.3	0.0	0.0	0.0	0.0
IE	Ireland	0.0	0.0	0.0	11.0	0.0	0.0	89.0	0.0	0.0	0.0	0.0	0.0
AD	Andorra	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RO	Romania	0.0	0.0	0.0	0.0	16.6	34.6	0.0	48.8	0.0	0.0	0.0	0.0
LU	Luxemburg	0.0	0.0	0.0	0.0	0.0	41.5	58.5	0.0	0.0	0.0	0.0	0.0
BE	Belgium	0.0	0.0	0.0	0.0	0.0	33.8	66.2	0.0	0.0	0.0	0.0	0.0
MO	Moldova	0.0	0.0	0.0	0.0	0.0	28.6	0.0	71.4	0.0	0.0	0.0	0.0
SL	Slovenia	0.0	0.0	0.0	0.0	74.8	6.0	0.0	1.3	0.0	17.3	0.6	0.0
BH	Bosnia-Herzeg	0.0	0.0	0.0	0.0	35.3	50.0	0.0	2.0	0.0	9.7	3.0	0.0
MT	Montenegro	0.0	0.0	0.0	0.0	39.4	31.0	0.0	0.0	0.0	17.1	12.5	0.0
SB	Serbia	0.0	0.0	0.0	0.0	2.2	50.4	0.0	47.4	0.0	0.0	0.0	0.0
H	Hungary	0.0	0.0	0.0	0.0	0.0	7.7	0.0	90.5	0.0	1.7	0.0	0.0
BG	Bulgaria	0.0	0.0	0.0	0.0	3.0	30.7	0.0	59.5	0.0	0.6	6.2	0.0
FR	France	0.0	0.0	0.0	0.0	8.3	3.4	48.5	0.2	20.1	8.9	9.2	1.4
HR	Croatia	0.0	0.0	0.0	0.0	9.4	31.2	0.0	16.6	0.0	29.1	13.8	0.0
MK	Macedonia	0.0	0.0	0.0	0.0	22.4	13.9	0.0	43.5	0.0	6.6	13.6	0.0
AL	Albania	0.0	0.0	0.0	0.0	15.2	6.6	0.0	0.0	0.0	36.3	30.3	11.6
SM	San Marino	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0
IT	Italy	0.0	0.0	0.0	0.0	12.2	0.0	0.0	0.0	0.0	25.6	43.1	19.2
ES	Spain	0.0	0.0	0.0	0.0	3.3	0.0	0.4	0.0	11.3	16.4	30.8	37.8
PT	Portugal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.8	0.6	39.4	26.1
GR	Greece	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.5	0.0	21.7	36.3	40.4
MC	Monaco	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.9	95.1	0.0
M	Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
CY	Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.8	0.0	73.2

Table 2 The 13 Climatic Zones or Environmental Zones (EnZs)

Nr	Environmental Zone	Main locations and characteristics
1	Alpine North (ALN)	Scandinavian mountains
2	Alpine South (ALS)	The high mountains of central and southern Europe
3	Atlantic North (ATN)	NW Europe; under influence of the Atlantic ocean and the North sea
4	Atlantic Central (ATC)	Western Europe, moderate climate
5	Boreal (BOR)	The lowlands of Scandinavia
6	Continental (CON)	Central Europe; warm summers and cold winters
7	Lusitenean (LUS)	The southern Atlantic area; warm summers and mild winters
8	Mediterranean North (MDN)	Mediterranean north, with Cork Oak, fruit plantations and Olive groves
9	Mediterranean Mountains MDM	Mediterranean mountains, influenced by Mediterranean and mountains
10	Mediterranean South (MDS)	Typical Mediterranean climate; mild winter and hot, dry summers
11	Nemoral (NEM	Southern Scandinavia, Baltic states and Belarus
12	Pannonian (PAN)	The steppe part of Europe; cold winters and dry hot summers
13	Anatolian (ANA)	The steppes of Turkey, a Mediterranean steppe environment

Table 3. Relative area in Europe, mean winter and summer temperature and rainfall and the number of days when the mean temperature is above 5 °C of the 13 Environmental Zones (EnZs).

		Relative	Mean temperature, ºC		# days	Mean rainfall, mm		
Nr	ENZs	area, %	Winter	Summer	Temp > 5ºC	Winter	Summer	Total
1	ALN	5	-6	6	130	504	432	937
2	BOR	14	-5	9	157	263	349	612
3	NEM	8	-1	13	196	276	374	650
4	ATN	5	4	12	255	658	491	1149
5	ALS	5	1	11	220	475	614	1089
6	CON	20	2	15	227	270	415	685
7	ATC	8	6	14	296	437	389	826
8	PAN	7	4	18	250	231	337	568
9	LUS	3	9	16	353	622	406	1028
10	ANA	1	3	12	n.a.	202	138	340
11	MDM	9	7	18	298	424	292	716
12	MDN	9	8	18	335	411	277	688
13	MDS	9	12	21	363	368	149	516

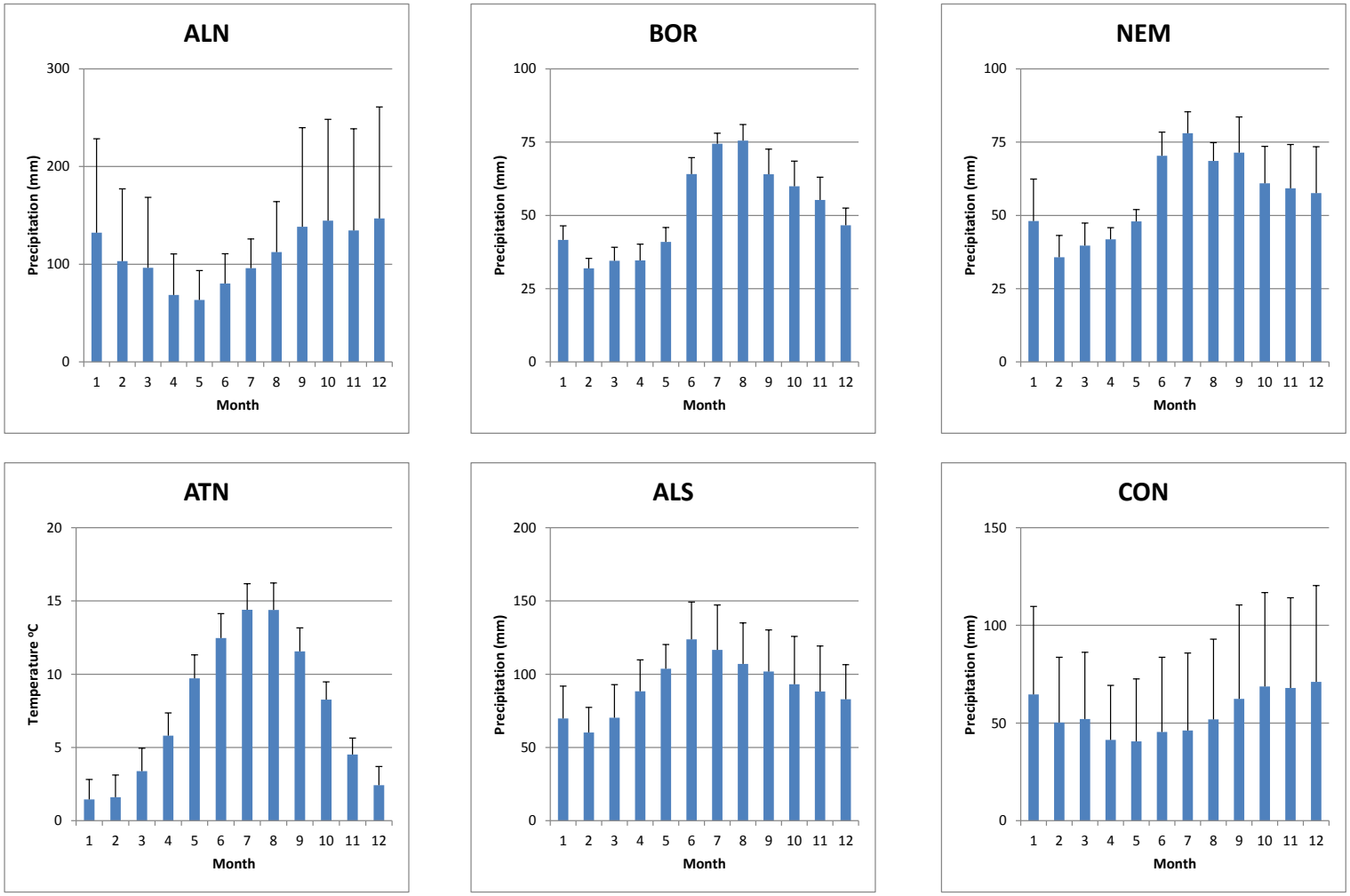


Figure 3. Average monthly precipitation (mm) in the Environmental Zones , the bar represents the standard deviation. Note the difference in scales.

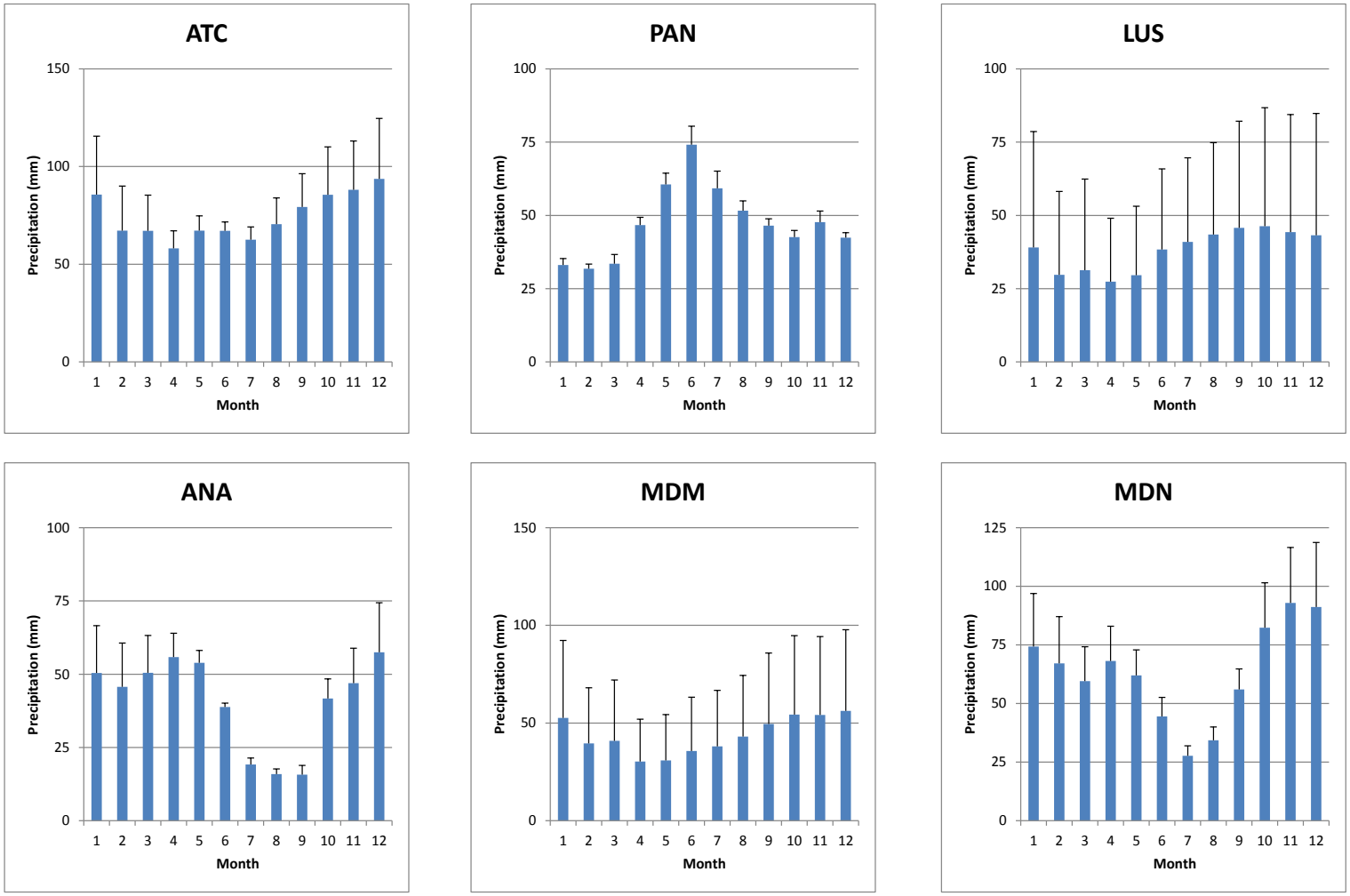


Figure 3. (continued)

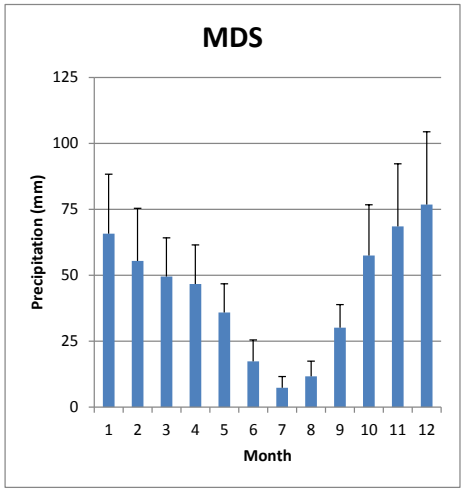


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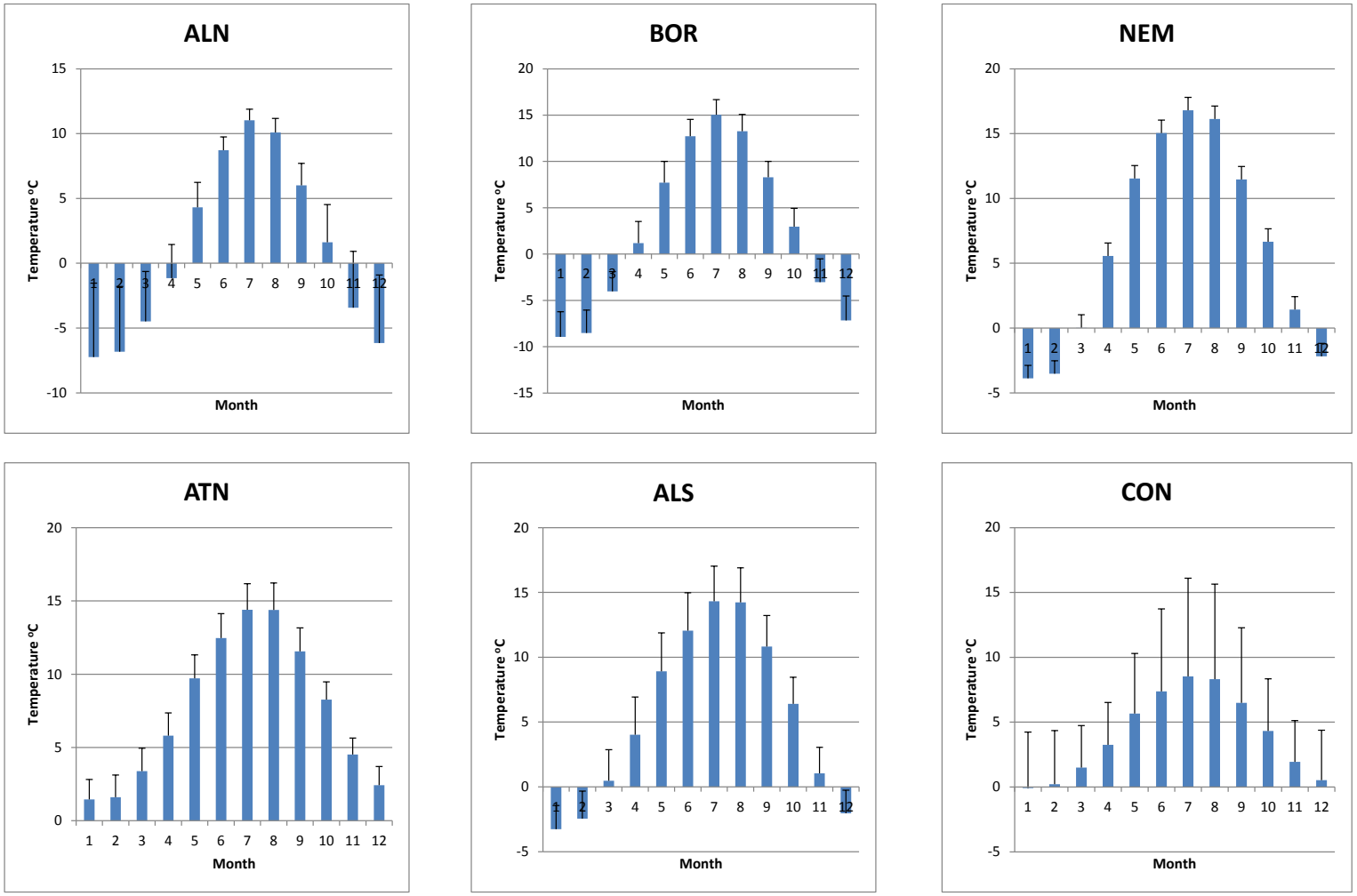


Figure 4. Average monthly temperatures (°C) in the Environmental zones, the bar represents the standard deviation. Note the difference in scales.

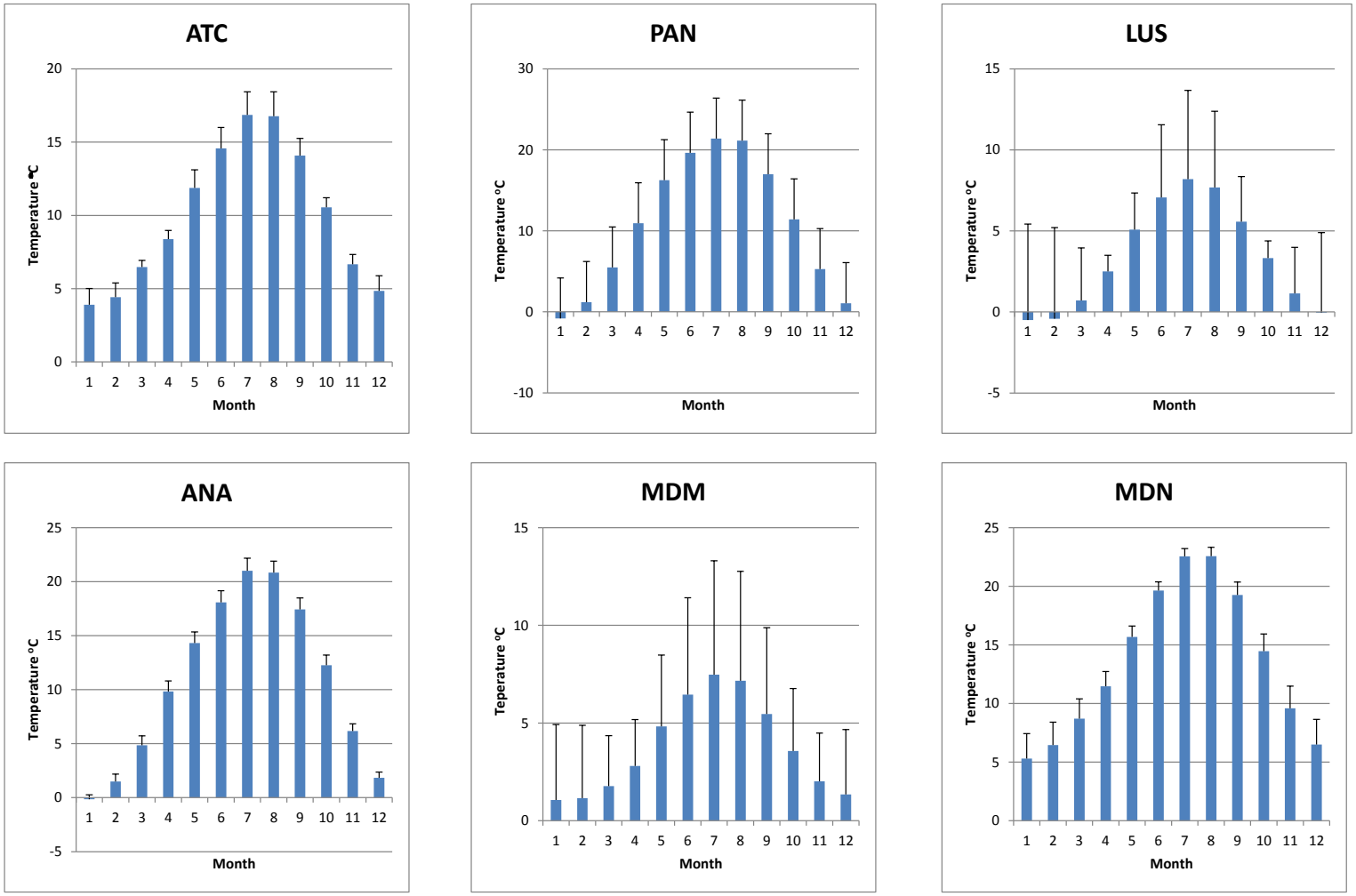


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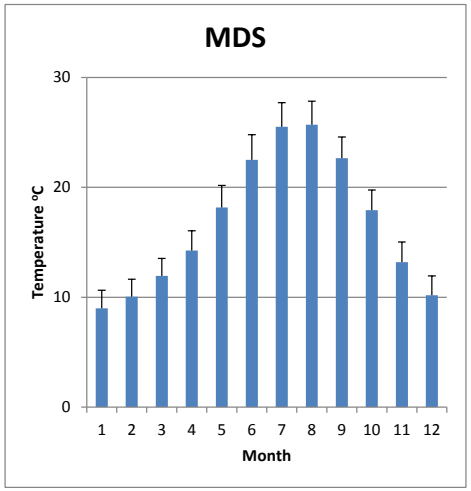


Figure 4. (continued)

5 Review of literature on soil stratification

5.1 Introduction

The Russian scientist Vasily Dokuchaev (1846 – 1903) is commonly regarded as the father of soil classification and mapping, the study of soils in its natural setting. He was the first person to make geographical investigations of different soil types. He introduced the idea that geographical variations in soil type could be explained in relation not only to geological factors (parent material), but also to climatic and topographic factors, and the time available for soil formation to operate. Using these ideas as a basis, he created the first soil classification.

The Swiss Hans Jenny's (1899–1992) gave with his book 'Factors of Soil Formation' in 1941 a generic mathematical relationship between observed soil properties (s) and independent factors that determine the process of soil formation and hence the soil properties, according to:

$s = f(cl, o, r, p, t)$
where s = soil type and soil properties, cl = climate, o = biota, r = topography, p = parent material, and t = time.

5.2 Soil classification and maps

Though the insights of Dokuchaev, Jenny and many other early soil scientists have been distributed and adopted by almost all soil scientists around the world, almost all countries have developed their own soil characterization, classification, survey and mapping systems and procedures. As a consequence, soil types and soil maps identified and made in different countries are difficult to compare.

Soil maps show the spatial distribution of soil types and/or soil properties (soil pH, textures, organic matter, depths of horizons etc.) in specific area. It is typically the end result of a soil survey inventory, i.e. soil survey. Soil maps are most commonly used for land evaluation, spatial planning, agricultural extension, environmental protection and similar projects. Traditional soil maps typically show only general distribution of soils, accompanied by the soil survey report. Many new soil maps are derived using digital soil mapping techniques, including geo-statistical techniques. Such maps are typically richer in context and show higher spatial detail than the traditional soil maps. Soil maps produced using geo-statistical techniques also include an estimate of the model uncertainty.

The United Nation 'Food and Agriculture Organization' (FAO) recognized the difficulties of country-specific soil characterization, classification, survey and mapping systems and procedures, and developed a supra-national classification, also called 'World Soil Classification'. It was first published in the form of the UNESCO Soil Map of the World (1974) (scale 1 : 5 Million). Many of the names offered in that

classification are known in many countries and do have similar meanings. A total of 106 so-called Soil Units have been distinguished, on the basis of the following characteristics:

- soil phases (soil properties, such as saline, lithic, stony),
- three textural classes (coarse, medium, and fine)
- slopes classes superimposed (level varying between gently undulating, rolling to hilly, and steeply dissected to mountainous)

By combining these 106 Soil Units 26 World Classes were formed. The FAO soil map was a simple classification system with broad units, but it was the first international system, and most soils could be accommodated on the basis of their field descriptions. The FAO soil map was intended for mapping soils at a *regional* scale but not at *local* scale.

5.3 World Reference Base for Soil Resources

In 1998 the original FAO soil classification system was replaced by the World Reference Base for Soil Resources (WRB). The WRB is the international standard taxonomic soil classification system endorsed by the International Union of Soil Sciences (IUSS). It was developed by an international collaboration coordinated by the International Soil Reference and Information Centre (ISRIC in Wageningen) and the FAO. The WRB has borrowed from other soil classification concepts, including USDA soil taxonomy, the legend for the FAO Soil Map of the World 1988, the Référentiel Pédologique (FR) and Russian concepts. The classification is based mainly on soil morphology. A total of 32 reference soil groups and 98 soil groups have been defined. The 32 Reference groups are as follows:

1. Soils with thick organic layers:	Histosols (HS)
2. Soils with strong human influence	
Soils with long and intensive agricultural use:	Anthrosols (AT)
Soils containing many artefacts:	Technosols (TC)
3. Soils with limited rooting due to shallow permafrost or stoniness	
Ice-affected soils:	Cryosols (CR)
Shallow or extremely gravelly soils:	Leptosols (LP)
4. Soils influenced by water	
Alternating wet-dry conditions, rich in swelling clays:	Vertisols (VR)
Floodplains, tidal marshes:	Fluvisols (FL)
Alkaline soils:	Solonetz (SN)
Salt enrichment upon evaporation:	Solonchaks (SC)
Groundwater affected soils:	Gleysols (GL)
5. Soils set by Fe/Al chemistry	
Allophanes or Al-humus complexes:	Andosols (AN)
Cheluviation and chilluviation:	Podzols (PZ)
Accumulation of Fe under hydromorphic conditions:	Plinthosols (PT)
Low-activity clay, P fixation, strongly structured:	Nitisols (NT)
Dominance of kaolinite and sesquioxides:	Ferralsols (FR)
6. Soils with stagnating water	
Abrupt textural discontinuity:	Planosols (PL)

Structural or moderate textural discontinuity:	Stagnosols (ST)
7. Accumulation of organic matter, high base status	
Typically mollic:	Chernozems (CH)
Transition to drier climate:	Kastanozems (KS)
Transition to more humid climate:	Phaeozems (PH)
8. Accumulation of less soluble salts or non-saline substances	
Gypsum:	Gypsisols (GY)
Silica:	Durisols (DU)
Calcium carbonate:	Calcisols (CL)
9. Soils with a clay-enriched subsoil	
Albeluvic tonguing:	Albeluvisols (AB)
Low base status, high-activity clay:	Alisols (AL)
Low base status, low-activity clay:	Acrisols (AC)
High base status, high-activity clay:	Luvisols (LV)
High base status, low-activity clay:	Lixisols (LX)
10. Relatively young soils or soils with little or no profile development	
With an acidic dark topsoil:	Umbrisols (UM)
Sandy soils:	Arenosols (AR)
Moderately developed soils:	Cambisols (CM)
Soils with no significant profile development:	Regosols (RG)

5.4 European soil maps and databases

The first soil maps in Europe, which started to appear in the 1800s, were just local or regional maps. Such maps were mostly produced for agricultural purposes and the taxation of rural lands. They emphasized surface geology, and the degree of weathering of the underground rock. The first European-scale maps were produced in 1928 and 1937. These maps also had a strong agro-geological base and were based on limited soil survey work. These first soil maps stimulated soil survey and research in most European countries, which subsequently led to the second generation of European soil maps (1965-1985). These were based on hundreds of detailed national and regional maps. The second generation is now being replaced by a third generation of maps in which use is made of existing soil information with remote sensing and a range of sensors. The second and third generation maps have been compiled in the first 'Soil Atlas of Europe' (Jones at al., 2005). The primary aim of the Soil Atlas of Europe is to provide comprehensive information about the soils of Europe and raising awareness of issues affecting soils; it is part of the European Soil Thematic Strategy (http://ec.europa.eu/environment/soil/index_en.htm).

The soil types of Europe are described following the World Reference Base (WRB) for soil resources. Seven of the 32 WRB soil types (reference groups) do not occur in Europe, like Ferralsols, Alisols and Lixisols. The soils with the largest extent are Albeluvisols that cover 15% of the European land mass; Podzols cover 14%, and Cambisols cover 12%. Overview maps in the Soil Atlas show the availability of soil maps at scales of 1:50,000 or 1:250,000 in Europe. It shows that large countries with large economies and populations (France, Germany, UK) not necessarily have good coverage of detailed soil information. In fact, smaller and more densely populated

countries have more detailed soil maps (with the exception of Denmark and Switzerland). There is an array of reasons, but in densely populated places there may have been a historical need to know the land characteristics as population pressure was higher. In larger countries, the need for detailed spatial information about soil resources might have been less pressing as land was amply available. A map showing the European soils is shown in Figure 4.

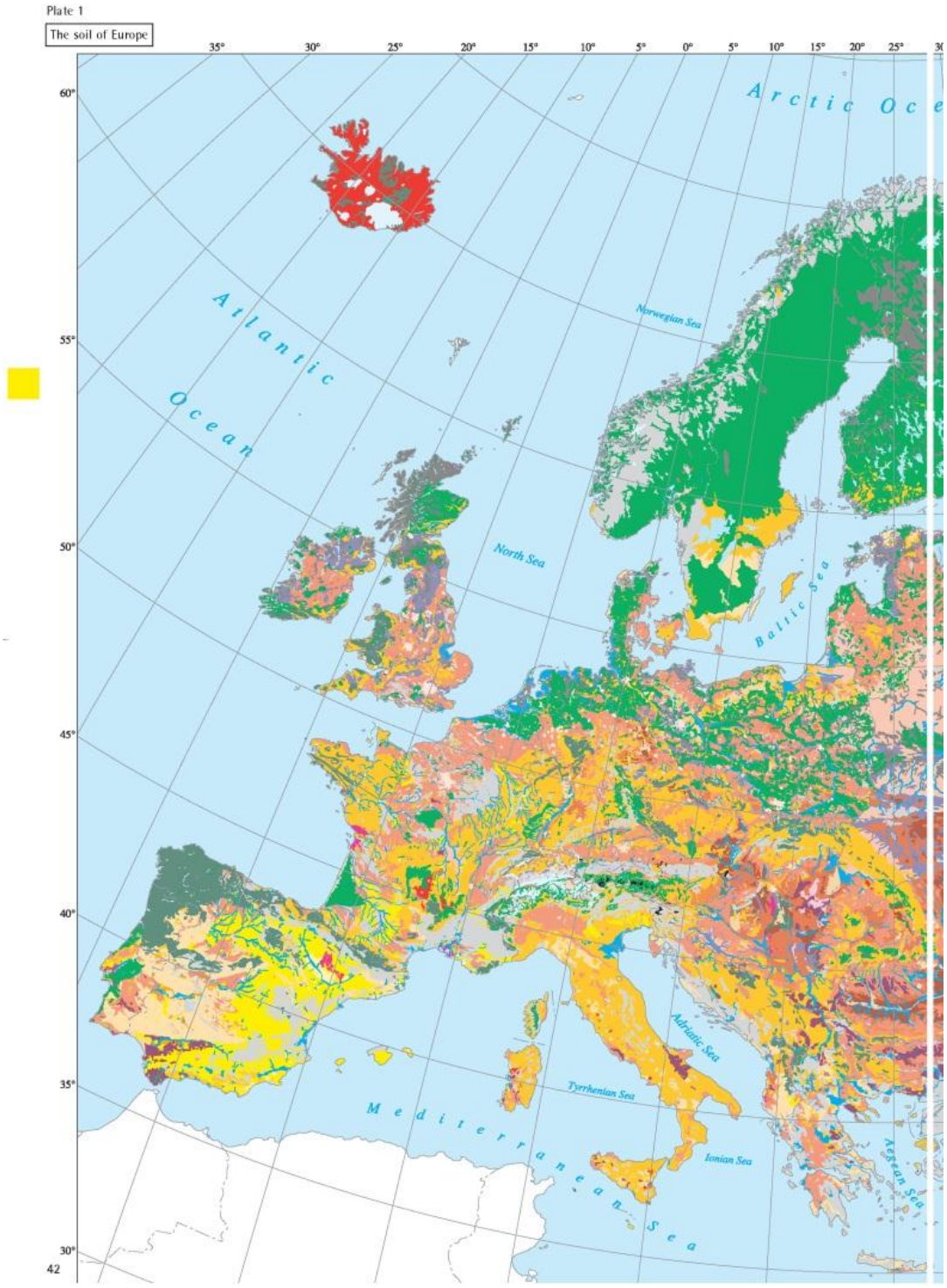


Figure 4. Map of European soils.

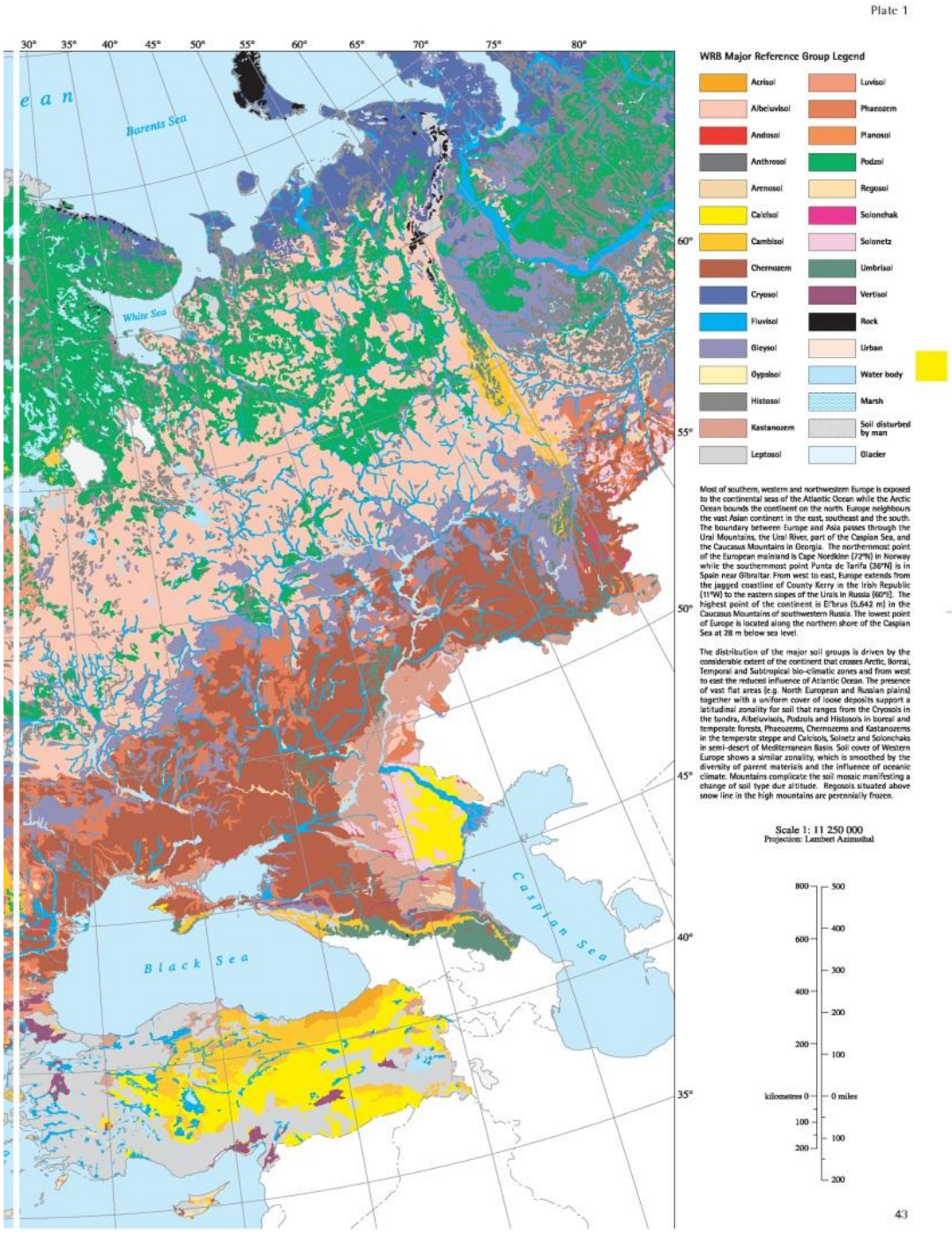


Figure 4 continued.

The European Soil Database (distribution version v2.0) consists of a number of databases:

- the 'Soil Geographical Database' of Eurasia at scale 1:1,000,000 (SGDBE)[4], which is a digitized European soil map and related attributes (version 4 beta)
- the 'PedoTransfer Rules Database' (PTRDB)[5], version 2.0, which holds a number of pedotransfer rules which can be applied to the SGDBE ; the results of the application of the pedotransfer rules to the SGDBE are delivered as a table with new attributes related to the European soil map
- the 'Soil Profile Analytical Database of Europa' (SPADBE)[6], version 2.1.0.0, delivered as tables
- the 'Database of Hydraulic Properties of European Soils' (HYPRES)[7], version 1.0, delivered as a set of Word documents

The Soil Geographical Database of Eurasia (SGDBE) at scale 1:1,000,000 is part of the European Soil Information System (EUSIS). It is a simplified representation of the diversity and spatial variability of the soil coverage. The methodology used to differentiate and name the main soil types is based on the terminology of the F.A.O. legend for the Soil Map of the World at scale 1:5,000,000. This terminology has been refined and adapted to take account of the specificities of the landscapes in Europe.

The SGDBE database contains a list of Soil Typological Units (STU). Besides the soil names they represent, these units are described by variables (attributes) specifying the nature and properties of the soils: for example the texture, the water regime, the stoniness, etc. The geographical representation was chosen at a scale corresponding to the 1:1,000,000. At such a scale, it is not feasible to delineate the STUs. Therefore they are grouped into Soil Mapping Units (SMU) to form soil associations and to illustrate the functioning of pedological systems within the landscapes. Each SMU corresponds to a part of the mapped territory and as such is represented by one or more polygons in a geometrical dataset.

Harmonisation of the soil data from the EU member states is based on a 'dictionary' and 'transfer functions'. Considering the scale, the precision of many soil variables is weak. Furthermore these variables were estimated over large areas by expert judgement rather than measured on local soil samples. These insights results also from the synthesis and generalisation of national or regional maps published at more detailed scales, for example 1:50,000 or 1:25,000 scales. Heterogeneity can be considerable in European regions. The spatial variability of soils is very important and is difficult to express at global levels of precision. Quality indices of the information (purity and confidence level) are included in part with data to guide usage.

[4] http://eusoils.jrc.ec.europa.eu/ESDB_Archive/ESDBv2/intro.htm#SGDBE
[5] http://eusoils.jrc.ec.europa.eu/esdb_archive/ESDBv2/popup/pt_meta.htm
[6] http://eusoils.jrc.ec.europa.eu/esdb_archive/ESDB/ESDB_data_intro.html
[7] http://eusoils.jrc.ec.europa.eu/esdb_archive/eusoils_docs/other/Hypres.pdf

Table 4. Soil variables determining soil characteristics.

Soil variable	Description
Depth	(1) Shallow (< 40 cm), (2) Moderate (40-80cm), (3) Deep (80-120cm), (4) Very deep (> 120cm)
Obstacle to roots	(1) no obstacles between 0 and 80 cm (2) between 60 and 80 cm depth, (3) between 40 and 60 cm, (4) between 20 and 40 cm, (5) between 0 and 80 cm and (6) between 0 and 20 cm
Slope	(1) Level (0 to 2 %), (2) Gently sloping (2-8%) (3) Sloping (8 to 15 %), (4) Moderately steep (15 to 25 %), (5) Steep (>25%)
Texture	(1) No mineral texture (Peat soils), (2) Very fine (clay > 60 %); (3) Fine (35% < clay < 60%); (4) Medium fine (≤35% clay and < 15% sand); (5) Medium (18% < clay < 35% and ≥ 15% sand, or ≤18%clay and ≥15% < sand < 65%), (6) Coarse (≤18% < clay and > 65% sand)

The database important for soil zoning is the SGDBE database. It contains raster (grid) data files with cell sizes of both 1km x 1km and 10km x 10km for a large number of soil related parameters. The soil characteristics important for leaching are soil depth, slope, and the texture of the soil. This information can be presented at 1km x 1km grids. The main variables are summarized below and in Table 4.

- **Depth to rock.** The depth to rock is the depth at which continuous rock is encountered in the soil profile. It is often called the soil depth.
- **Depth class to obstacles to roots**. Obstacles are layers that restrict roots to permeate the soil such as rocks and impermeable deep soil layers. The classes refer to the depth were obstacles are encountered.
- **Dominant slope class**. The dominant slope gradient is expressed as a class. The classes do not correspond with the FAO classifications of slope classes.
- **Texture.** Soil texture refers to the proportion of the various particle-size classes (or soil separates, or fractions) in a given soil volume and is described as soil textural class. The soil texture in this case refers to the fine earth fraction (< 2 μm). The names for the particle-size classes correspond closely with commonly used standard terminology.

All these variables can be used in determining the risk of leaching and/or run off, although it must be emphasized that resolution in the slope classes used is rather rough, since risk of run off may occur already at slopes << 8% especially when the infiltration rate of water (and irrigation) into the soil is low and the intensity and duration of rainfall (an irrigation) are large. The latter may occur when the soil is saturated with water or the (sub) soil is frozen or has a low permeability (e.g. Brogan, 1981).

5.5 Towards statistical clustering of soil characteristics.

Currently no European geological map is available and the available European soil maps are difficult to include in statistical clustering due to the classification method that is used for mapping soils (Metzger et al., 2005; Jongman et al., 2006). Soil classification and mapping is often based on expert knowledge of soil scientists, often without quantitative critical thresholds.

A second problem is that soil maps often contain nominal data, which are not easily incorporated into the statistical clustering that is based on continuous data only[8] (Metzger et al., 2005; Jongman et al., 2006). Transformation of nominal data into continuous data is possible, but transformation would unbalance the final set of variables, as discussed by Bunce et al. (1996a), making a proper statistical analysis impossible. Finally, soil variables derived from pedo-transfer functions (e.g. pH and water-holding capacity) can be incorporated into the clustering, but because the climate variables vary at a broader scale than the soil variables, the resulting map is fragmented and shows little internal consistency and little relation to climate zones.

5.6 European maps of mountainous zones

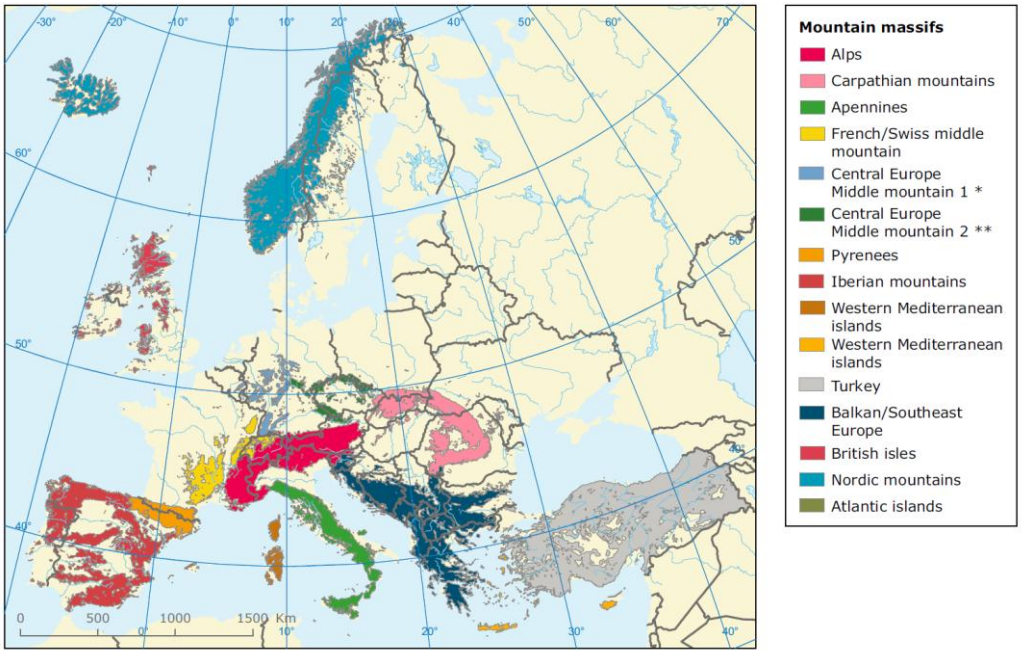
One of the most recent studies on the morphological, relief or mountainous zones in EU is the study of the EEA "Europe's ecological backbone: recognising the true value of our mountains". The mountain areas in Europe are defined on the basis of the criteria mentioned in Table 5. Interestingly, the definition of mountainous areas differs between different countries. The spatial distribution of the mountain areas are visualised in Figure 2 with the areas of mountains in each EU country tabulated in Table 6. These areas can roughly be considered as areas where agriculture is a minor activity, due to the high altitude and/or steep slopes.

[8] nominal or discrete data are categorical data where the number of the categories is arbitrary, with clear distinct borders e.g. soil classes; continuous data in contrast, have no distinct borders, e.g. temperature, altitude and latitude

Table 5. Criteria for definition of mountain area in European countries (EEA, 2010).

State	Minimum elevation	Other criteria
Albania	650 m	
Austria	700 m	Also above 500 m if slope > 20 %
Belgium	300 m	
Bulgaria	600 m	Also > 200 m altitudinal difference/km2; or slope > 12 °
Croatia	650 m	
Cyprus	800 m	Also above 500 m if average slope 15 %
Czech Republic	700 m	
France	700 m (generally) 600 m (Vosges) 800 m (Mediterranean)	Slope > 20 % over > 80 % of area Climatic difficulties
Germany	700 m	
Greece	800 m	Also 600 m if slope > 16 %; Below 600 m if slope > 20 %
Hungary	600 m	Also above 400 m if average slope > 10 %; or average slope >20 %
Italy	600 m	Altitudinal difference > 600 m
Norway	600 m	
Poland	350 m	Or > 12 ° for at least 50 % of agricultural land in a municipality
Romania	600 m	Also on slopes > 20 °
Slovakia	600 m	Also above 500 m on slopes > 7 °; or average slope > 12 °
Slovenia	700 m	Also above 500 m if more than half the farmland is on slopes of > 15 %; or slope > 20 %
Portugal	700 m (north of Tejo river) 800 m (south of Tejo river)	Slope > 25 %
Spain	1 000 m	Slope > 20 % Elevation gain 400 m
Ukraine	400 m	Also relating to scarcity of agricultural land and climatic conditions

Sources: Castelein et al. (2006); national reports for European Commission (2004b); European Observatory of Mountain Forests (2000); Price (2000).



Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Figure 2. Mountain massifs (EEA, EEA Report 6/2010)

Table 6. Mountain areas across the countries of Europe (EEA, EEA Report 6/2010)

Country	National area (km²)	Mountain area (km²)	Mountain area %
European Union			
Austria	83 929	61 960	74
Belgium	30 663	1 340	4
Bulgaria	110 797	54 057	49
Cyprus	9 248	4 259	46
Czech Republic	78 866	25 668	33
Denmark	43 360		
Estonia	45 330		
Finland	337 797	5 031	1
France	549 169	137 524	25
Germany	357 678	57 764	16
Greece	132 021	94 886	72
Hungary	93 018	4 755	5
Ireland	70 177	10 096	14
Italy	301 424	181 150	60
Latvia	64 603		
Lithuania	64 892		
Luxembourg	2 596	212	8
Malta	316	35	11
Netherlands	37 357		
Poland	311 894	16 308	5
Portugal	92 187	34 980	38
Romania	237 948	90 094	38
Slovakia	49 026	29 454	60
Slovenia	20 274	15 378	76
Spain	505 964	274 613	54
Sweden	449 445	92 275	21
United Kingdom	244 722	60 689	25
European Union	**4 231 683**	**1 247 773**	**29**
Non-European Union			
Albania	28 531	23 002	81
Andorra	465	465	100
Bosnia And Herzegovina	51 275	40 379	79
Croatia	56 634	22 512	40
Former Yugoslav Republic of Macedonia	25 153	22 695	90
Iceland	102 907	67 413	66
Liechtenstein	161	161	100
Moldova	33 924	1 132	3
Montenegro	14 148	13 267	94
Norway	323 453	252 112	78
Serbia	88 428	47 035	53
Switzerland	41 288	38 806	94
Turkey	780 120	605 062	78
Ukraine	592 135	21 662	4
Europe	**6 672 759**	**2 409 601**	**36**

Source: Mountain massif delineation as defined for this study, country borders from EEAMapdata_5210_v2_3EEA16722I.

6 Review of crop growth potential

Crop growth and crop yield are strongly influencing total evapotranspiration, which subsequently influences leaching rate and also run off. Here, we briefly review the potential yield and the water limited yield of winter wheat and forage. Winter wheat can be considered as a model crop for arable crops and forage is a model crop for grasslands.

Crop growth and biomass yield are determined by (i) the genetic potential (G) of the crop cultivar, (ii) environmental conditions (E) , including climate, weather, altitude, soil, geomorphology, hydrology, and (iii) management (M), including cultivation practices (date of sowing, amounts of irrigation and fertilizer) and pest and disease management. Hence, crop yields are determined by the interactions of G x E x M. The crop growth potential of a given crop at a given site is determined by G x E, while considering M optimal (i.e. crop growth is neither limited by nutrient and water limitations, nor reduced by pests and diseases). Often, a distinction is made between (a) crop growth potential, and (b) water-limited crop growth potential. In the latter case, crop yields are limited by the availability of water, while assuming no irrigation, but not by nutrient limitations and also not by yield reducing pests and diseases

Maps of crop biomass yield potentials are based on the genetic potentials of the crop and climate data, and are produced by crop growth simulation models. One of such models is WOFOST (WOrld FOod STudies) for the quantitative analysis of the growth and production of annual field crops (http://www.wofost.wur.nl). It is a mechanistic model that explains crop growth on the basis of the underlying processes, such as photosynthesis, respiration and how these processes are influenced by environmental conditions. With WOFOST, potential crop production, biomass, water use, etc. for a location can be estimated, using site specific information about soil type, crop type, weather data and crop management factors (e.g. sowing date). WOFOST has been implemented in the Crop Growth Monitoring System which is used operationally to monitor arable crops in Europe and to make crop yield forecasts for the current growing season. WOFOST is used also in the Monitoring Agro-ecological resources with Remote sensing and Simulation (MARS) project, and has been used also as a yield estimating tool in an early warning system for food security in Africa.

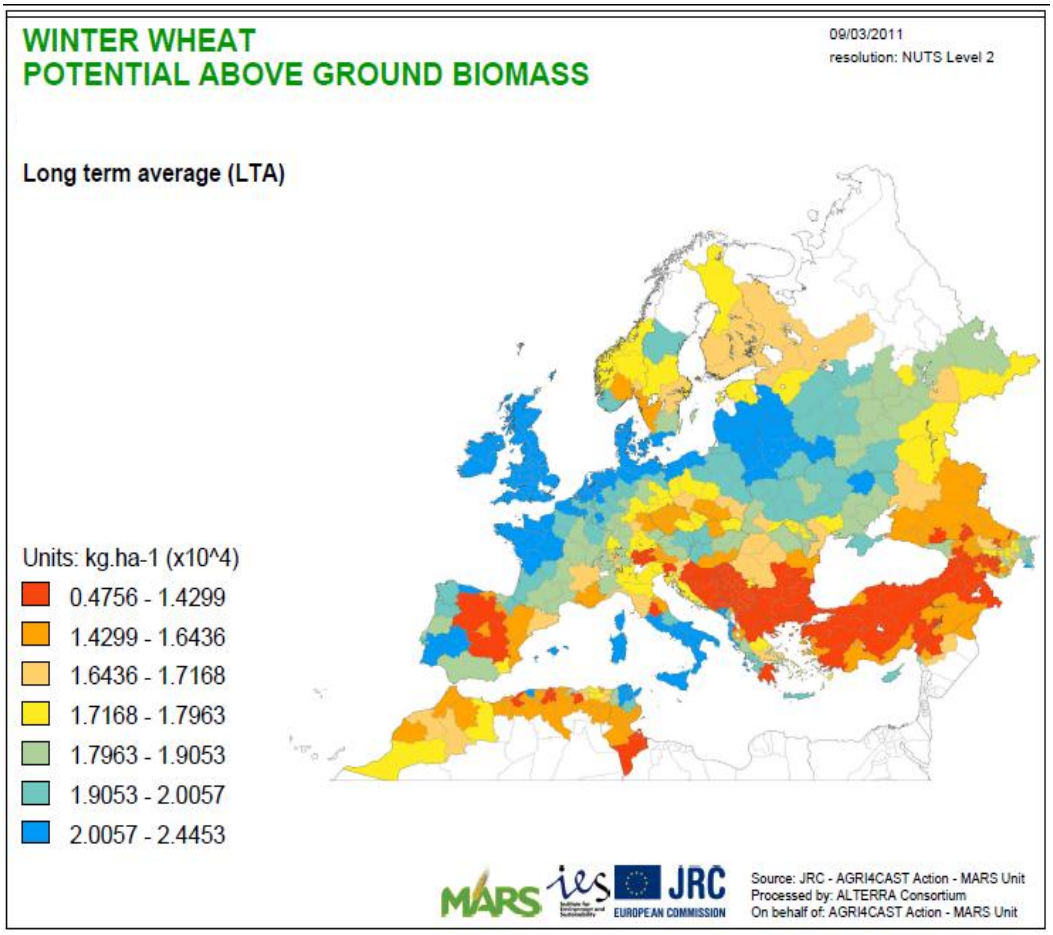


Figure 3. Potential annual winter wheat biomass production in Europe, as estimated by WOFOST.

The average potential biomass yield and water limited yield of winter wheat are shown in Figures 3 and 4, respectively. These yields are based on long-term weather data, and basic soil characteristics (e.g. soil depth, soil moisture holding capacity). Potential production of winter wheat is predominantly determined by day length, solar radiation and temperature with the lowest production in the Northern parts of Europe and the higher altitudes. In the extreme North and on the highest mountain tops, no growth is possible (Figure 3). The highest potential production is in the North West and central parts of Europe as well as south of Italy and Spain and Portugal, as a combined effect of temperature and the day length during the relatively short period of maximum photosynthesis and nutrient uptake for winter wheat, which stops mostly after flowering.

Water limited biomass yield is mostly determined by rainfall during the growth period (Figure 4). The difference in patterns between the potential biomass yield and water-limited biomass yield maps is not very large; water-limited production is lower, especially in the Mediterranean countries.

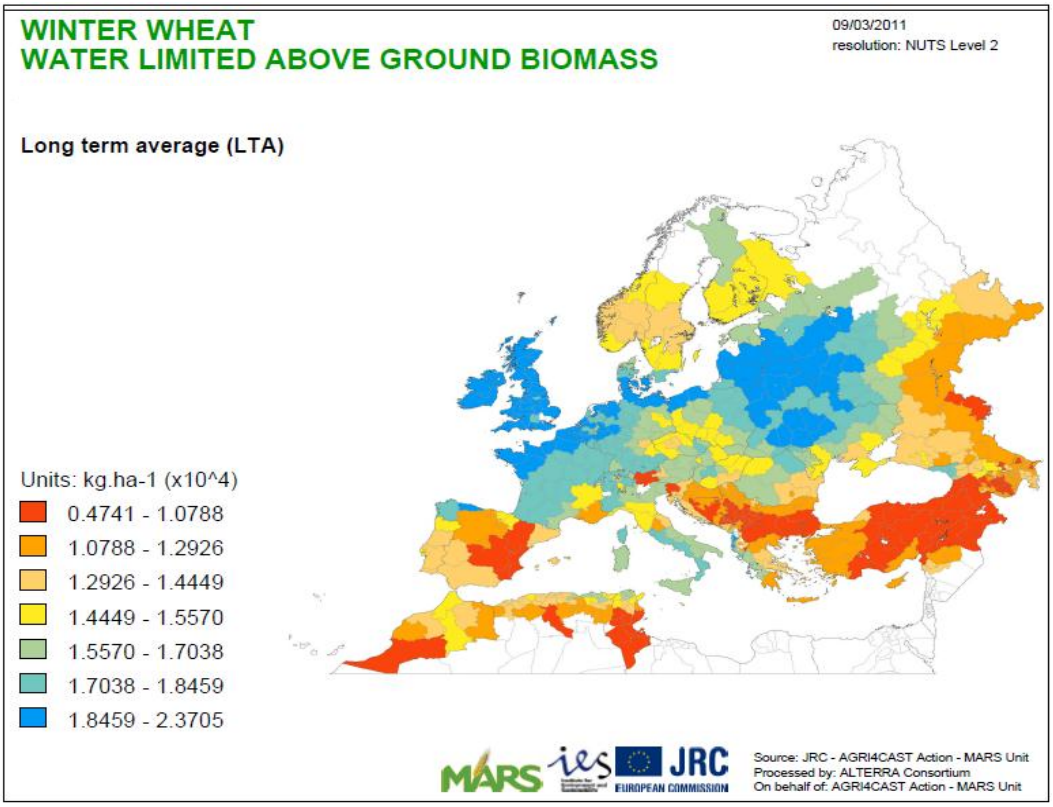


Figure 4 Water-limited annual winter wheat biomass yield in Europe, as estimated by WOFOST.

The average potential biomass yield and water limited biomass yield of forage are shown in Figures 5 and 6, respectively. For forage day length and temperature even more determines potential production than for winter wheat. Due to shortage of water during a long period of the year, the areas with a high potential biomass production in southern parts of Europe (Figure 5), belong to the areas with the lowest water-limited biomass production (Figure 6). Hence, the water-limited crop yields are mainly determined by low temperature (and short growing season) in northern Europe and by water shortage in southern Europe.

The map of crop production illustrates the importance of climate for crop production: day length, incoming solar radiation and temperature being the most important factor for potential production and water availability the most important factor for water limited production. Note also that the patterns of crop growth potentials resemble similar patterns as shown on the map for the environmental stratification in Figure 1.

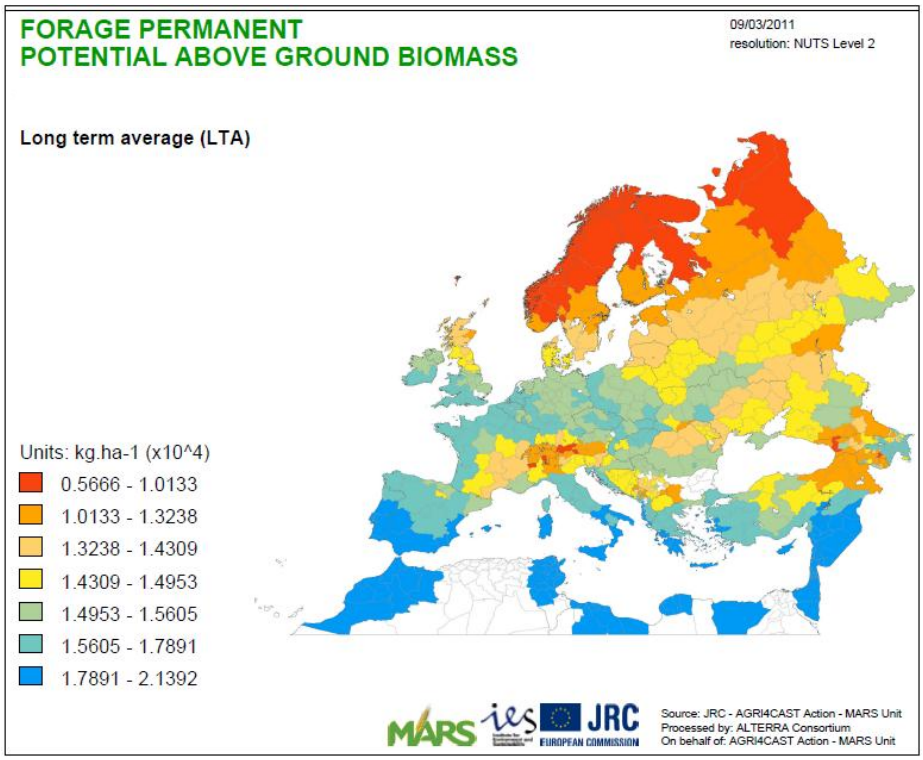


Figure 5 Potential annual forage biomass yields in Europa, as estimated by WOFOST.

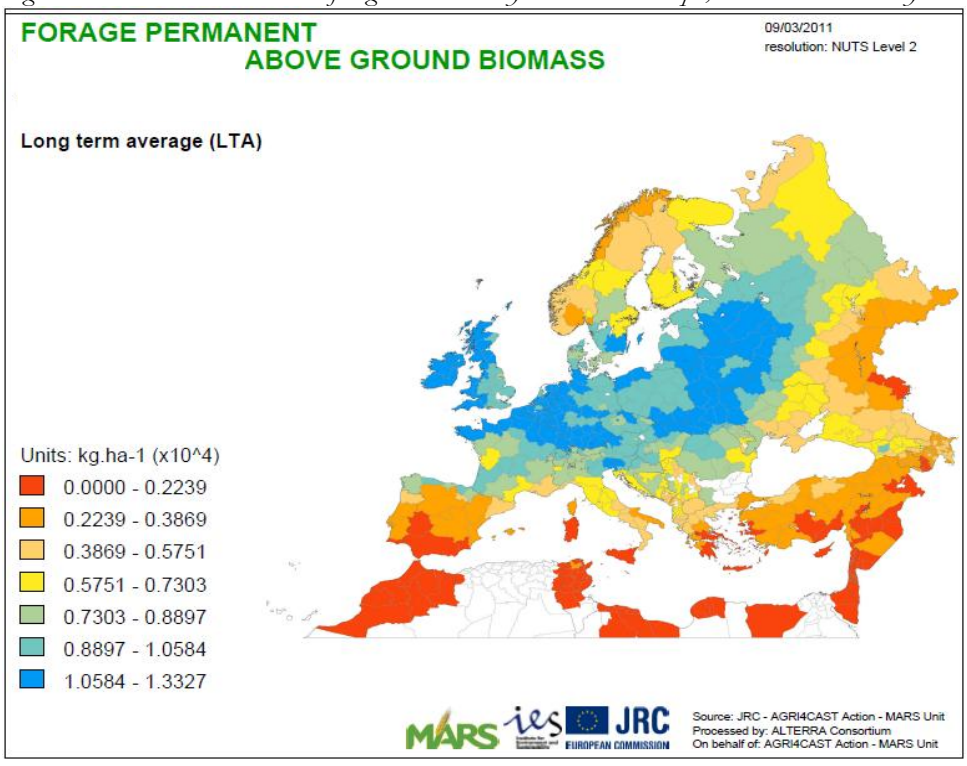


Figure 6 Water limited annual forage biomass yields in Europa, as estimated by WOFOST

The maps for the potential and water-limited forage production provide also a basis for a regional differentiation of irrigation and fertilization. Conversely, they also indicate the areas with a potential risk of pollution of waters with nutrients, especially when the fertilization rates are not adjusted to the actual yield potential. Areas with a high potential biomass yield will be the areas with relatively high levels of fertilization. However, when the actual biomass yields are much lower than the mean potential biomass yields, due to for example pest and diseases, weather conditions strongly deviating from mean weather conditions, or simply poor management, and the fertilization rates are not sufficiently adjusted to these actual biomass yields, the risk of nutrient losses may be large. Moreover, unbalanced irrigation and fertilization in areas with a large difference between potential and water limited biomass yields also harbours the risks of nutrient losses via leaching and run off.

7 Criteria for pedo-climatic zones in Action Programmes

In line with the context of the Nitrates Directive, i.e. prevention of pollution of groundwater and surface waters by nitrates (and phosphates) from agriculture, the 12 different elements of the Action Programmes and the literature reviewed in Chapters 2 to 6, as well as those reviewed in part B of this report, we defined three general (main) criteria for pedo-climatic zoning; (i) Crop growth potential, (ii) Risk of runoff and leaching to surface waters, including eutrophication, and (iii) Risk of leaching to groundwater. Risk for eutrophication has not been explicitly considered for the definition of pedo-climatic zones, as this process is very complex and encompasses various parameters and aspects. However, as eutrophication is caused by excessive concentrations of nitrogen and phosphorus in water, it is assumed that the above defined criteria will also cover risk for eutrophication.

Re 1. Zones determining crop growth potential and the demand for nitrogen and phosphorus

The demand for nutrients and (irrigation) water, and the demand for pest and disease control depend also on the crop growth potential. Hence, crop growth potential is an important determinant for the demand for nitrogen and phosphorus by the growing crops, and indirectly also for the leaching of nitrogen and phosphorus to groundwater and surface waters.

The spatial patterns of crop biomass yield is slightly different for wheat and forage (grassland), because of differences in genetic traits. Moreover, the spatial patterns are different for potential biomass yields and water-limited biomass yields (Figures 3-6). These maps distinguish 7 broad classes of biomass yields. The size range of these classes are chosen in such a way that the surface areas within each class are roughly equal.

Clearly, the spatial patterns of the potential crop biomass yields resemble similar spatial patterns as shown for environmental stratification in Figure 1, because both stratifications are based on climate data. Note, that all maps (Figures 1 and Figures 3-6) show general south-west to north-east zoning patterns, but also local and regional spots that deviate due to different environmental conditions (e.g. latitude and general soil characteristic). The resemblance of the patterns of potential crop biomass yields and environmental stratification provides justification for choosing the environmental stratification as one of the pillars for pedo-climatic zoning. Areas with a high potential biomass yield demand more nutrients than areas with a low potential biomass yield. On the other hand, areas with high biomass yield may also be the high risk areas, especially when there is a significant difference between actual and potential biomass yields, and/or when management is poor. Further, a large difference between potential biomass yield and water-limited biomass yield indicates the areas where irrigation may be important and hence, where irrigation induced nutrient losses may occur.

Re 2. Zones determining the potential risk of runoff and leaching of nitrogen and phosphorus to surface waters

The potential risk of runoff and leaching to surface waters is determined by a combination of the amounts of dissolved total nitrogen and total phosphorus in the top soil and (b) pedo-climatic factors. The amounts of total N and total P in the top soil are mainly determined by fertilization practices. The important pedo-climatic factors are:

- Rainfall amount and distribution, especially heavy rainfall events,
- Water infiltration rate into the soil, which is determined by
    - Slope
    - Soil texture,
    - Soil structure, including soil cracking, slaking and preferential flow characteristics
    - Soil depth to underlying rock, including karst formations, and to impermeable soil layers, which affect subsurface lateral drainage.
    - Soil cover, which determines evapotranspiration and affect surface roughness.
    - Soils with frost, with frozen layers, either in top soil or subsoil
- Presence of surface waters, lakes, streams, and ditches, vulnerable to nitrates and phosphorus,
- Terraces, tree-lines, buffer zones, riparian zones, which all contribute to intercepting overland flows.

The process of enrichment of surface waters with nitrogen and phosphorus is commonly termed 'eutrophication' (see also part C report). Eutrophication generally promotes excessive plant growth and decay, favouring simple algae and plankton over other more complicated plants, and causes a reduction in water quality. Enhanced growth of aquatic vegetation or phytoplankton and algal blooms disrupts normal functioning of the ecosystem, which may cause a variety of problems such as a lack of oxygen needed for fish and shellfish to survive. The water becomes cloudy, typically coloured a shade of green, yellow, brown, or red. Eutrophication also decreases the value of rivers, lakes, and estuaries for recreation, fishing, hunting, and aesthetic enjoyment. Health problems can occur where eutrophic conditions interfere with drinking water treatment.

Re 3. Zones determining the potential risk of nitrate leaching to groundwater

The potential risk of downward nitrate leaching to groundwater is determined by a combination of the amounts of nitrate in soil and pedo-climatic factors. The amounts of nitrate in soil are mainly determined by fertilization practices and the uptake capacity of the growing crop(s). The important pedo-climatic factors are:

1. Rainfall amount, distribution and especially rainfall surplus (i.e., rainfall minus evapo-transpiration),
2. Water infiltration rate into the soil and the hydrological conductivity of the soil, which is determined by
    - Soil texture,
    - Soil structure, including soil cracking, slaking and preferential flow characteristics,

- Soil depth to underlying rock, including karst formations (e.g. shallow karst formation within 1 m depth), and
- Slope, which increases overland flow and run-off,
- Soil cover, which determines evapotranspiration

3. Nitrate removal or denitrification capacity of the soil, which is mainly determined by the amount of decomposable organic matter and the soil hydrological conductivity.

Soils with a high nitrate leaching vulnerability have a high infiltration rate and a high hydrological conductivity, such as coarse-sandy soils and shallow soils overlying karst formations. This vulnerability is increased in case of crops with short growing periods in a climate with high rainfall.

Summarizing, crop yields, surface runoff of nitrogen and phosphorus, and nitrate leaching are strongly determined by pedo-climatic factors. Dominant climate-related factors are solar radiation, day length, and temperature, which are related to latitude and altitude, and rainfall. Here, both mean values and the distributions of the values over the year are important. Dominant soil-related factors are slope, soil texture, structure, depth, and soil cover.

8 Pedo-climatic stratification

8.1 Introduction

A central element in the classification of pedo-climatic zones is the objective to use such zones to identify the risks of leaching and run off of nutrients from agriculture to groundwater and surface waters. Climate and land and soil properties together determine the potential risks and for that reason they form the basis of pedo-climatic zones. The actual risk is determined by the climate characteristics and the land and soil properties, underlying the pedo-climatic zones, combined with the farm practices discussed in Part B of this report.

Ideally, the climate-environmental stratification discussed in Chapter 4 should be combined with the soil related factors as discussed in Chapters 5 and 6 and analysed together statistically, to arrive at a pedo-climatic clustering. However, attempts to combine (and integrate) the climate-environmental stratification with the soil-related factors into one cluster analyses for pedo-climatic zonation have failed, mainly because of the different natures of both datasets. The resulting zones and maps were ambiguous, and practically not manageable. Hence, the available European soil maps are difficult to include in statistical clustering; the resulting map is fragmented and showed little internal consistency.

Based on the abovementioned experiences, we made the pedo-climatic zones on the basis of two separated layers of information. The first layer of information is the environmental stratification discussed in Chapter 4: the Environmental Zones (EnZs). The second layer of information consist of landform and soil-related information, that is key to determining crop growth potential, the potential risk of leaching to groundwater and the potential risk of leaching to surface waters; so-called landform and soil-related risk areas. The two-layer approach is further discussed in the section below. By the additional use of geo-statistical information regarding utilized agricultural land, the risks of leaching and run off are restricted to areas with agriculture.

8.2 The two-layer approach for pedo-climatic zones

The first layer of information relates to the Environmental Zones as derived from the Environmental Stratification (see Metzger et al 2005; Jongman et al 2005). This stratification is based on climate data, data on the ocean influence and geographical position (latitude). Soil data are not included, as the soil classification systems tend to differ for each country, and soil types are nominal and not continuous but qualitative (class-based) data (for explanation see foot note 8) . Eighty-four strata have been classified and these are summarized into thirteen major zones. This aggregation into Environmental Zones (EnZs) facilitates communication. Environmental Zones are based on statistical procedures (principal component analysis), can be reproduced by others and have a clear scientific basis. The EnZs have been ordered systematically,

by the mean value of the first principal component, which expresses the north-south environmental gradient across Europe.

A summary of the EnZs is presented in Table 7; a more detailed characterization of each ENZ is presented in Chapter 4 and annex I. Note that roughly half of the EnZs have relatively large utilized agricultural areas (mainly ATN, ATC, CON, NEM, LUS, MDN, PAN), while the other half of the EnZs are dominated by forests, mountains and (semi-)natural grasslands (ALN, ALS, BOR, MDM, ANA).

Table 7. The 13 Environmental Zones (EnZs) as the first layer of information for pedo-climatic zonation in Europe (EnZs after Metzger et al 2005; Jongman et al 2005).

Nr	Environmental Zone	Main locations and characteristics
1	Alpine North (ALN)	Scandinavian mountains
2	Alpine South (ALS)	The high mountains of central and southern Europe
3	Atlantic North (ATN)	NW Europe; under influence of the Atlantic ocean and the North sea
4	Atlantic Central (ATC)	Western Europe, moderate climate
5	Boreal (BOR)	The lowlands of Scandinavia
6	Continental (CON)	Central Europe; warm summers and cold winters
7	Lusitenean (LUS)	The southern Atlantic area; warm summers and mild winters
8	Mediterranean North (MDN)	Mediterranean north, with Cork Oak, fruit plantations and Olive groves
9	Mediterranean Mountains MDM	Mediterranean mountains, influenced by Mediterranean and mountains
10	Mediterranean South (MDS)	Typical Mediterranean climate; mild winter and hot, dry summers
11	Nemoral (NEM	Southern Scandinavia, Baltic states and Belarus
12	Pannonian (PAN)	The steppic part of Europe; cold winters and dry hot summers
13	Anatolian (ANA)	The steppes of Turkey, a Mediterranean steppic environment

The second layer of information contains landform and soil-based information needed to assess the risks of nutrient leaching and run-off., which basically overlay the EnZs. The important landform and soil-related factors have been identified in Chapter 7. These include slope, soil depth, soil texture, soil structure, soil organic matter, soil cover and frozen soils. Note that 'risk' should be perceived as 'potential risk', as the actual risk depends on the combination climate, soil and farm practices and management related factors. The farm management-related activities are not addressed here but in parts B and D of this report. Maps showing the slope classes, soil depth, (depth class to obstacles to roots), organic matter and texture are presented in Figures 7-10, respectively. The combining of landform and soil-related factors into classes and the spatial implementation of these classes to the agricultural land of the EnZs has been done with the model MITERRA-EUROPE(Velthof et al., 2009) .

MITERRA-EUROPE was developed in the project "Integrated measures in agriculture to reduce ammonia emissions" for the Directorate-General Environment of European Commission (http://www.scammonia.wur.nl/UK/). It is a model that can be used to assess the effects of the implementation of NH_3 and NO_3 abatement

measures and policies on the emissions of NH_3, N_2O, NOx, and methane (CH_4) to the atmosphere, leaching of N (including nitrate) to ground water and surface waters, and on the N and phosphorus (P) balance on both EU-27 level, country level, and regional (NUTS 2) level. MITERRA-EUROPE consists of an input module with activity data and emission factors, a set of (packages of) measures to mitigate NH_3 emission and NO_3 leaching, a calculation module, and an output module. The starting point for MITERRA-EUROPE were the existing models CAPRI and RAINS, supplemented with existing databases (e.g. FAO and Eurostat), soil data and expertise about emission processes. The database of MITERRA-EUROPE is on NUTS 2 level and includes data of N inputs, N outputs, N surplus, land use, crop types, soil type, topography, and livestock numbers and emission factors for NH_3, N_2O, NO_X and CH_4, and leaching factors for NO_3. The leaching module comprises methods to calculate N leaching to groundwater and surface waters.

Recently, the database and emission factors for gaseous N emissions of MITERRA-EUROPE were updated in the project "The impact of the Nitrates Directive on gaseous N emissions. Effects of measures in nitrates action programme on gaseous N emissions". The leaching module of MITERRA-Europe is calibrated and validated in the integrated project GENESIS (www.thegenesisproject.eu). The data set with nitrates concentrations in groundwater and surface water obtained from the reporting under art 10 of the Nitrates Directive of the 27 EU Members States for the period 2004-2007 are used for the calibration and validation.

Leaching risk potential

The leaching risk potential is based on a classification of leaching factors into three classes, i.e. low, medium and high. The leaching factors are based on the factors that are used in the MITERRA-Europe model. These leaching factors are calculated by multiplying a maximum leaching fraction, which depends on soil type, by a number of reduction factors, i.e. precipitation (f_p), , temperature (f_t), soil organic carbon content (f_c) and rooting depth (f_r). For a more in depth discussion of the effects of soil characteristics on leaching, the reader is referred to part B of this Report.

The leaching fraction (LF, in % of the N surplus corrected for NH_3 volatilization losses and surface runoff losses,) is calculated as:

$$LF = LF_{soil\ type,\ max} * f_p * f_r * f_t * f_c$$

The maximal leaching fractions are derived from results of monitoring studies in which both the N surplus and the NO_3 concentration in the upper ground water for sandy soils and drainage and ditch water for clay and peat soils were determined. Based on these data the following maximum leaching fractions are used:

- Maximum leaching fraction on sandy soil ($LF_{sand,\ max}$) = 1
- Maximum leaching fraction on loamy soil ($LF_{loam,\ max}$) = 0.75
- Maximum leaching fraction on clay soil ($LF_{clay,\ max}$) = 0.50
- Maximum leaching fraction on peat soil ($LF_{peat,\ max}$) = 0.20

The reduction factor for the precipitation surplus (f_p) is dependent on soil type (Table 8). It is assumed that leaching on sandy and loamy soils is high when precipitation surplus is high. However, a high precipitation surplus creates anaerobic soil conditions in peat and clay soils and therefore higher denitrification losses and lower leaching losses. Therefore, a smaller leaching fraction is assumed for peat and clay at a high rain surplus. For all soils, a small leaching fraction is assumed at low (or negative) precipitation surplus, because in dry regions with low precipitation surplus leaching may occur during heavy rainfall events.

Table 8. Reduction factor for precipitation surplus: f_p

Precipitation surplus (mm)	f_p sand and loam	f_p peat and clay
> 300	1	0.50
100 – 300	0.75	1
50 – 100	0.50	0.75
< 50	0.25	0.25

Soils with a very shallow rooting depth are more susceptible for leaching than soils with a deep rooting depth. The reduction factors for rooting depth are:
- Rooting depth < 40 cm: $f_r = 1$
- Rooting depth > 40 cm: $f_r = 0.75$

Denitrification increases with increasing temperature. In MITERRA-Europe, the following leaching fractions are used, assuming the denitrification at an average annual temperature of 15 °C is twice of that at 5 °C (a general effect of temperature on microbial activity):
- Temperature < 5 °C: $f_t = 1$
- Temperature between 5 and 15 °C: $f_t = 0.75$
- Temperature > 15 °C: $f_t = 0.50$

It is assumed that denitrification decreases (and leaching fraction increases) when total C content of the soil decreases. The reduction factors for total C (f_c) are:
- Soil organic carbon content < 1% $f_c = 1$
- Soil organic carbon content 1-2% $f_c = 0.90$
- Soil organic carbon content 2-6% $f_c = 0.75$
- Soil organic carbon content > 6% $f_c = 0.50$

It is assumed that the aforementioned coefficients hold for whole EU-27. This assumption has been validated by comparing calculated mean nitrate concentrations in shallow groundwater with measured mean nitrate concentrations in monitoring stations. However, a validation at regional level has not been taken place yet.

Surface runoff risk potential

The surface runoff risk potential is based on a classification of surface runoff leaching factors into three classes, i.e. low, medium and high. The surface runoff factors are based on the factors that are used in the MITERRA-Europe model. The surface runoff factor is calculated by multiplying a maximum leaching fraction, which depends on slope, by a number of reduction factors, i.e. precipitation, soil texture and rock depth.

$$LF_{surface\ runoff} = LF_{surface\ runoff,\ max} * f_p * f_{rc} * f_s$$

In which

- $LF_{surface\ runoff}$ = leaching fraction for surface runoff, in % of the N applied
- $LF_{surface\ runoff,\ max}$ = the maximum leaching fraction for surface runoff for different slope classes
- f_p = reduction factor for precipitation
- f_s = reduction factor for soil type
- f_{rc} = reduction factor for depth to rock

For a more in depth discussion of the effects of landform and soil characteristics on surface runoff, the reader is referred to part B of this Report.

The slope is an important factor controlling surface runoff. For four slope classes, a maximum surface runoff factor was set. Also in flat areas, surface runoff can occur during wet periods, especially on heavy textured soils.

The following slope classes and surface runoff factors (in % of the N applied) are distinguished:

- Level (dominant slope ranging from 0 to 8 %): $LF_{surface\ runoff,\ max} = 0.10$
- Sloping (dominant slope ranging from 8 to 15 %): $LF_{surface\ runoff,\ max} = 0.20$
- Moderately steep (dominant slope ranging from 15 to 25 %): $LF_{surface\ runoff,\ max} = 0.35$
- Steep (dominant slope over 25 %): $LF_{surface\ runoff,\ max} = 0.50$

Surface runoff is dependent on rainfall. Most runoff occurs in periods with heavy rainfall in which the soil is already wet. The precipitation surplus is chosen as an indicator of rainfall effect on surface runoff. It is assumed that surface runoff may also occur during wet conditions in dry regions (i.e. in regions with a low precipitation surplus).

The following precipitation surplus classes and surface runoff factors are distinguished:

- Precipitation of surplus > 300 mm: $f_p = 1$
- Precipitation surplus of 100 - 300 mm: $f_p = 0.75$
- Precipitation surplus of 50 – 100 mm: $f_p = 0.50$
- Precipitation surplus of less < 50 mm: $f_p = 0.25$

Soil type affects surface runoff, i.e. risk on surface runoff increases when clay content of the soil increases because rainfall infiltration rates into the soil tend to decrease. The following reduction factors f_s are included:

- Very fine (clay > 60 %): $f_s = 1$
- Fine (35% < clay < 60%): $f_s = 0.90$
- Medium (18-35% clay): $f_s = 0.75$
- Coarse (18% < clay): 0.25
- Peat: 0.25

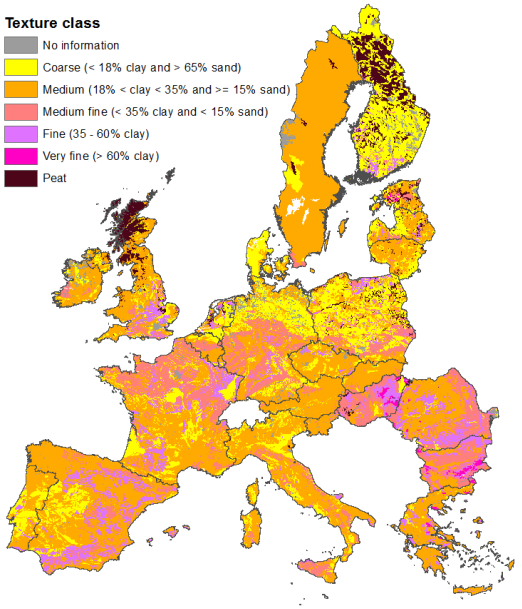
The last factor that is included is the depth to rock, because surface runoff is highest in shallow soil. The surface runoff factors for depth to rock are:

- For a depth of less than 25 cm: $f_{rc} = 1$
- For a depth of more than > 25 cm: $f_{rc} = 0.8$

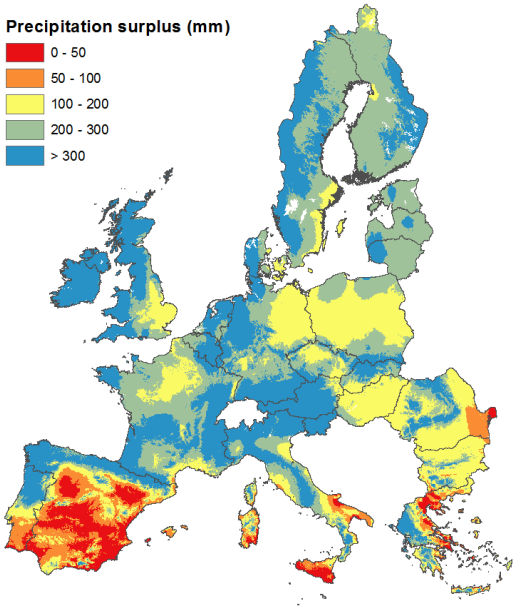
Maps with potential risk areas

For all above-mentioned factors that determine the leaching and surface runoff risk a grid based map was derived at a resolution of 1x1 km (Figure 7). The description and source of each of these input maps are stated in Table 9. The maps with the leaching and surface runoff risk potential refer to arable land. For grassland the risk is lower, since it is a permanent crop and with its dense rooting system it decreases the leaching and surface runoff risk.

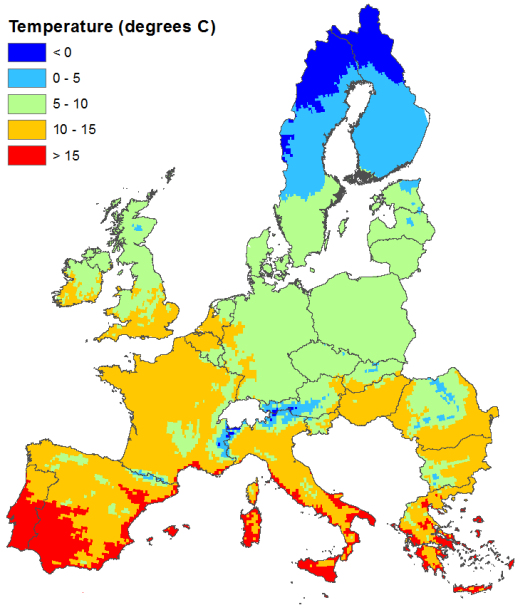
Soil texture



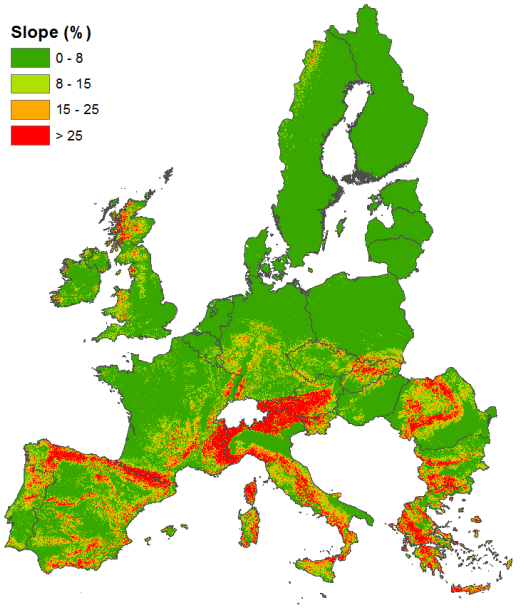
Precipitation surplus



Annual temperature



Slope



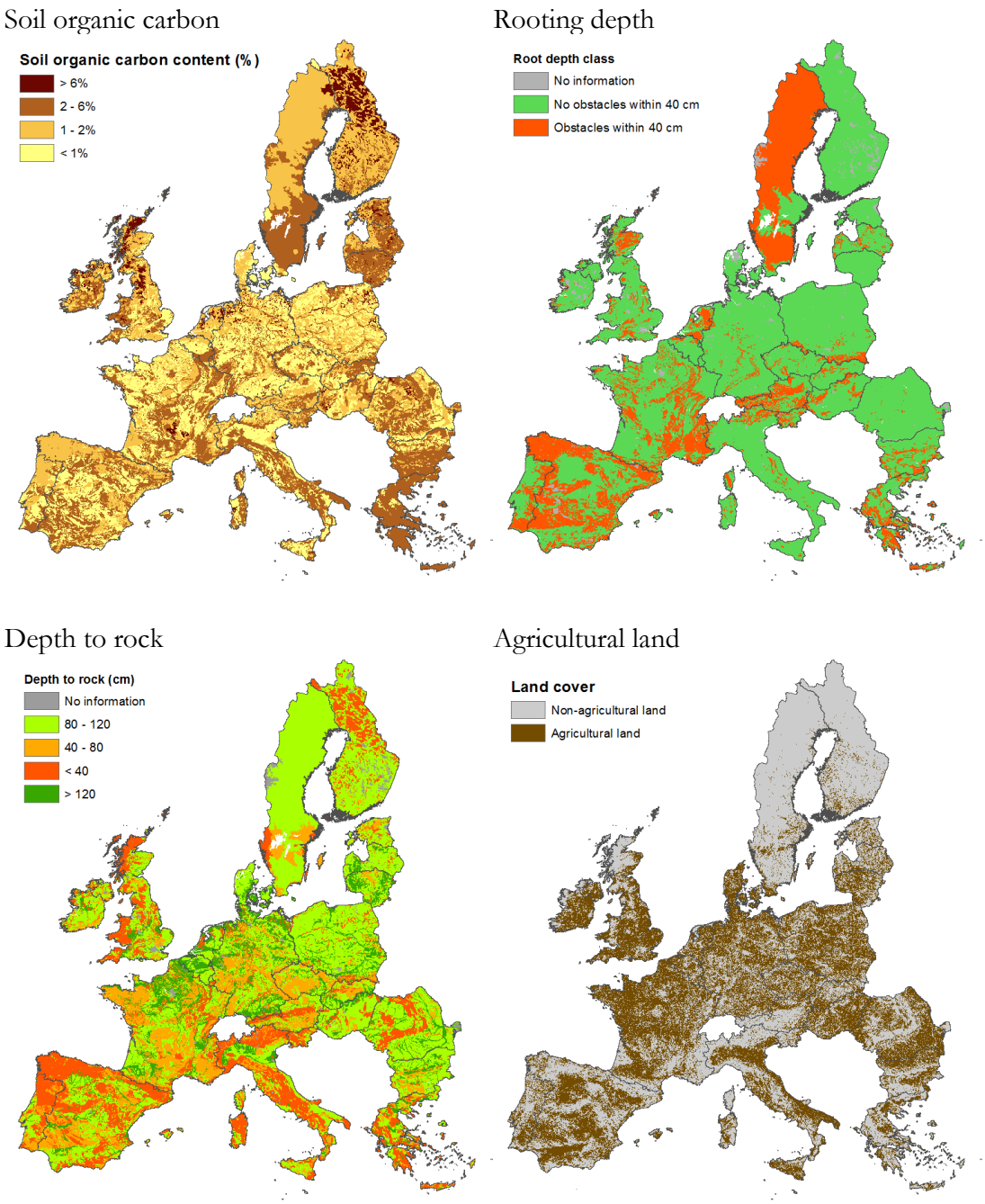


Figure 7. Input maps of the factors that determine the potential leaching and surface runoff risk, the source and further information of the maps is provided in Table 9.

In MITERRA-Europe for grassland the leaching factor is multiplied by 0.36, and the surface runoff by 0.25[9] (Velthof et al., 2009).

[9] Due to a high denitrification rate and a high hydraulic resistance, respectively in grassland.

Table 9. Description and source of the input maps that were used to derive the potential leaching and surface runoff risk

Input map	Description	Source
Soil texture	Dominant surface textural class of the Soil type unit	European Soil database http://eusoils.jrc.ec.europa.eu/
Precipitation surplus	The precipitation surplus was calculated for each 1 x 1 km grid cell based on the steady state annual water balance of the land surface. The mean annual temperature and annual precipitation was taken from Worldclim 1.4a Hijmans, et al. (2005).	Keuskamp et al. (in press)
Temperature	The mean annual temperature was derived from the CRU database for the years 1900-2000 (Mitchell et al., 2003). The original resolution of the CRU database is monthly at a 10'x10' grid. The long term mean annual average was calculated for the years 1980-2000 and downscaled to a 1 by 1 km grid.	
Slope	Slope map (in percentage) derived from a Digital Elevation Model based on SRTM3 elevation data (70x70 m resolution) for most countries and GTOPO30 data for Sweden and Finland. The detailed slope map was rescaled to 1x1 km resolution.	http://glcf.umiacs.umd.edu/data/srtm/index.shtml
Soil organic carbon	Topsoil organic carbon content	European Soil database http://eusoils.jrc.ec.europa.eu/
Rooting depth	Depth class of an obstacle to roots within the soil type unit	European Soil database http://eusoils.jrc.ec.europa.eu/
Depth to rock	Depth to rock	European Soil database http://eusoils.jrc.ec.europa.eu/
Agricultural land	Agricultural land derived from the CORINE land cover 2000[10] map at 1x1 km resolution, selecting the arable land, permanent crops and pasture land	http://sia.eionet.europa.eu/CLC2000

The resulting leaching fraction map was reclassified to a leaching risk potential map using the following classes:

- Low: LF < 0.20
- Medium: LF between 0.20 and 0.35
- High: LF > 0.35

The resulting surface runoff fraction map was reclassified to a surface runoff risk potential map using the following classes:

- Low: $LF_{surface\ runoff} < 0.02$
- Medium: $LF_{surface\ runoff}$ between 0.02 and 0.10
- High: $LF_{surface\ runoff} > 0.10$

These class boundaries were chosen in order to obtain a map with more or less similar surface areas in each class at EU level. The maps present the areas with relatively low, medium and high leaching and surface runoff potentials.

[10] CLC 2006 data are incomplete for the EU 27

8.3 Pedo-climatic Zones; potential risk areas within Environmental Zones

Pedo-climatic zones within the context of the EU-Nitrates Directive differ in the risks of leaching to groundwater and the risks of runoff and leaching to surface waters. The pedo-climatic zones are based on a two-layer approach, i.e., Environmental Zones (EnZs) discussed in Chapters 4 and 7, and landform-, soil- and climate-specific leaching and surface runoff risk potentials, discussed in Chapter 7 and 8.2. Hence, the pedo-climatic zones reflect differences in (see Chapter 7):

- (i) Crop growth potential,
- (ii) Risk of runoff and leaching to surface waters, including eutrophication.
- (iii) Risk of leaching to groundwater

Figure 1 shows the 13 different climatic zones in the EU and Figures 3-6 show the potential and water limited growth of forage and wheat. The distribution of agricultural land use and the landform and soil parameters is shown in Figures 7-10. Together they form the newly proposed pedo-climatic zones. A total of three classes for surface runoff potential and three classes for the leaching risk potential have been distinguished (Figures 11 and 12, respectively). The same information for each Member State is provided in Appendix 2.

Leaching risk potential is strongly related to soil texture and also soil organic matter. Coarse soils have a higher risk of leaching than fine soils, while soils rich in organic matter have a high denitrification potential, which reduces the leaching risk. Soil depth is also an important determinant, as shallow soils are highly vulnerable to leaching, especially also in karst areas.

Surface runoff risk potential is strongly related to slope and soil texture. Heavy textured (clay) soils are responsible for the sometimes medium surface runoff risk potential in rather flat areas.

The choice to distinguish three different risk classes for leaching and three for surface runoff in combination with 13 different climatic zones leads to a total number of 52 different pedo-climatic combinations for the EU 27. Though this total number of different classes would suggest a great level of detail, it is clear that in practice there is even much greater variation. However, increasing the number of classes would make the maps less readable and would also suggest a false precision. As indicated before, the pedo-climatic zones are strongly related to landform and soil-related properties, which show large spatial variations. There are also uncertainties related to the soil maps of Europe, related to the fact that Member States have used their own classification system. As a consequence, there may be also slight differences between Member States in the outcome of the surface runoff risk assessment and leaching risk assessment for similar environments, simply because of the underlying information used in the model MITERRA-EUROPE. Hence, the maps have to be interpreted with caution.

Another possible limitation is the fact that irrigation has not been included in the pedo-climatic zoning. Irrigation is an important factor for leaching. However, in the leaching risk potential map this factor is not included, due to lack of EU-wide spatial data.

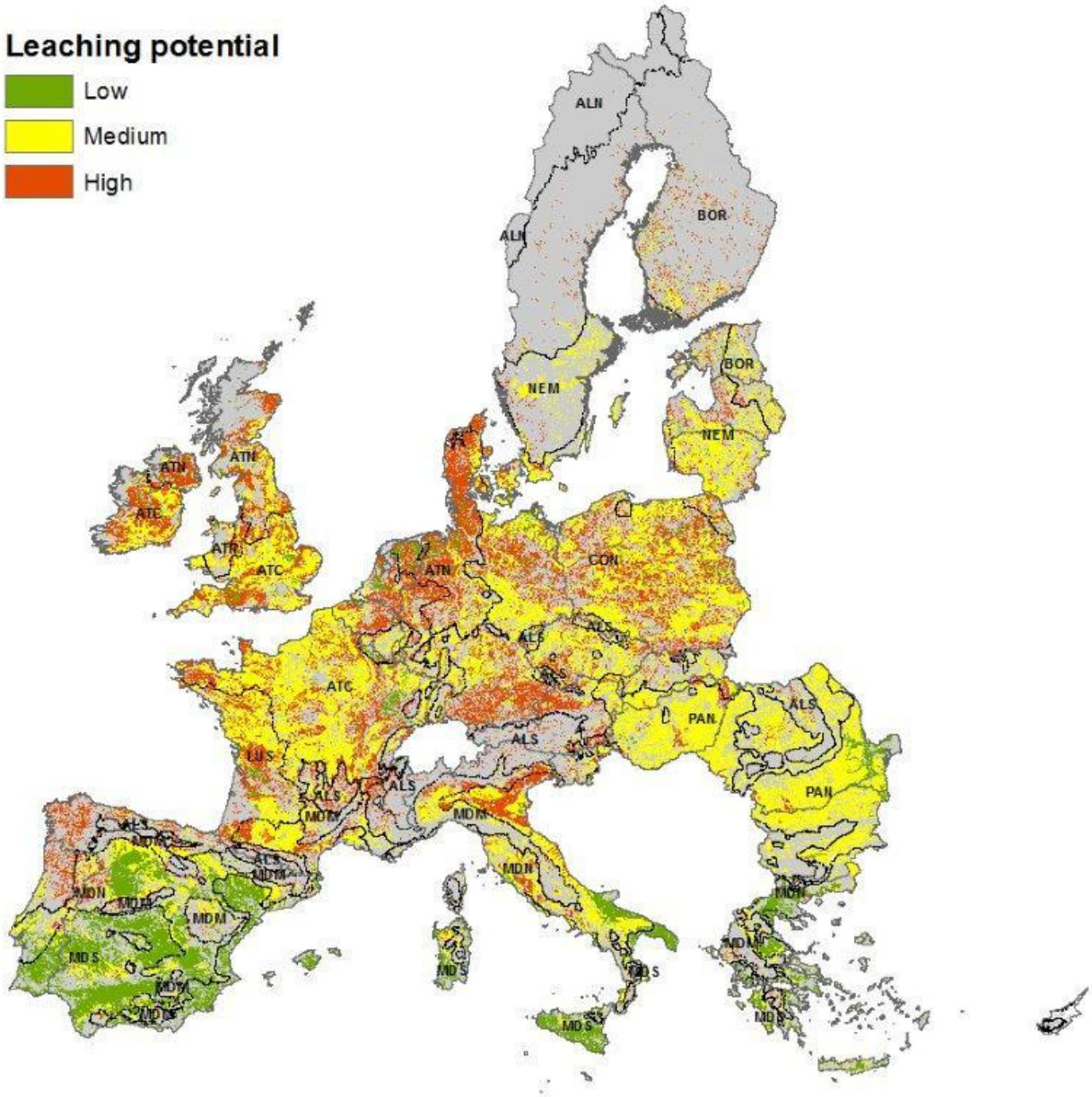


Figure 11. Map showing the leaching risk potential for agricultural land within the Environmental Zones in the EU-27. Abbreviations of the Environmental Zones are explained in Figure S1 and Table S1. Note that grey areas indicate non-agricultural areas.

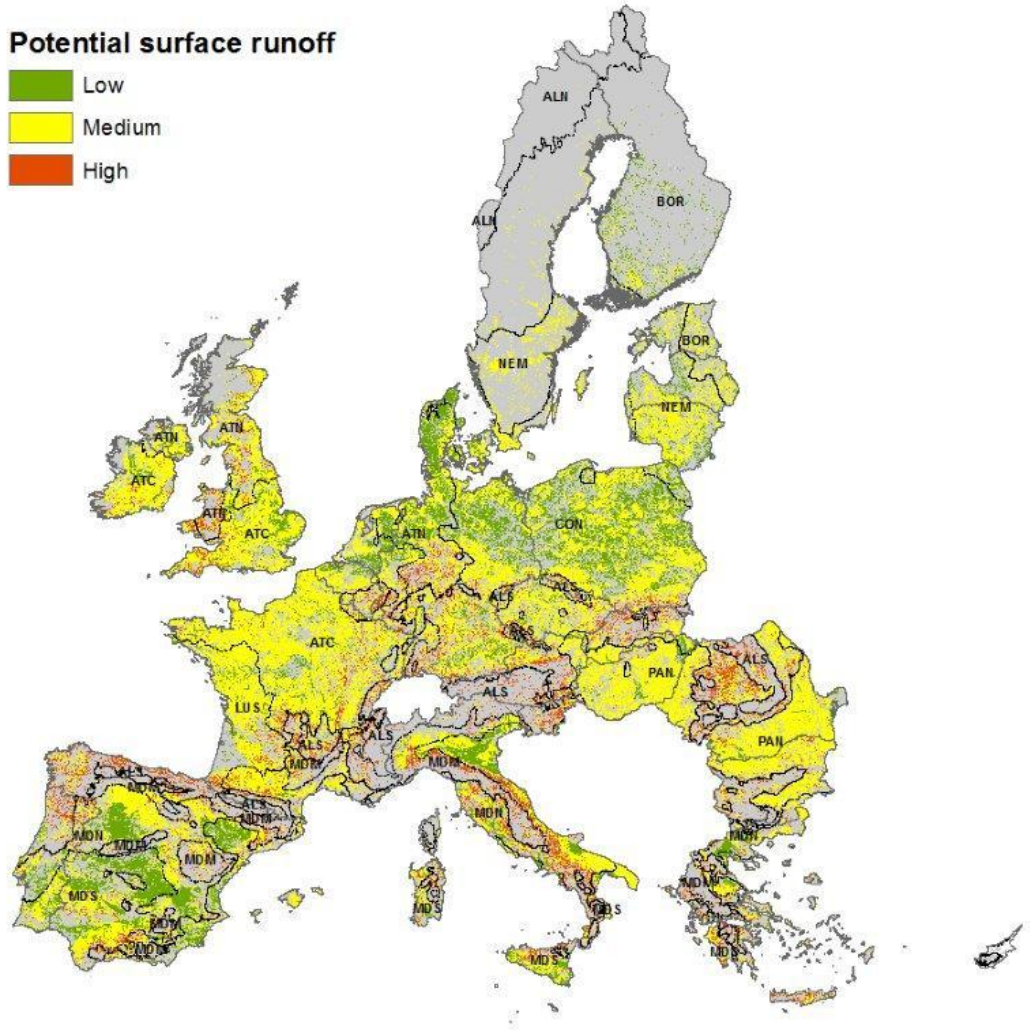


Figure 12. Map showing the surface runoff risk potential for agricultural land within the Environmental Zones in the EU-27. Abbreviations of the Environmental Zones are explained in Figure S1 and Table S1. Note that grey areas indicate non-agricultural areas.

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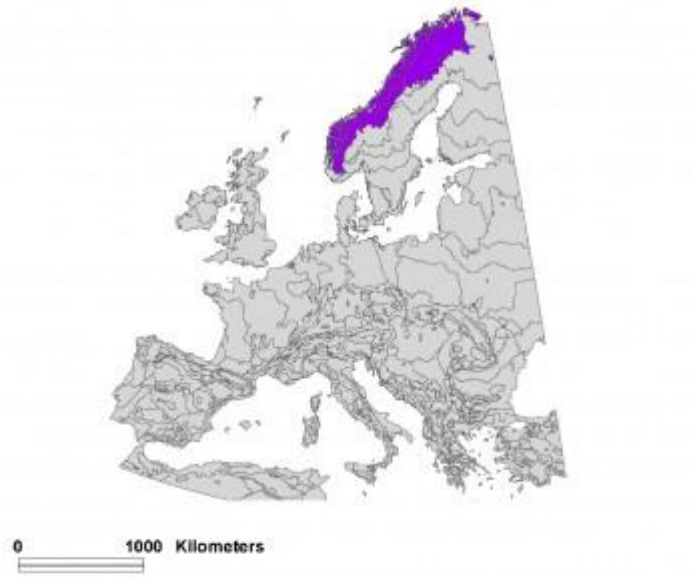
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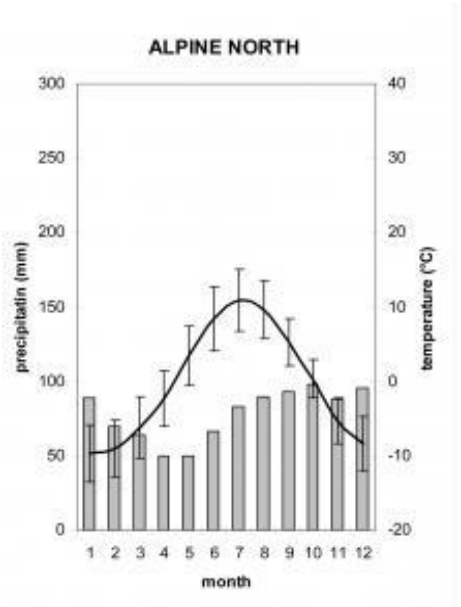
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Appendix 1 Detailed description of the 13 Environmental Zones

Alpine North (ALN)



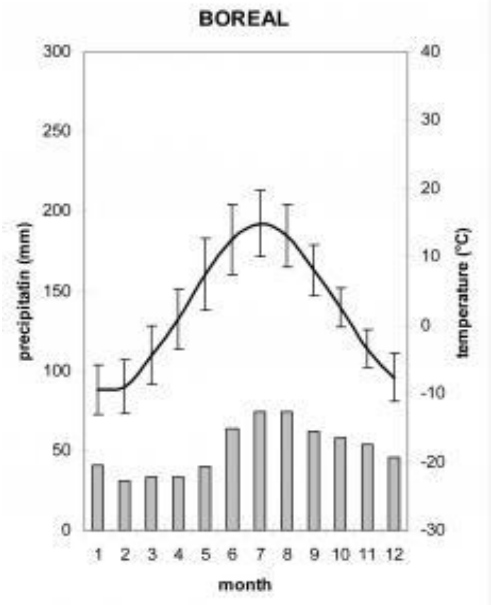
Landscapes in Alpine North are dominated by arctic tundra (uplands in the north), arctic-alpine tundra (high mountain regions) and various forest and dwarf-scrub tundras changing on the southern uplands and less elevated eastern plateaus to sparse coniferous forests. The relief bears fresh traces of the last glaciation. The climate of western slopes is strongly influenced by the North-Atlantic current, meanwhile eastern uplands are influenced by continental air masses. The growing season lasts on average 130 days (116-155); sum of active temperatures is on average 1416° (1277° - 1719°.



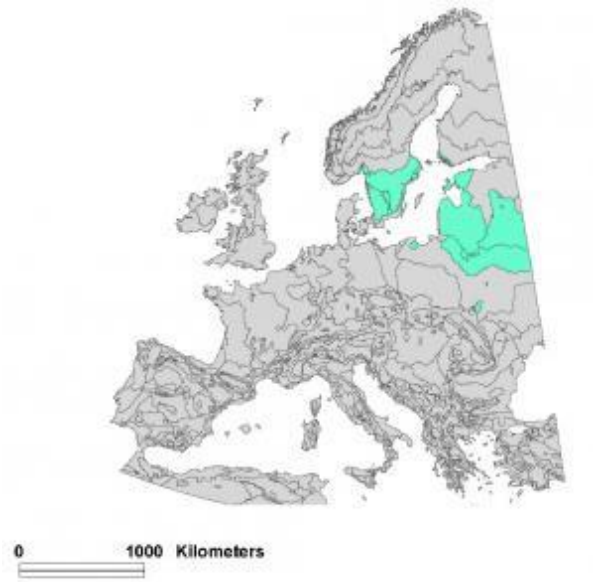
Boreal (BOR)



The Boreal Zone (BOR) includes the eastern dip slope of the Scandinavian mountains, as well as the undulating plains and lowlands of the northern and eastern Baltic. The Zone has been heavily glaciated which resulted in the deposition of many residual features such as moraines and eskers . The climate is continental, with a large annual temperature range. The severe temperature restricts crop production to the extreme south but fertile grasslands are present further north. The land is dominated coniferous forests of spruce and pine often mixed with birch and aspen, utilised by a major forest industry. There is also an extensive cover of bog types, as well as dwarf and low heaths at higher altitudes which are often grazed by reindeer. There are many wetlands and lakes, especially in Finland. The climate is continental. The growing season lasts on average 157 days (126 – 185); the sum of temperatures above +10° is on average 1966° (1471°C to 2523,3 °C).

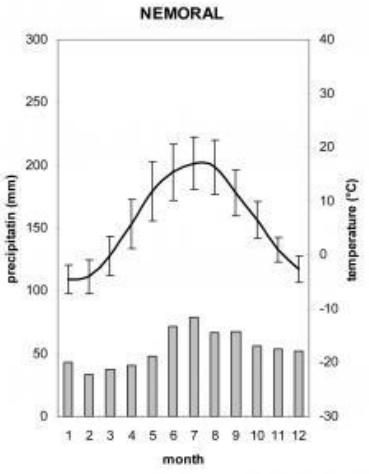


Nemoral (NEM)

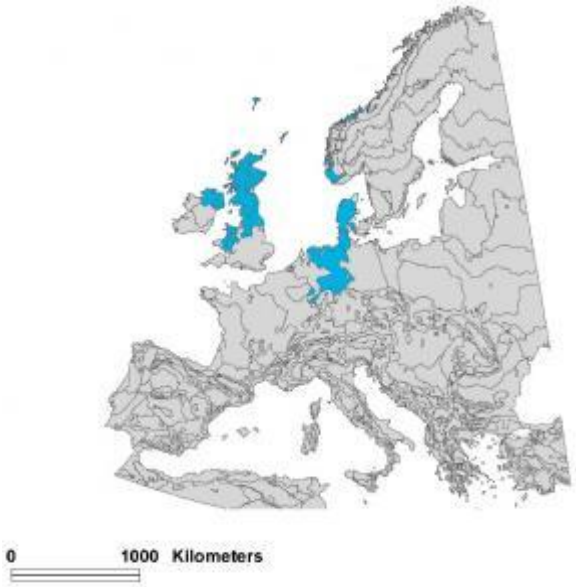


The Nemoral Zone (NEM) includes the lowlands and undulating plains of the southern and eastern Baltic to a variable extent inland and extending in the west to the North Sea coast in southern Sweden. The Zone has been heavily glaciated which has resulted in deposition of many surface features such as moraines and eskers. The climate is continental but suitable for crop production on the best soils. Whilst managed grasslands are widespread, the land is mainly covered by coniferous forest of pine and spruce often mixed with birch and aspen, utilised by a major forest industry. Abandonment of agriculture is also taking place on poor soils. Bogs and large floodplain marshes are also present throughout the Zone but especially in the east.

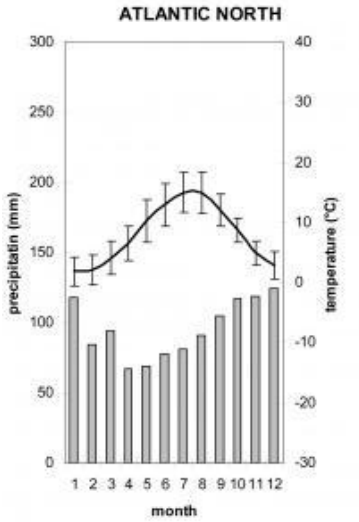
The growing season lasts on average 196 days (190-204), the sum of temperatures above +10° is on average 2717°C (2561°-2898 °). The most characteristic in the Nemoral zone are well developed forms of glacial accumulation (moraine and fluvioglacial) and mixed and evergreen coniferous forests.



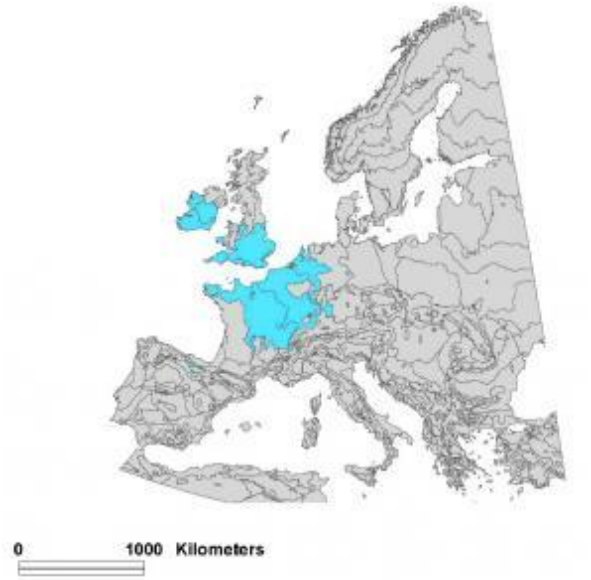
Atlantic north (ATN)



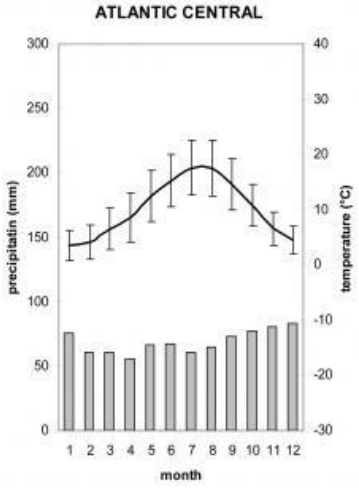
The Atlantic North Zone (ATN) includes the uplands and low mountains in central and northern Britain, Northern Ireland, and the west coast of Norway as well as the coastal plains. The lowlands of Denmark, north west Germany and the northern part of the Netherlands are also in the Zone. There is therefore a contrast between the glaciated landscapes of the north and west of the Zone with the deposition features present in the south and east. The climate is strongly oceanic in the west with typical mild wet winters and moist cool summers but becomes more continental in the east. Crops can be grown throughout zone except in the north and west where they are restricted to the lowlands. As a result the southern strata of the Zone are dominated by arable land whereas the northern have various types of grassland enterprise such as dairy and sheep. The former strata also have much urban land cover. Low heaths and bogs are also widespread in the mountains but have largely now disappeared in the lowlands. In the British uplands there are extensive plantations of spruce but otherwise the forest cover is deciduous. The growing season lasts on average 255 days (199-278), the sum of temperatures above +10° is in average 3198,1° (2459°-3214°).


ATLANTIC NORTH
precipitatin (mm)
temperature (°C)
month
300
250
200
150
100
50
0
40
30
20
10
0
-10
-20
-30
1 2 3 4 5 6 7 8 9 10 11 12

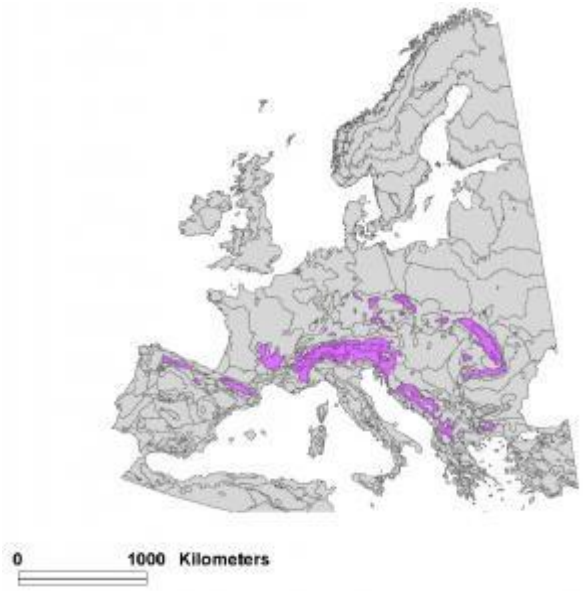
Atlantic central (ATC)



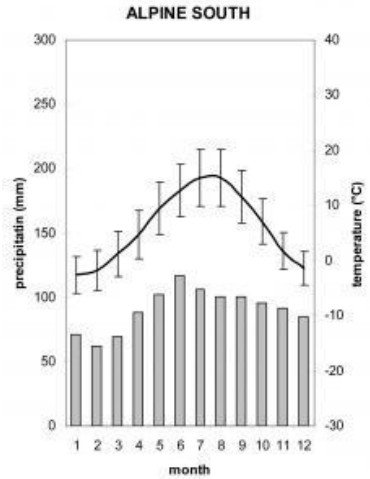
The Atlantic Central Zone (ATC) includes the south west and south of the British Isles, Northern France and the Low countries. The land consists mainly of lowlands with level or undulating terrain according to geology, but also has some uplands in the west and south. The climate is typically strongly oceanic in the west, with cool wet winters and mild moist summers becoming less extreme in the east. The Zone is characterised by a mixture of arable agriculture and fertile and extensive grasslands and in the uplands that have associated grazing systems present. It is the major European dairy and cheese producing region. Some low heaths are also present in the west but were originally more widespread. Now they are mostly protected in nature reserves. Deciduous forests are present locally on shallow soils as well as some coniferous plantations, mainly pine. Many major conurbations are present throughout the Zone. The sum of precipitations does not vary much during a year; the contrast on average monthly temperatures is usually within 10°. The growing season lasts 296 days (270-327) and the sum of active temperatures (above +10°C) is 3849° (3497 °C-4092 °C).



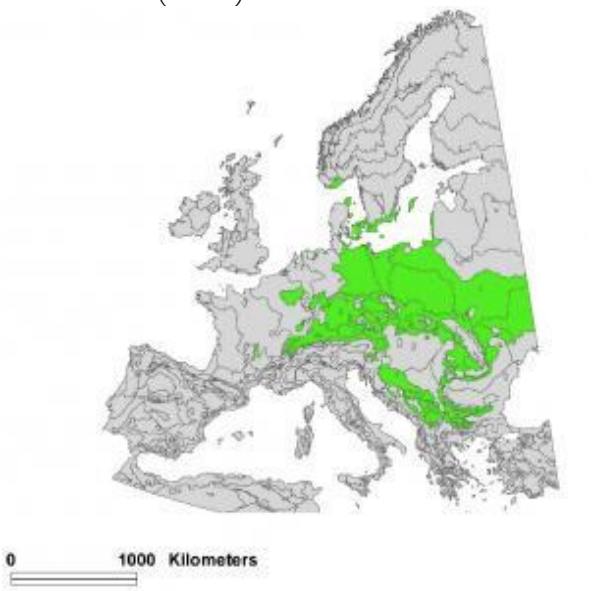
Alpine South (ALS)



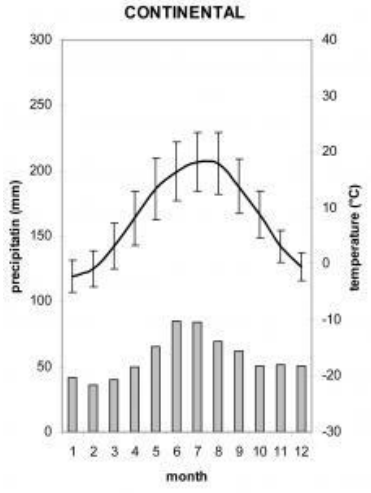
The Alpine South Zone (ALS) includes the high, medium and low mountains of Central Europe, mostly belonging to the main Alpine orogenic belt (e.g. the Carpathians, Pyrenees and Alps) as well as minor ranges (e.g. the Massif Central, Picos de Europa, Harz and Tatra). The deep U-shaped glaciated valleys have been dissected by ?the peaks, which are sufficiently high in the Alps to have glaciers but even elsewhere may have long snow cover. Crops are therefore restricted to the valleys where there are also extensive urban areas as well as much fertile pasture. The mountain slopes are covered by coniferous forests of spruce and larch, as well as various types of deciduous forest on the more fertile soils. The former are used for forestry and the latter are mainly for protection. Above the tree line there are extensively managed grasslands and various types of alpine heaths depending on altitude and soil type as well as bare rocks and glaciers. The climate and vegetation vary greatly from west to east and also depend on the orientation of slopes. The growing season lasts 220 days, the sum of temperatures above +10°C is 3005°C.



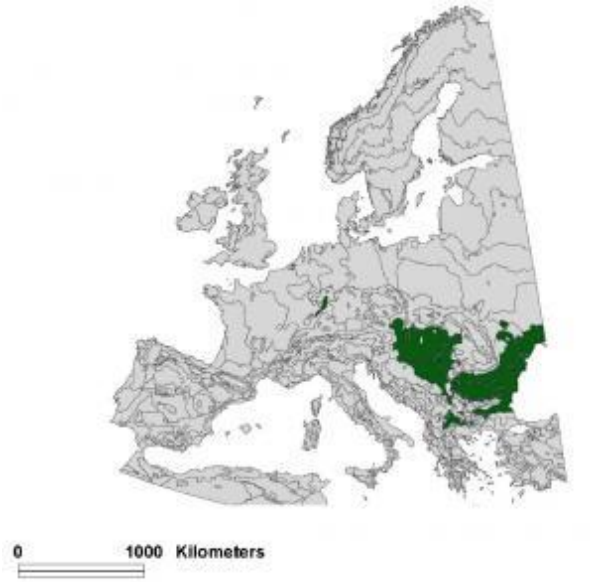
Continental (CON)



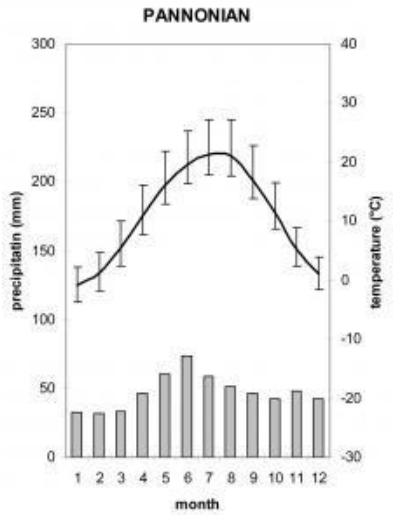
The Continental Zone (CON) is the Zone with the widest range and includes the plains and lowlands of Central and Eastern Europe and the Balkans as well as some of the lower hills on the margin of ALS. The geology and soils are variable and cause much of the variation in land cover. The climate is continental, with a large annual temperature range and precipitation concentrated during the summer months but is more pronounced in the east than in the extreme west of the Zone. Crops, fertile grasslands and associated agricultural enterprises are dominant in much of the Zone. Extensive forests are present locally on shallow and poor soils with beech and planted spruce and pine widespread with most areas being managed for timber. Major urban areas are also present throughout the Zone which also has major river systems. The climate has a clear summer maximum of precipitations. There is a relatively large (15-20°) difference in the average summer month temperatures. The growing season lasts 227 (213-257) days, the sum of active temperatures is 3294° C (3037°- 3049°). The highest values are reached in the continental parts of the Balkan peninsula.



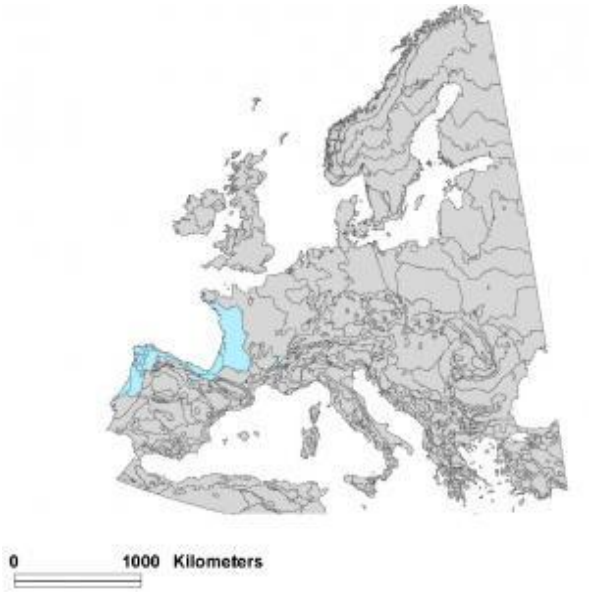
Pannonic-Pontic (PAN)



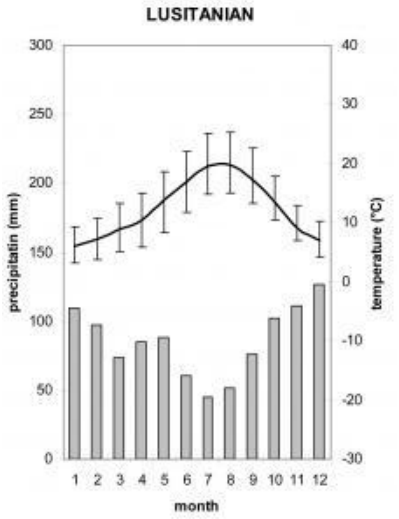
The Pannonic-Pontic Zone (PAN) includes the plains, valleys and mountain fringes in the middle and the lower Danube basin, the Black Sea lowlands and a small outlier in the central Rhine valley. There warm continental climate has a steppic character and the concentration of precipitation in early summer can lead to water shortages. Much of the land is relatively flat but there are some low hills and variations in geology which lead to local variations. Wine cultivation dominates in the German part and arable agriculture dominates in the rest of the Zone converted from the original steppic grasslands which now only remain usually in small patches. Forest cover although locally important is restricted in extent. There are some large lakes and major river systems. The zone is characterised by its dry continental climate (maximum of precipitations in summer, the yearly amplitude of temperature is 20°) and steppe-like natural vegetation. The growing season lasts 250 days (245-252), the sum of temperatures above +10° is 4099°C (3831°- 4361°).



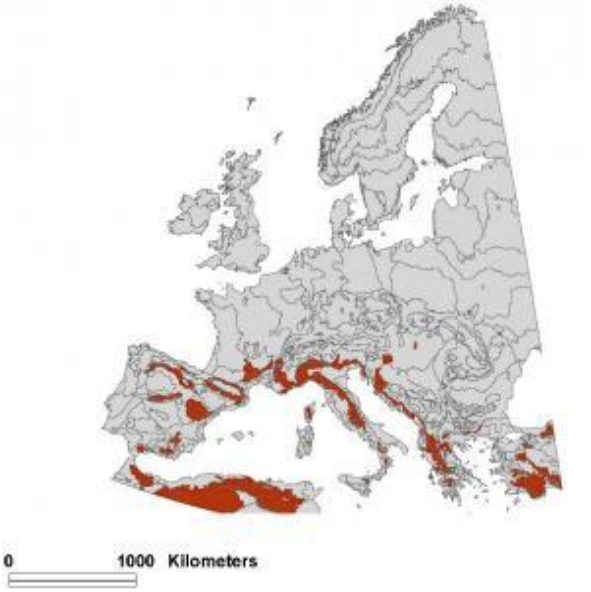
Lusitanean (LUS)



The Lusitanian Zone (LUS) includes the coastal plain and low hills of west and south west France as well as northern Spain and Portugal. The climate is warm and wet, with precipitation concentrated in the winter and spring. The long growing seasons and high water availability means that the widespread fertile grasslands can be cut several times in the year. Crops are locally important on better soils and vineyards are also important throughout the Zone. There is a major pine plantation in the Landes in France but there are also extensive pine and Eucalypt plantations on former heathlands in Spain and northern Portugal. Native woodlands are restricted in cover. The heathlands are now fragmented and only extensive in the inlands and mountain regions. The coastal plains in Spain and Portugal are heavily urbanised. The most characteristic in the environmental zone Lusitanian is the relatively humid Atlantic climate with Mediterranean-like distribution of precipitation within a year (maximum in winter). The growing season lasts 353 days (345-365), the sum of temperatures above +10° is 4749°C (4462°-5302°).

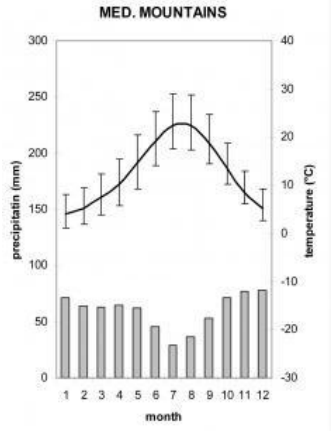


Mediterranean mountains (MDM)

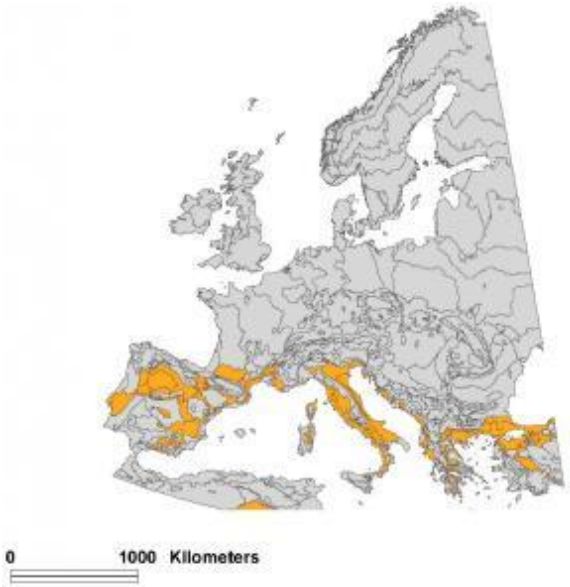


The Mediterranean Mountain Zone (MDM) includes the low- and medium high mountains in the northern Mediterranean around the margins of the main mountain ranges such as the Pyrenees and Alps as well as high mountains in the south. The climate is Mediterranean, with warm summers and precipitation concentrated in the winter months with more precipitation than elsewhere in the Mediterranean and temporary snow cover in winter. Poor soils and difficult terrain restrict crop production over much of the Zone but, together with vineyards, these are still locally important. Extensive grasslands are still widespread and used for cattle and sheep grazing but overall these are in decline, with subsequent scrub invasion especially of broom and Cistus species. There are some alpine grasslands on the highest mountains and locally extensive deciduous and coniferous forests sometimes planted. Land abandonment is an important driver of change. Compared to other Mediterranean zones the Mediterranean Mountains receive more precipitation. This and difficult access to the mountains preserve the natural vegetation of the region – deciduous and coniferous forests. Primary and secondary (various stages of

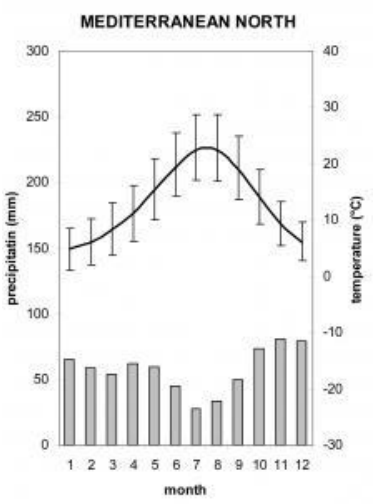
degradation) shrub formations (e.g. maquis, garriga, carrascal, phrygana, shibljak) are also very common. The growing season lasts 298 days (271-353), the sum of temperatures above +10°C is 4548° (3984°-5833°-).



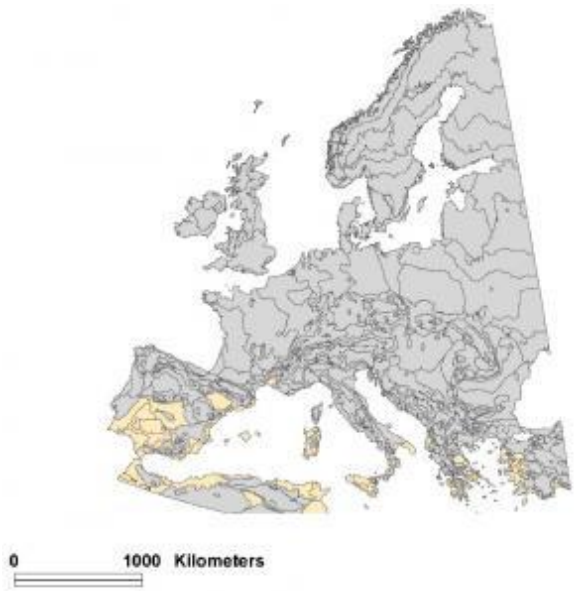
Mediterranean north (MDN)



The Mediterranean North Zone (MDN) includes the lowlands of the northern and central Mediterranean but also hills and low mountains further south. The topography is diverse and includes coastal plains, plateaus with isolated mountains, foothills and mountain valleys. The climate is Mediterranean, with warm and dry summers and precipitation concentrated in the winter months. Crop production is constrained by water availability, and permanent irrigation is locally important to increase yield. Vineyards and olive groves are important throughout the Zone. Orchards are also locally important as are grasslands in agricultural use although these are often in decline. Various scrub formations are therefore widespread and increasing in cover as well as evergreen and pine forests . There are many major conurbations in the Zone and the coastal belt is also highly urbanised.
Climate is Mediterranean, typical for the winter maximum of precipitations and dry summer. The growing season lasts 335 days (290-365), sum of active temperatures is 5104°C (4509°-6112°).

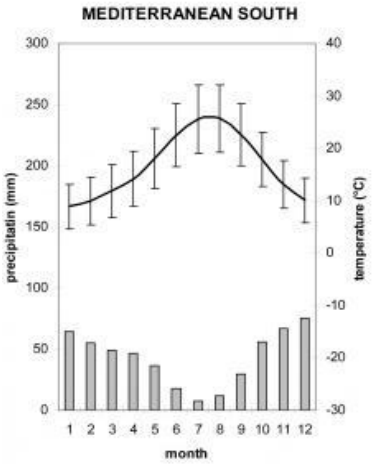


Mediterranean south (MDS)



The Mediterranean South Zone (MDS) includes plains and uplands in the southern Mediterranean and some lowlands in northern Spain and the Rhone delta in France. The topography is diverse and includes coastal plains, plateaus with isolated mountains, foothills and mountain valleys. The climate is Mediterranean with hot and dry summers and maximum of precipitations in winter. Water availability restricts crop production but arable land is still widespread and yields are often increased by permanent irrigation and plastic greenhouses. Vineyards and olive groves are an important land cover throughout the Zone. Grazing of extensive grasslands is in decline with widespread scrub invasion adding to the existing extensive cover. Dehesas and Montados are also important in Spain and Portugal. Otherwise forest cover is restricted because of long over-exploitation but pine forests are important locally. The coastal belt is highly urbanised. The description of this zone is restricted to the European part of the Mediterranean. The climate is Mediterranean with hot

and dry summer and maximum of precipitations in winter. The growing season lasts 363 days (363-365), sum of active temperatures is 6021°C (5904°-6578°).



Appendix 2 Maps per Member State