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Deliverable 2.6 Methodological approaches to identify and map marginal land suitable for industrial crops in Europe

Elbersen, B.[a], Eupen,van E.[a], Mantel, S.[b], Verzandvoort, S.[a] , Boogaard, H.[a] , Mucher, S.[a], Cicarreli, T.[a] & Elbersen, W.[a], Bai, Z.[b], Iqbal, Y.[c] , Cossel, M.[c], Ian MCallum, I.[g], Carrasco,J.[d], Ciria Ramos, C.[d], Monti, A.[e],Scordia, D.[f], Eleftheriadis, I.[h]

[a] Wageningen University & Research, Earth Informatics
[b] International Soil Reference and Information Centre (ISRIC)
[c] University of Hohenheim, Institute of Crop Science, Biobased Products and Energy Crops
[d] CIEMAT
[e] Alma Mater Studiorum - University of Bologna
[f] University of Catania, Agricultural, Food and Environment
[g] International Institute for Applied Systems Analysis (IIASA)
[h] Center for Renewable Energy Sources and Saving (CRES)

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This deliverable 2.6 was finalised and published by Month 12. In the DoA the planned completion date is month 3. This was however an error in the DoA. Basically this deliverable 2.6 presents the approach of mapping marginal land and the results of the mapped approach and could not be ready by month 3 but only after Month 10 when the second version of the Marginal-Agrienvironmental zonation (M-AEZ) was finalised. Since further up-dates of the M-AEZ are planned in month 36 and 44 (D2.4 and D2.5) further up-dates of D2.6 will also be produced in month 36 and 44.

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1.Introduction

1.1. Context and objective

The purpose of the work in WP 2 of the MAGIC project is to map, characterize and analyze projections for current and future marginal lands in Europe facing natural constraints and provide a spatially explicit classification that will serve as a basis for developing sustainable best-practice options for industrial crops in Europe.

This report provides a description of the approach applied to map marginal lands based on the definition and focus described in D2.1 of MAGIC ‘Definition and classification of marginal lands suitable for industrial crops in Europe’. Different succeeding versions of a spatially explicit database (MAP-DB) of a Marginal Agro-Ecological Zonation (M-AEZ) of Europe will be generated. In this deliverable the methodological approach to mapping the first version of Marginal Agro-Ecological Zonation (M-AEZ) in MAGIC is presented.

The M-AEZ will be a spatially explicit classification of marginal lands serving as a basis for developing sustainable best-practice options for industrial crops in Europe. The M-AEZ should incorporate all variables according to which lands have been classified in marginal and non-marginal lands and it should enable the presentation of the marginal land areas according to a flexible choice of other classifying variables such as on current land management (cropping, permanent crops, abandoned), socio-economic and ecosystem service presence. The M-AEZ should also provide all underlying statistics per relevant marginal land class according to classifying and descriptive variables. The M-AEZ should enable approaching the classification according to very different perspectives users like to take (e.g. only biophysical limitations, or only socio-economic limitation, etc.).

In every new version of the M-AEZ the quality of the data contained will improve and grow as more evaluation and validation of results has been done and an increasing amount of characteristics is added to the marginal land strata. MAP-DB will be made accessible in the project website after one year of the project and will be up-dated with further validated and refined results in years 2, 3 and 4 of the project.

It was already decided from the start of the project that ‘natural constraints’ with regard to soil, climate and topographic factors should form an important starting point for mapping marginal lands. For the identified marginal lands, current land uses and state of abandonment should be identified and taken into consideration to facilitate the choices for using the lands for industrial cropping. Additional descriptive characteristics will cover aspects other than natural constrains (demographic regional characterization, dominant agricultural activities, etc.) also by using assessments done for the agri-environmental Indicators (Eurostat, EEA) and the mapping of ecosystem services (MAES). The changes in marginal land in Europe between 2015 and 2020 and 2030 will be modelled using the GLOBIOM model. This however, will happen in a later stage in the project and is not discussed further in this report. The first mapping of marginal lands will focus on identifying the current state of marginal lands.

In D2.1, based on the literature review on marginal lands and the requirements from the MAGIC project discussed and elaborated further at a WP2 QUICKScan workshop held in September 2017, a MAGIC working definition for marginal lands was proposed. This definition will be used for designing the approach to mapping marginal lands in MAGIC as a basis to further investigate the potential use for sustainable industrial cropping. The proposed definition starts from a combined definition of marginal, fragile and degraded lands as defined by FAO-CGIAR and of contaminated lands as defined by EEA. The reason to choose these combinations of land types initially is rooted in the decision taken at the QUICKScan working meeting that WP2 should concentrate on mapping lands that are biophysically constrained, either by natural limitations and/or limitations imposed through unsustainable human management, and lands that remain unused by other activities (e.g. by agriculture, forestry, urban uses, etc.). So the combined definition of these 4 types of lands form the MAGIC definition of Marginal lands:

lands having limitations which in aggregate are severe for sustained application of a given use and/or are sensitive to land degradation, as a result of inappropriate human intervention, and/or have lost already part or all of their productive capacity as a result of inappropriate human intervention and also include contaminated and potentially contaminated sites that form a potential risk to humans, water, ecosystems, or other receptors.

The approach to mapping marginal lands in MAGIC and presented in this report will be based on the literature review in D2.1 but also on joined insights derived through a working meeting with the MAGIC WP2 project team facilitated by the QUICKScan mapping tool. This Quickscan mapping workshop served to evaluate and agree on the final definition and classification of marginal lands and to take a joint decision on the approach to mapping these marginal lands and investigate the options to use them for the production of industrial crops. The minutes of the QUICKScan working meeting are included in Annex I of this report.

1.2. Quickscan mapping approach

It was called a 'QUICKScan' workshop because it used the QUICKScan software for participatory mapping to facilitate the discussions (Verweij et al., 2016). QUICKScan is a method, process and spatially explicit tool, to jointly construct and evaluate mapped rules in a participatory setting. It enables to investigate visually and interactively the most important state of knowledge and data for mapping marginal lands. Data layers, combination of data and classifications are generated with QUICKScan during the workshop on the spot and evaluated and improved on the spot. QUICKScan facilitates a process of trial and error and therefore deepens the ability of a group of experts to develop insights in best approaches to mapping, problem understanding and solving specific challenges. The tool is not restricted to a specific geographic location or spatial resolution. Knowledge rules, capturing participant knowledge, are used to combine data and derive indicators. Typically the rules use classifications to describe quantitative data and typologies to give qualitative data meaning. Rules may be linked together to form a chain of rules. Alternative (chains of) rules are used to capture different options. Derived data from alternatives can be aggregated (e.g. by administrative units, or biophysical units such as catchments, or climatic zones) to be displayed in tables and charts for overviews.

In the case of MAGIC the QUICKScan modelling environment was filled with spatial and statistical data before the WP 2 workshop was held (28-29 September 2017). For the whole of Europe most of the already available data sources on biophysical constraints, socio-economic constraints, environmental threats and challenges and ecosystem services were already collected (see Annex 2 for an overview of data sources collected and incorporated in QUICKSan). For the biophysical criteria identified through the literature review different classified maps and combinations of data layers were prepared beforehand to feed and structure the discussion and also provide an overview of possible data sources to be used.

The QUICKSCan mapping workshop was prepared by: writing a position paper that was the basis for the current D2.1 on the state of play regarding marginal land definitions and mapping approaches sofar.

Compiling, collecting and ordering an extensive amount of spatial data on biophysical (soil & weather), socio-economic characteristics of lands, ecosystem services, environmental threats and drivers and different environmental typologies already elaborated in several other EU projects. An overview of the data compiled before/for the QUICKScan workshop and from which a great number of data are used for further mapping of marginal lands is included in Annex 2 of this report.

Processing the several soil and weather data into sub-indicators for areas of natural constraints following the JRC guidelines (Van Oorschoven et al., 2014). The sub-indicators were further evaluated by the experts during the workshop and suggestions were made on how to best map, integrate the different indicators and best data sources to use.

The QUICKScan workshop took a step by step approach covering the different aspects of marginal lands as visualized in the Figure 1. The summary of the outcomes of the whole QUICKScan workshop is included in Annex I of this report.

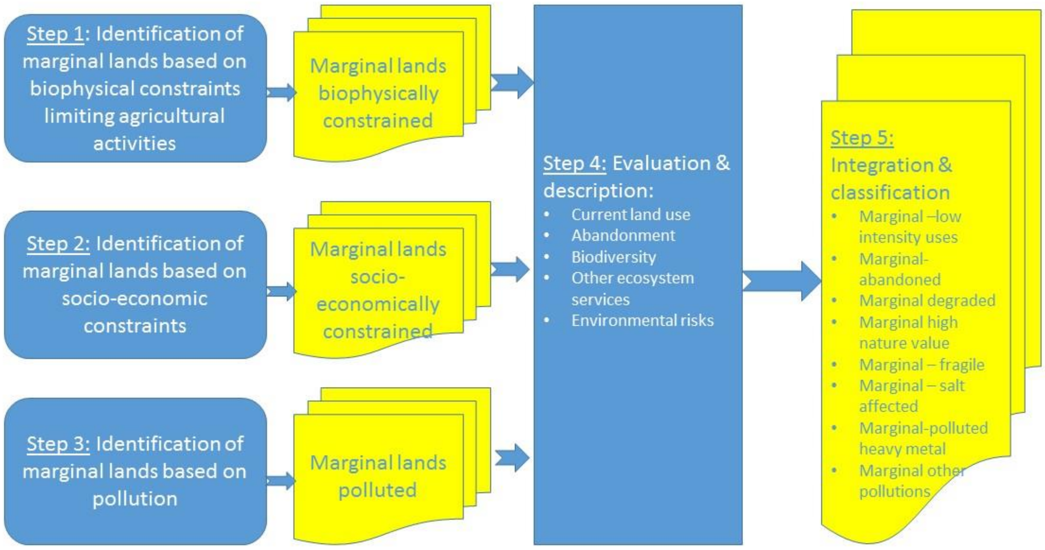


Figure 1: Conceptual scheme of steps covered in the QUICKScan workshop to design best approaches to mapping marginal lands for the sustainable production of industrial crops in Europe

1.3. Approach and structure of this deliverable

In chapter 2 the overall methodology for mapping marinal lands is described. This approach is a direct outcome of the inventory described in D2.1, the outcome of the QUICKScan WP 2 workshop where decisions were made on the final definition for marginal lands to follow, the main componenets determining marginality and the main factors to take into account to make a good selection of marginal land types representative for the situation in different environmental zones in Europe.

In chapter 3 a detailed description is given of the methodology applied and data used to map marginal lands according to biophysical constraints and land management. In the same chapter the resulting maps are also presented including statistical characterisation of sub-classes in Annex 1.

Chapter 4 describes the methodology and results of further classifying marginal lands according to socio-economic constraints and ecosystem services. Again mapped results of the classification are presented with detailed maps Annex 1.

In Chapter 5 the approach to mapping contaminated sites is presented, but the mapping results are not part of this report as these will be mapped in a later stage of the project.

The report finalises with a concluding chapter 6 discussing main achievements sofar and further steps to take in relation to further improving, validating and refining the M-AEZ in the rest of the project. After all this report focusses on mapping the current status of marginal lands in Europe based on first year's work in WP 2 of MAGIC.

2. Marginal lands definition and overall approach to mapping it

2.1 Introduction

In this chapter the definition of marginal lands as proposed in the conclusions of D2.1 and discussed further in the QUICKScan working meeting is presented. Basically there are four marginal land types distinguished and their mapping requires different steps and data sources.

2.2. Starting point: marginal land definition in MAGIC

The decision on which definition of marginal lands to use as a basis for mapping marginal lands in MAGIC was taken during the QUICKScan workshop and was based on the following considerations:

Firstly, it should be based on the recent scientific literature focussing on defining and characterising marginal lands.

Secondly, we strive to identify best options to grow industrial crops on land that is not used for food production at this moment nor is likely to be used for it in the future. This consideration is of course rooted in the general political and scientific concern about indirect land use change (ILUC) effects. ILUC refers to a process in which new demand for biomass additional to the existing food demand leads to a displacement in land use for existing food production as it needs to be produced elsewhere. This displacement leads directly or indirectly (through a number of other displacement steps) to conversion of natural (e.g. forests and wetlands) and semi-natural lands (e.g. extensively grazed grasslands) into agricultural land and this again leads to an increase of Green House Gas (GHG) emissions and to loss of (semi) natural habitats with adverse effects on biodiversity. By focusing on marginal lands in this MAGIC project we expect to identify options for growing industrial crops without displacement effects. Furthermore, it implies that the marginal land definition should be interpreted broadly sothat it is likely to cover the large envelope of land that is currently not used for other functions e.g. agriculture, urban, forestry or where existing functions can be combined with industrial cropping in order to create win-win situations.

Thirdly, we need to identify marginal lands carefully in terms of their bio-physical characteristics because that determines the options for industrial crop choice and economic feasibility. After all, marginal lands according to the MAGIC project plan will at least comprise of areas with natural constraints. Types of natural constraints and thresholds will need to be based on former work done by JRC and other land evaluation approaches to establish agronomic suitability of lands. For both the identification and characterization of marginal lands the soil, topographic and climate factors will play an important role. For the identification of sustainable best-practice options for industrial crops in Europe we need to ensure that these focus on marginality characteristics that are most commonly appearing in every environmental region in Europe and that's why the mapping of marginal lands is an important basis for selecting and testing the industrial crop types and development of best practices.

Fourthly, we want to ensure that options for growing industrial crops are not destroying ecosystems services but rather enable the co-creation of win-win options. To ensure this it will be needed to identify marginal lands carefully in terms of their exact location and extend, but also in terms of the presence of ecosystem services and also pressures on these ecosystem functions. Marginal lands, even though not used for cropping, may still be extensively grazed at very irregular time intervals and/or have important functions in terms of provisioning of habitats for flora and fauna, water regulation, carbon sequestration, recreation and hunting etc. The mapping of marginal lands will therefore need to go together with a good characterization of these lands in order to be able to establish if sustainable cropping of industrial crops is at all an option or that only specific crops in specific management systems can be tuned sustainably with the ecosystem services present to create win-win situations.

A key conclusion of the QUICKScan workshop (see also Annex 2) was that MAGIC should focus initially on mapping land that is biophysically constrained, either by natural limitations and/or limitations imposed through unsustainable human management, and the envelope of land between land that is good for food production and land that cannot be used for any cropping activity and/or where ecosystems and ecosystem services can well be combined with industrial cropping. Given this, and the literature inventory results (Deliverable 2.1) the working definition for marginal lands indicates towards 4 types of lands that need to be identified:

1) 'Areas with natural constraints' for which the JRC provided mapping guidelines and which overlaps strongly with the 'marginal' land class as distinguished in the FAO-CGIAR (1999) land classification. Both JRC and FAO-CGIAR include the biophysical limitations (in JRC approach referred to as 'natural constraints'), but the FAO-CGIAR definition also suggests that marginal lands have socio-economic limitations.

2) 'Fragile lands' as defined by FAO-CGIAR (1999) as land that is sensitive to land degradation, as a result of inappropriate human intervention. This class is likely to largely overlap with 'areas of natural constraints' as many of the natural constraints determining marginal lands also make these lands sensitive to land degradation in case of unsustainable land management.

3) 'Degraded lands' as defined by FAO-CGIAR (1999) as land that has lost part or all of its productive capacity as a result of inappropriate human intervention. Various forms and degrees of degradation, both reversible and irreversible, may occur. Again this type of land is likely to overlap strongly with the marginal and fragile lands in terms of biophysical limitations as these determine the sensitivity to degradation.

4) Contaminated and potentially contaminated sites as defined by EEA (2011) as areas where the presence of soil contamination has been confirmed or is suspected but not verified and this presents a potential risk to humans, water, ecosystems, or other receptors. Risk management measures (e.g., remediation) may be needed depending on the severity of the risk of adverse impacts to receptors under the current or planned use of the site (EEA, 2011).

So the combined definition of these 4 types of lands form the MAGIC definition of Marginal lands is:

l*ands having limitations which in aggregate are severe for sustained application of a given use and/or are sensitive to land degradation, as a result of inappropriate human intervention, and/or have lost already part or all of their productive capacity as a result of inappropriate human intervention and also include contaminated and potentially contaminated sites that form a potential risk to humans, water, ecosystems, or other receptors.*

The definition of the marginal lands determined by marginal, fragile and degraded land classes starts from the perspective of agricultural use. These lands occur in areas that were in continuous or discontinuous agricultural use in the last decades. The definition by FAO-CGIAR combines biophysical and socio-economic limitations and provides clear guidance on how to position marginal lands from other favored lands used for agriculture. It is also clear in that it excludes lands used for other functions such as forestry, urban uses, recreation, nature conservation etc.

An additional mapping approach needs to be developed however for lands with contaminations. In these contaminated sites the biophysical constraints do not have a natural cause, but come from human actions such as waste disposal, industrial and mining activities such as for oil extraction and production, and power plants, military sites and war affected zones, storages of chemical substances like oil and obsolete chemicals, transport spills on land (oil spill sites and other hazardous substance spills sites), nuclear sites and other sources. Some of these site may be interesting to be used for industrial crops, particularly for non-food crops that can also be used for bioremediation of these sites (Fernando, 2005, Lewandowski et al. 2016).These sites can occur anywhere and are certainly not limited to rural and agricultural land classes. What these contaminated site can have in common with marginal, fragile and degraded sites in (former) agricultural lands is that they are currently left unused and are clearly constrained by adverse chemical composition of the soil. They are therefore an interesting land category for industrial crops for non-food purposes and particularly those with a bioremediation capacity. The mapping of these contaminated sites will build as much as possible on existing data bases and inventories of contaminated sites by EEA EOINET and ESDAC. Their mapping will require a different approach from the mapping of the marginal, fragile and degraded lands which cover a much larger land area and are mostly linked to (former) agricultural land classes. In the following a distinction is therefore made in the approach to mapping the marginal, fragile and degraded and the contaminated lands. The mapping of the latter is discussed in a separate chapter 4 but the mapped results are not presented in this report.

2.3 Overall approach to mapping marginal lands in MAGIC

The marginal land definition taken as a starting point in MAGIC builds on the FAO-CGIAR classification and definition of marginal, fragile and degraded lands in areas with an agricultural land use or history as they can become abandoned for other uses or no-use in recent years. On the other hand, contaminated sites need to be mapped, but these are located in any type of land cover class, and require a complete other mapping approach. The methodology to mapping marginal lands presented here will only refer to the lands that are characterised in the MAGIC marginal land definition as:

lands having limitations which in aggregate are severe for sustained application of a given use and/or are sensitive to land degradation, as a result of inappropriate human intervention, and/or have lost already part or all of their productive capacity as a result of inappropriate human intervention

The work of mapping marginal lands in this WP is to be performed in the context of using marginal land for growing industrial crops (MAGIC). It should therefore not result in one map of marginal lands but it should result in a so-called ‘Marginal Agro-Ecological Zonation ‘(M-AEZ) for Europe. This should be a spatially explicit classification of marginal lands serving as a basis for developing sustainable best-practice options for industrial crops in Europe. The M-AEZ should incorporate all variables according to which lands have been classified in marginal and non-marginal lands and it should enable the presentation of the marginal land areas according to a range of classifying variables and provide all underlying statistics per relevant marginal land class according to classifying and descriptive variables. The M-AEZ should enable approaching the classification according to very different perspectives.

The elements to be taken into account in building the classification have been discussed in the former and include:

1) Biophysical limitations
2) Land use management
3) Socio-economic limitations
4) Ecosystem services and drivers and pressures influencing the ecosystem functions

Given the definition of marginal lands and the elements of relevance according to which to map, characterize and further enable a flexible classification of the marginal lands prescribe a step wise approach. A stepwise approach enables the development of a multi-dimensional classification of marginal lands which is fully transparent in terms of the data layers used, the classes and thresholds applied. It also enables providing flexibility to the user of the M-AEZ in terms of choosing the relevant classifying layers and descriptive statistics.

An important distinction will be made between factors that determine the delimitation of the marginal land areas and factors that are only used for further classifying and characterizing marginal lands (see Figure 2). As to the factors determining the delimitation of marginal lands, the focus will entirely be on the biophysical limitations (referring to natural constraints in JRC terminology (van Oorschoven et al., 2014). Part of these biophysical limitations have been neutralised by taking specific land improvement measures. Because of these measures, certain marginal lands have become converted to improved agricultural lands which have now become part of the envelope of favoured land used for efficient agricultural activities. These improved naturally constrained lands should be excluded from the marginal land classification as the constraining influence of biophysical factors on the land use is no longer applicable.

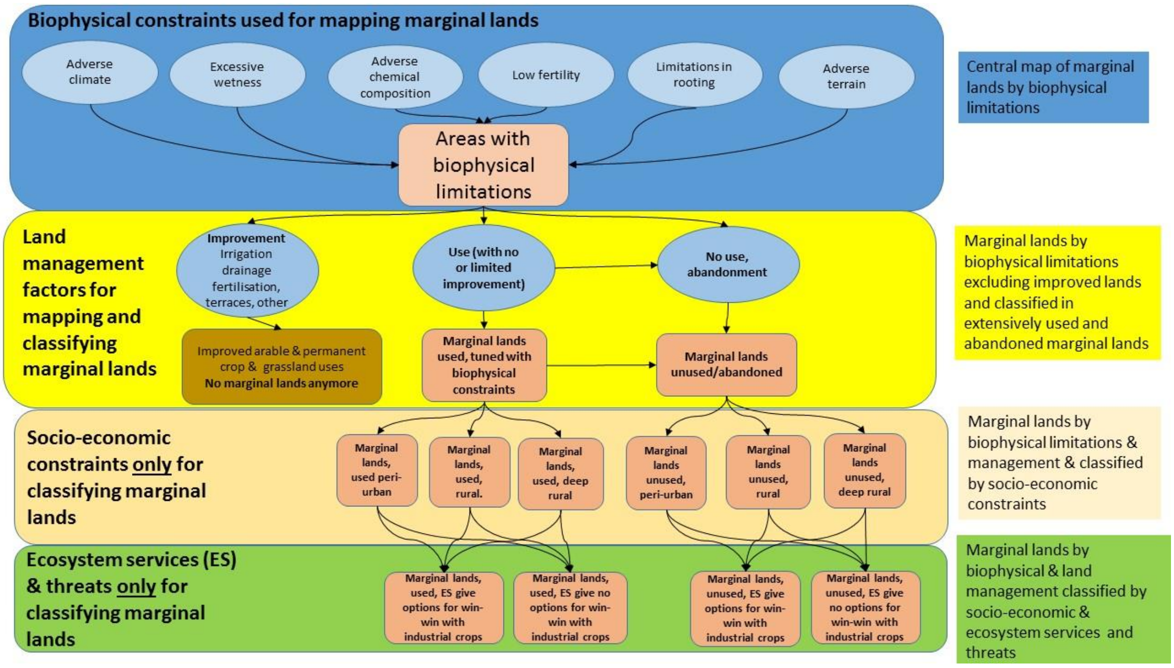


Figure 2: Stepwise approach followed to mapping and classifying marginal lands for the M-AEZ

For the elaboration of the M-AEZ the following stepwise approach will be followed (see also Figure 2) in which the first 2 steps detemine the detailed mapping (spatial delimitation) of marginal lands and the rest of the steps support the further classification and chracterisation of the marginal lands.

Step 1: A basic map of marginal lands is produced based entirely on biophysical limitations. The developed approach by JRC to identify areas of natural constraints (Van Oorschoven et al., 2014 and Terres et al., 2014) and de several land evaluation systems for agronomic suitability as discussed in D2.1 (e.g. USDA-Land Capability Classification System (LCC) , Muencheberg classification by Mueller et al., 2010 and Soil Quality Rating by Shepherd, 2000) provide a good overview of biophysical indicators and related threshold to be included. These biophysical limitations can be clustered in 6 groups of limitations: adverse climate (too cold, too dry), excessive wetness, adverse chemical composition of the soil, low soil fertility, soil characteristics limiting rooting depth and adverse terrain (steep slopes). For mapping the marginal lands with biophysical constraints the 6 clusters of constraints need to be mapped in 6 aggregated cluster maps showing where land fall in the marginal land thresholds and outside it (See the 6 maps in Annex 1). The 6 cluster maps can then be integrated into one map showing the lands falling within the marginal threshold limits for one or more of the 6 biophysical limitation clusters.

The constraints developed in the JRC approach to mapping 'lands of natural constraints' (Van Oorschoven et al., 2014) is taken as a key starting point for the detection of marginal lands in MAGIC. An important challenge for the mapping of the biophysical constraints is however the availability and use of good quality data at high spatial resolution. The approach by JRC to areas of natural constraints is valuable, but does not provide guidance on what data to use. In MAGIC the different data sources to map the biophysical constraints are collected and evaluated. To ensure a high quality mapping of marginal lands it will be necessary to exclude certain sub-indicators for biophysical constraints suggested by JRC for lack of reliable data. An alternative proxy indicator was then identified as is explained in Chapter 3 where further details about the mapping of the marginal lands according to biophysical constraints is given and the resulting mapping results are presented.

Step 2: The marginal land zonation mapped in step 1 is further combined with data on land management to enable a further exclusion and classification. As to the exclusion this step will enable identification of marginal lands that have been improved, so the natural constraints have been neutralised, for efficient agricultural land use. As to further classification the aim of this step is to identify for the marginal lands that have remained unimproved how they are used: they can either be used for extensive (agricultural) uses such as extensive grazing or be left unused.

Land management can have an important influence on the current agronomic suitability of land. Land improvement measures can help to neutralize the natural constraints and enable converting marginal lands into productive lands (e.g. cropland and improved grasslands). Land management can also be stopped, particularly if biophysical and socioeconomic constraints limit the economic returns. Another category of land very much determined by unsustainable land management is that of marginal lands in the degraded land class. On these lands, which in general are characterized by biophysical constraints making the land more sensitive to degradation (fragile lands) in case of intensive agricultural use, the productive capacity is partly or fully disappeared. This goes together with a loss of ecosystem functions. This however will not be addressed in step 2 of the land management mapping but in step 4 where a further classification of marginal lands according to ecosystem services and threats to these services is done. The mapping of marginal lands to classify according to degradation status will not be done in MAGIC however. In D2.1 is was already explained that little consensus exists about how land degradation should exactly be defined and estimates of land degradation differ considerably and are very limited for Europe. Very different definitions of land degradation and approaches to mapping the concept are seen ranging from mapping the extend according to perceptions of experts (Oldeman et al., 1990) to mapping more the outcome of degradation in terms of changes in land conditions and ecosystem functions and threats to ecosystem services, particularly those related to the productive capacity of lands and different soil functions (Van der Esch et al., 2017; Louwagie et al., 2009 and Bai, et al., 2008). The approach and outcome of the mapping of land improvement measures neutralising natural constraints and the classification of unimproved marginal lands according to land uses and abandonment is also presented in Chapter 3. Chapter 4 presents the classification of marginal lands according to ecosystem services and threats to these services, particularly those for soil functions which can also be seen as proxy indicators for land degradation risk.

Step 3: The marginal land classes from step 2 were further classified according to socio-economic constraints with regard to accessibility, status of infrastructure, demographic parameters and economic density (income/km2).

For the identification of marginal lands there is no clear consensus in relation to whether socio-economic constraints alone can be used to identify marginal areas. In MAGIC the approach is chosen to first identify the biophysically constrained areas and on top of that further determine which socio-economic constraints occur simultaneously. There are several socio-economic characteristics according to which regions can be characterized, but the typical characteristics found in the rural development literature about factors constraining the development of rural regions (OECD, 2006, 2007 & 2009, EC, 2017) refer to factors like:

- Relative location (remoteness, central-decentral)
- Presence of infrastructure influencing the accessibility (lack of it)
- Low population density
- Low density of economic activities
- Large dependence on primary sector
- Ageing population

Often there is a strong relationship between several of the socio-economic factors, e.g. low population density usually goes together with low accessibility, low income and an ageing population, which implies that a rural multidimensional typology would be the best approach to classifying marginal lands further according to socio-economic constraints.

Step 4: The marginal land classes from step 3 will be further characterized in terms of ecosystems present and threats to functions such as biodiversity areas, risk for soil erosion, compaction, loss of SOM, and more. This last classification step is logical from the literature inventory showing that the use of marginal lands for industrial cropping has sustainability challenges and opportunities. The sustainability impacts of growing industrial crops in marginal lands can be positive and negative, but depend strongly on the ecosystem services present and the current status and threats to ecosystem services. The marginal land classification requirements according to ecosystem threats and win-win opportunities to match industrial cropping with improving ecosystem services is discussed further in chapter 4.

2.3.1 Focus on lands with an historic agricultural land use

The mapping of the first version of M-AEZ (excluding the contaminated lands) will be limited to a so-called 'agricultural mask'. This mask will include all land that was classified in an agricultural land cover class (see Table 1) in at least one of the four Corine Land Cover (CLC) versions:

CLC 1990

CLC 2000

CLC 2006

CLC 2012

Using this mask also enables to generate comparable statistics for the mapped classes in terms of area coverage within the EU territory, per country and per environmental zones. The latter are all regions according to which the mapped totals will be reported.

Table 1 CORINE land cover classes (CLC)* agricultural non agricultural

CLC-NR	CLC Description_Level3	Agricultural mask MAGIC	Grazing	Cropping
0	UNCLASSIFIED	No	No	No
111	Continuous urban fabric	No	No	No
112	Discontinuous urban fabric	No	No	No
121	Industrial or commercial units	No	No	No
122	Road and rail networks and associated land	No	No	No
123	Port areas	No	No	No
124	Airports	No	No	No
131	Mineral extraction sites	No	No	No
132	Dump sites	No	No	No
133	Construction sites	No	No	No
141	Green urban areas	No	No	No
142	Sport and leisure facilities	No	No	No
211	Non irrigated arable land	**Yes**	No	**Yes**
212	Permanently irrigated land	**Yes**	No	**Yes**
213	Rice fields	**Yes**	No	**Yes**
221	Vineyards	**Yes**	No	**Yes**

CLC-NR	CLC Description_Level3	Agricultural mask MAGIC	Grazing	Cropping
222	Fruit trees and berry plantations	Yes	No	Yes
223	Olive groves	Yes	No	Yes
231	Pastures	Yes	Yes	No
241	Annual crops associated with permanent crops	Yes	No	Yes
242	Complex cultivation patterns	Yes	Yes	Yes
243	Land principally occupied by agriculture- with significant areas of natural vegetation	Yes	Yes	Yes
244	Agro forestry areas	Yes	Yes	Yes
311	Broad-leaved forest	No	No	No
312	Coniferous forest	No	No	No
313	Mixed forest	No	No	No
321	Natural grasslands	Yes	Yes	No
322	Moors and heathland	Yes	Yes	No
323	Sclerophyllous vegetation	No	No	No
324	Transitional woodland shrub	No	No	No
331	Beaches- dunes- sands	No	No	No
332	Bare rocks	No	No	No
333	Sparsely vegetated areas	No	No	No
334	Burnt areas	Yes	Yes	Yes
335	Glaciers and perpetual snow	No	No	No
411	Inland marshes	No	No	No
412	Peat bogs	No	No	No
421	Salt marshes	No	No	No
422	Salines	Yes	Yes	No
423	Intertidal flats	No	No	No
511	Water courses	No	No	No
512	Water bodies	No	No	No
521	Coastal lagoons	No	No	No
522	Estuaries	No	No	No
523	Sea and ocean	No	No	No

*For a detailed description of all CORINE 2012 classes see: http://uls.eionet.europa.eu/CLC2000/classes/index_html

3. Mapping marginal lands according to biophysical constraints

3.1 Introduction

As to biophysical constraints both FAO-CGIAR, and main land classification approaches (e.g. USDA-LCC, Mueller et al. (2010), Cai et al. (2010), Fischer, 2002 and 2008) underpin well the choice of indicators proposed by JRC (van Oorschoven et al., 2014, Terres et al., 2014) to identify areas of natural constraints in the EU. So on the level of criteria proposed for biophysical constraints typical to marginal lands the groups of constraints listed below will be used in MAGIC.

Basically the biophysical factors or land characteristics listed and described for mapping 'areas of natural constraints' by JRC and in the different land evaluation systems mentioned in D2.1 can be grouped into 6 clusters (compound land characteristics) of constraints:

1. Adverse climate
    a. Low temperature
    b. Dryness
    c. Excessive wetness
2. Excess soil moisture
    a. Limited soil drainage
3. Adverse chemical conditions
    a. Salinity (Ec)
    b. Sodicity (Na/ESP)
    c. Natural toxicity (e.g. Al, S)
    d. Toxicity by pollutants
4. Low soil fertility
    a. Soil reaction (pH)
    b. Low soil organic carbon (SOC)
5. Limitations in rooting
    a. Unfavourable soil texture
    b. Coarse fragments
    c. Organic soils
    d. Abrupt textural difference
    e. Surface stones and rocks
    f. Shallow rooting depth

6. Adverse terrain conditions
    a. Steep slope
    b. Flooding risk

Then there are lands that have natural constraints, but these have been neutralised by human interference, making them well suited for normal and even high productive agriculture. This implies that although originally natural constraints were present, they are no longer limiting. These improved naturally constrained areas should be classified separetely from the marginal land areas mapped in MAGIC. On the other hand, for the remaining biophysically constrained marginal lands, land management status also needs to be established. These can be uses of the unimproved marginal lands, e.g. for grazing or other forms of very extensive agriculture, or no uses, e.g. abandoned.

In the next section first an explanation is given of the detailed indicator selection, data selection and mapping of the biophysical constraints. In section 3 an explanation is given of how land management status of the marginal lands is further mapped. In Section 4 of the chapter the results of the mapping of marginal lands according to biophysical limitations and land management is presented.

3.2. Mapping marginal land according to biophysical constraints

Clustered biophysical factors

The clusters of biophysical factors that were defined are: 1. Adverse climate, 2. Excessive wetness, 3. Adverse chemical composition conditions, 4. Low soil fertility, 5. Limitations in rooting, 6. Adverse terrain conditions. These clustered biophysical factors are considered major environmental characteristics that, when critical threshold values are exceeded, they are (severly) limiting agricultural production. Critical limits were defined for each individual factor making up the 6 clustered factors. The factors selected are related to generic requirements of agricultural crops and land management with regards to soil, climate and terrain. In line with the JRC approach for the identification of lands with natural constraints (Van Oorschoven, J., et al., 2014), a restricted set of soil, climate and terrain factors were defined for assessment of land marginality. The objective was to design and apply a method that is transparent (the resulting marginal land classes results can be interpreted back to the determining single factors), simple and repeatable. The interaction between single factors is taken into account by the clustering of single factors into 6 groups and by the pairwise combinations of single factors that may jointly aggravate (negative combination) or counterbalance (positive combination) limiting conditions (based on Terres et al., 2014). This simplified approach is considered appropriate since major limitations for agriculture are identified, rather than optimal conditions for plant growth and land management. For the latter a more elaborated approach is justified that takes land qualities into consideration (Van Oorschoven, J., et al., 2014).

Data quality

An important challenge for the mapping of the biophysical constraints was good quality data availability. The approach by JRC to areas of natural constraints is valuable, but does not provide guidance on what data to use. In MAGIC the different data sources to map the biophysical constraints were collected and evaluated because the use of high quality data is very important. Classifications and threshold levels for marginal lands need to be identified using good quality data only. The selection of the appropriate indicator and the mapping of the marginality factor according to the threshold has to be scientifically robust, but also needs to be mappable given data quality and availability. Sometimes it was decided that certain sub-indicators being part of one of the 6 clusters could not be reliably mapped. In the next much attention is therefore paid to explaining data sources used and evaluation of the quality of the data (see Table 2).

Single biophysical factors

In the following the selection of single factors making up the 6 clusters of biophysical limitations according to which marginal lands are mapped is described. An overview of single factors, the threshold levels choosen the scientific source used for the definition and the data used to map it is also given in Table 2.

1. Adverse climate

To evaluate limitations related to climate two parameters were selected as proposed in the JRC approach to mapping areas of natural constraints (van Oorschoven et al., 2014): low temperatures and drought. Very low temperatures exclude or limited growth of many agricultural crops. As an indicator the Length of Growing Period was used of: number of days (threshold at 180 days) with daily average temperature > 5°C (LGPt5) or Thermal-time sum (degree-days; threshold at 1500 degree days) for Growing Period defined by accumulated daily average temperature > 5°C.For dryness the ratio of precipitation over potential evapotranspiration is indicative of soil moisture conditions for agricultural crops. In case of low rainfal and high evaporative demand then the soil moisture supply will be low and the growth potential for crops is low. The indicator for dryness is assessed by takin the ratio of the annual precipitation (P) to the annual potential evapotranspiration

(PET). The Threshold limit is set at 0.5 (P/PET ≤ 0.5) The threshold value is set at P/PET is 0.5.

2. Excessive wetness

Excess of soil moisture (water content above field capacity) over prolongued time in the field is limiting for crops and for management. Access of the field with machines and the workability of the soil is hampered and lack of oxygen for root growth limits crop growth. This is evaluated by soil moisture content exceeding field capacity for at least 210 days (7 months). Soil drainage status is a morphometric parameter that relfects the combined effects of cliamte,landscape and soil. It is described in the field and is indicative for the wetness of a soil over longer periods of time (and that is reflected in the soil status,
judged by a.o. soil colour and mottling). The poorly drained soils from WRB (at Soil Reference Group level and at the level of principle qualifiers) were selected from the European Soils Database.

3. Adverse chemical conditions

The clustered factor of 'adverse chemical conditions' combines the excess of salts and toxic elements in the soil that hamper crop growth ormay pose a health risk. The excess of salts is affects crop growth in various ways: by toxicity effects, by reducing the water availability to plants through increased osmotic pressure and by causing nutritional disorers. Excess of salts occurs through salinity (access of free salts) and sodicity (saturation of the soil exchange complex with sodium), (Mantel and Kauffman, 1995).

Salinity is identified through units on the soil map of Europe (European Soils Database) which were mapped in the ESDAC project (Toth et al., 20018). Solonchaks soil and soils with a salic qualifier that cover more than 50% of the mapping unit area were ranked as highly saline (ECse > 15 dS/m). Sodicity is mapped from the same source (ESDAC). It is derived from the mapping units that have more than 50% area of sodic soils (Solonetz) and soils with a sodic qualifier. Sodic soils are soils with saturation of the exchange complex with sodium (ESP) of more than 15%.

There are several naturally occuring toxicities in soils that have a negative effect on crop growth. In acid subsoils this may be aluminium. Yet on the basis of the soil database available this parameter is not represented well, limiting the possibility to map aluminium toxicity. Aluminium toxicity is therefore not taken into account in the mapping of marginal lands. Acid sulphate soils are soils that once they are drained, they become extremely acidic, as sulfides react with oxygen to form sulfuric acid. Extremely high acidity, high sulfur availability and aluminium toxicity that result in drained acid sulphate soils are posing great limitations to land management for farming. These soils are identified through the Thionic qualifier of soils in the European Soils Database.

Table 2 Overview of biophysical constraints used to map marginal lands

Cluster	Sub- factor	Description	Selection based on (JRC, Meuncheberg, other...)	Threshold for marginal lands	Data source used for mapping
1. Adverse climate	Low temperature	Length of Growing Period: number of days with daily average temperature > 5°C (LGPt5) or Thermal-time sum (degree-days) for Growing Period defined by accumulated daily average temperature > 5°C.	JRC (Van Oorschoven et al, 2014)	LGPt ≤ 180 days Or Degree days <= 1500 days (<= 1575 = sub-severe)	CRU CY v. 3.24. Climatic Research Unit - CRU (1901-2015). Harris et al. (2014) doi:10.1002/joc.3711
	Dryness	Ratio of the annual precipitation (P) to the annual potential evapotranspiration (PET). Thresholdlimit: (P/PET ≤ 0.6)	JRC (Van Oorschoven et al, 2014)	P/PET ≤ 0.5 (< 0.6 = sub-severe)	CRU CY v. 3.24. Climatic Research Unit - CRU (1901-2015). Harris et al. (2014) doi:10.1002/joc.3711
2. Excessive wetness	Excess soil moisture	Water content in the soil exceeds field capacity for at least 210 days (7 months)	JRC (Van Oorschoven et al, 2014) with slight adaptation for threshold to follow mapped classes.	210 days severe (190 days = sub-severe)	CRU CY v. 3.24. Climatic Research Unit - CRU (1901-2015). Harris et al. (2014) doi:10.1002/joc.3711
	Limited soil drainage	Soils with high water tables throughout the year that have a lack of oxygen in the rooting zone, effectively limiting growth of crops	JRC (Van Oorschoven et al, 2014) but with adapted thresholds/selections from the Reference Soil Groups (RSGs) of the World Reference Base for Soil Resources	Gleysols, Histosols, Stagnosols, Planosol, Soils with primary qualifiers Histic, Gleyic and Stagnic and marshlands	ESDB v2.0: The European Soil Database distribution version 2.0, European Commission and the European Soil Bureau Network, CD-ROM, EUR 19945 EN, 2004
3. Adverse chemical conditions	Salinity (Ec)	Soils with high salinity content	Toth et al. (2008) and Van Oorschoven et al (2014)	Solonchaks and soils with a salic qualifier. For these salt level > 15 dS/m and more than 50% of the mapping unit area	Toth et al., (eds) (2008), Threats to soil quality in Europe. EUR 23438 EN - 2008 and https://esdac.jrc.ec.europa.eu/content/saline-and-sodic-soils-european-union
	Sodicity (Na – ESP)	Soils with high sodicity content	Toth et al. (2008) and Van Oorschoven et al, (2014)	Solonetz, 'natric' soils, or 'Sodic' soils. Saturation with exchangeable sodium of more than 15% (ESP), and more than 50% of the mapping unit area	https://esdac.jrc.ec.europa.eu/content/saline-and-sodic-soils-european-union and ESDB v2.0: The European Soil Database distribution version 2.0, European Commission and the European Soil Bureau Network, CD-ROM, EUR 19945 EN, 2004
	Natural toxicity (e.g. Al, S)	Soils with high content of sulfur that have acidification potential upon drainage	JRC (Van Oorschoven et al, 2014) but with adapted thresholds/selections from the Reference Soil Groups (RSGs) of the World	Soils with Thionic qualifier	ESDB v2.0: The European Soil Database distribution version 2.0, European Commission and the European Soil Bureau Network, CD-ROM, EUR 19945 EN, 2004
	Toxicity by	Soils that have been polluted by	Data not included yet	NOT INCLUDED YET	Data currently not available to the project:

Cluster	Sub- factor	Description	Selection based on (JRC, Meuncheberg, other...)	Threshold for marginal lands	Data source used for mapping
	pollutants	man mostly through waste disposal or industrial processes	(Toth et al, 2016)		Tóth, G., et al. (2016). "Heavy metals in agricultural soils of the European Union with implications for food safety." Environment International 88(Supplement C): 299-309. doi.org/10.1016/j.envint.2015.12.017
4. Low soil fertility	Soil reaction (pH)	Highly acidic and alkaline soils (0-30 cm)	JRC (Van Oorschoven et al, 2014) (with adapted threshold values)	Soils with pH below 4.5 or pH above 8 (at depth 0-30 cm)	Hengl, T., Mendes de Jesus, J., Heuvelink, G. B.M., Ruiperez Gonzalez, M., Kilibarda, M. et al. (2017) SoilGrids250m: global gridded soil information based on Machine Learning. PLoS ONE 12(2): e0169748. doi:10.1371/journal.pone.0169748
	Soil organic carbon (%)	Low organic carbon containing soils as an indicator for soils with low fertility and low biomass turnover (0-30 cm)	Based on Mantel et al (2010)	SOC % average of depth range 0-30 cm at <0.5% (<0.75% = sub-severe)	Hengl, T., Mendes de Jesus, J., Heuvelink, G. B.M., Ruiperez Gonzalez, M., Kilibarda, M. et al. (2017) SoilGrids250m: global gridded soil information based on Machine Learning. PLoS ONE 12(2): e0169748. doi:10.1371/journal.pone.0169748
5. Limitations in rooting	Unfavourable soil texture	Texture class in half or more (cumulatively) of the 100 cm soil surface is sand, loamy sand defined as: silt% + (2 x clay%) ≤ 30%	JRC (Van Oorschoven et al, 2014) but with adapted thresholds/selections	Sand, loamy sand defined as: silt% + (2 x clay%) ≤ 30% (= Max 70% sand) (max 60% sand = sub-severe)	AGLIM1 : Code of the most important limitation to agricultural use of the STU https://esdac.jrc.ec.europa.eu/resource-type/european-soil-database-maps ESDB v2.0: The European Soil Database distribution version 2.0, European Commission and the European Soil Bureau Network, CD-ROM, EUR 19945 EN, 2004
	Coarse fragments 7 surface stones	> 35 cm (0-30 cm)	JRC (Van Oorschoven et al, 2014) but with adapted thresholds/selections	Course material At depth: 0-35 cm covering a surface of >35% and/or > 15% rock coverage (> 25% and/or > 10% respectively for sub-severe)	AGLIM1 : Code of the most important limitation to agricultural use of the STU https://esdac.jrc.ec.europa.eu/resource-type/european-soil-database-maps ESDB v2.0: The European Soil Database distribution version 2.0, European Commission and the European Soil Bureau Network, CD-ROM, EUR 19945 EN, 2004
	Organic soils	Organic matter ≥ 20%)	JRC (Van Oorschoven et al, 2014) but with adapted thresholds/selections	>= 20% organic matter = Histosols	ESDB v2.0: The European Soil Database distribution version 2.0, European Commission and the European Soil Bureau Network, CD-ROM, EUR 19945 EN, 2004
	Shallow rooting depth	Depth (cm) from soil surface to coherent hard rock or hard pan	JRC (Van Oorschoven et al, 2014) but with adapted thresholds/selections	< 30 cm rooting depth possible. Selected soils for mapping: Leptosols, Albeluvisols, Lithic, Petrocalcic, Fragipans, Duripans, Petroferric	AGLIM1 : Code of the most important limitation to agricultural use of the STU https://esdac.jrc.ec.europa.eu/resource-type/european-soil-database-maps ESDB v2.0: The European Soil Database distribution version 2.0, European Commission and the European Soil Bureau Network, CD-ROM, EUR 19945 EN, 2004
6. Adverse terrain	Steep slope	Change of elevation with respect to planimetric distance (%).	JRC (Van Oorschoven et al, 2014) but with adapted	>80% of area has a slope of > 15% slope > 60% of the area has a slope of >15% slope = sub-	European Digital Elevation Model (EU-DEM), version 1.1

Cluster	Sub- factor	Description	Selection based on (JRC, Meuncheberg, other...)	Threshold for marginal lands	Data source used for mapping
conditions			thresholds/selections	severe)	
	Flood risk	Risk of flooding in relation to risk of damage to the field and to crops during the growing season	Meuller et al. (2011)	> 2 m flood in 2yrs return time (>1-2 m flood in 2 yr return time (=sub-severe)	JRC_Lisflood_2025 2 Years Return rate. Dankers, R. and L. C. D. Feyen (2009). "Flood hazard in Europe in an ensemble of regional climate scenarios." Journal of Geophysical Research: Atmospheres 114(D16). DOI 10.1029/2008JD011523

Toxicity in soils caused by human induced soil pollution is not taken into account in this version, but will be taken into account in year 2 of the project to elaborate the next version of the M-AEZ (see also Chapter 6). Therefore this factor is ignored for current version of M-AEZ.

4. Low soil fertility

The combined factor of low soil fertility may be evaluated by various parameters. It refers to the availability of nutrients over time to crops. Soil nutrient availability is often highly variable in both space and time and depends on many variables. Sandy soils (most of which are poorly fertile and have a low nutrient content) are taken into account in other grouped factors. For this method to classify marginal lands therfore a simple approach was followed that ranks two parameters that influence soil fertility: soil reaction (pH) and organic carbon content. Soil reaction is an indicator for the availability of nutrients (poor in alkaline and in acid soils). Soils with pH (0-30 cm) below 4.5 or above 8 are considered (severly) limited.

Organic carbon contributes to the nutrient buffering capacity of the soil and it (organic matter) is a direct source of nutrients. Low carbon containing soils are indicative for low soil fertility and low biomass turnover. The threshold was set at 0.5% carbon (lower is severly limited).

5. Limitations in rooting

Root growth is directly related to possibility for uptake of nutrients and water and provides food for the crop. Root growth constraining factors selected, for the classification of marginal lands, to evaluate limitations in rooting were: unfavourable soil texture, coarse fragments, organic soils, surface stones and rocks, and shallow rooting depth.

Unfavourable texture concerns the sandy soils and the heavy clays. Very sandy soils have a low water holding capacity and are often low in nutrient content and capacity to buffer nutrient. Normal fertilization practices have limited efficiency on very sandy soils (Van Oorschoven, J., et al., 2014). Heavy clays are limiting for crop cultivation as they have linitations in access for machinery during wet parts of the season, difficult workability and may have shrinking and swelling characteristics during dry and wet conditions that may damage plant roots. Water movement may be slow in heavy clays (due to low porosity) and water may accumulate on the surface in high rainfall events.

Coarse fragments limit crop cultivation because the negative effect on workability. The main effect is though in rootable volume. The volume occupied by stones is limits rootable space and the volume of storage for water and nutrients in the soil.

Organic soils are soils with organic matter content ≥30% in a layer of 40 cm or more, either extending down from the surface or taken cumulatively within the upper 100 cm of the soil (histic horizon, IUSS Working Group WRB (2006), Foothold for roots is limited in organic soils, especially for perennial crops. Peatlands are both ecological valuable and fragile. Cultivation of organic soils required drainage. This causes oxidation of the peat and CO2 release. This is not sustainable and should be avoided. Peat soils are therefore best left uncultivated.

Surface stones and rocks are a limitation for soil workability and access of machinery. Furthermore surface stones and rocks hamper seed germination. The threshold is set a ≥ 15% surface cover.

Shallow rooting depth is defined as the depth in cm's from soil surface to coherent hard rock or hard pan. The rootable soil volume is a critical characteristic of land in relation to suitability for farming. It determines the foothold for roots, but most of all the total store of nutrients and water that will be potentially available to the plant during the growing season. Rootable soil volume may be limited by chemical or physical barriers. In assessment of marginal lands a shallow depth from the soil surface to an impeding layer (hardpan) or to bedrock (30 cm or less in Leptosols) is considered.

6. Adverse terrain conditions

Steeply sloping lands are a limitation for land access with machines. On sloping land less water infiltrates into the soil and surface runoff leads erosion. The slope is described as the change of elevation with respect to planimetric distance (%). The threshold is set a slopes of ≥ 20% are considered severely limiting and 15%- 20% is rated as subsevere.

Flooding is a risk for crops on the field. It may damage standing crops directly through the resistance of the water flow and the resulting (prolonged) water ponding may damage crops.

Pairwise combinations of biophysical factors

Biophysical factors have been indentified for the classification of severe linitations for crop production; 18 single factors, grouped into 6 clustered factors. Following the method as described by Terres et al. (2014), pairwise combinations, 24 in total, were made to assess possible negative and positive synergies and interactions of biophysical factors. Furthermore the land units were identified with biophysical factors within the 20% margin of the threshold value of severity. This allows to map areas with one or more factors close (within 20%) of the threshold. i.e. the sub-severe level. When two factors are within sub-severe level the land units were classified from sub-severe to severe.

Table 3 Overview of pair wise combinations of biophysical factors used (elaborated from Terres et al., 2014)

Cluster	Pairwise combination	+/-	Thresholds	
			Marginal limit	Within 0-20% of limit
1A - Low temperature			1500 degrees Tsum	1400 degrees Tsum
	Excess soil moisture	-	210 Days/Year	170 Days/Year
	Heavy clay	-	> 60% clay	> 50% clay
	Organic soil	-	Peat Soils	NA
1B - Dryness			35% (PET/PT)	45% (PET/PT)
	Stoniness	-	> 35% Stones	> 25% Stones
	Sand, loamy sand	-	> 70% sand	> 60% sand
	Heavy clay	-	> 60% clay	> 50% clay
	Rooting depth	-	Lithic-/Leptosols (WRB)	Lithic-/Leptosols (WRB)
	Salinity	-	> 50% of the area	< 50% of the area
	Slope	-	> 17.5 degr	> 15 degr
2A Excess soil moisture	Organic soils	-	Peat Soils	NA
	Rooting depth	-	Lithic-/Leptosols (WRB)	Lithic-/Leptosols (WRB)
	Slope	+	> 17.5 degr	> 15 degr
2B Poor drainage	-		Lithic-/Leptosols (WRB)	Lithic-/Leptosols (WRB)
3. Adverse chemical conditions	-			
4. Low soil fertility	-			
5. Rooting conditions				
5A –Sand, loamy sand	Organic soil	+	Peat Soils	NA
	Salinity	-	> 50% of the area	< 50% of the area
	Rooting depth	-	Lithic-/Leptosols (WRB)	Lithic-/Leptosols (WRB)
5A – Heavy clay	Rooting depth	-	Lithic-/Leptosols (WRB)	Lithic-/Leptosols (WRB)
	Salinity/sodicity	-	> 50% of the area	< 50% of the area
	pH	-	<4.5 or > 8	< 5
5B – Stoniness	Sand, loamy sand	-	> 70% sand	> 60% sand
	Organic soil	+	Peat Soils	NA
	Rooting depth	-	Lithic-/Leptosols (WRB)	Lithic-/Leptosols (WRB)
	Slope	-	> 17.5 degr	> 15 degr
5C – Rooting depth	Salinity/sodicity	-	> 50% of the area	< 50% of the area
	Slope	-	> 17.5 degr	> 15 degr
6. Adverse terrain conditions				

The method for assessment of marginal lands using critical threshold levels for single biophysical factors is considered robust and transparent. The most limiting factor determines the marginality rating (Libieg’ s law of the minimum). The difficulty with creating discrete classess is that there may be lands with one or more factors very close to the threshold for ‘severely limiting’, which consequently are not considered as ‘marginal’. To address this, all land units with biophysical factors within a margin of 20% of the indicated threshold (severity) value were assessed. Land units with sub-severe constraints to crop production can thus be mapped. Crop production is however often not a linear function of the interaction or combination of the single biophysical factors (soil, climate, crop properties). Single factors may be more limiting to crop growth (below individual thresholds for severe limitation) in combination (negative synergy). Or, one factor may compensate the severe limitation of the other when occuring together (positive synergy). Furthermore there are factors for which no synergy is thought to occur (neither positive nor negative) and for some combinations of factors the synergy is not clear. Terres et al. (2014) have documented a scheme, designed by a group of experts, in which the synergy between combinations of two biophyscial factors (below the severity threshold level) is described in the following classes: 1) not occuring, 2) unclear, 3) sub-severe threshold not possible or not accepted (e.g. vertic properties or poorly drained), 4) no interaction between criteria or interaction already embedded in criteria definition, 5) positive synergy, whichmeans two combined severe constraints result in no severe limitation, 6) negative synergy,meaning that two combined sub-severe constraints result in severe limitation.

Pairwise combinations of sub-severe single factors

The concept of the pairwise combination of subsevere biophyscial factors is that they have a different impact on agricultural productivity than either of these two specified criteria acting independently at sub-severe threshold levels. The agronomic rationale for the pairwise combinations are presented in Terres et al. (2014). A summary of this discussion is provided here.

- **Low temperatures**

Low temperatures are limiting for crop growth and development beause the growing season is short and (low temperatures) during the growing season crops means that the crop may be longer on the field with increased risk of crop failure due to drought, plagues or other limiting conditions.

- **Low temperatures in combination with excess of soil moisture (negative synergy)**

Excess of soil moisture limits root development and excessively wet soils affects workability and trafficability of the soil negatively. The drying of soils at or above field capacity is slower under low temperatures than under higher temperatures. This means that effectively soils remain saturated longer when temperatures are lower.

- **Low temperatures in combination with heavy clay (negative synergy)**

Heavy clays have a narrow range of workability and trafficability greatly dependent of soil moisture conditions. They often have a low permeability once the soil is moist or wet. The negative interaction stems from the shortening of the effective growing season on these soils. Heavy clay top soils require more heat units than other soils for warming up and for drying in order to reach suitable tillage and growing conditions. The shortening of the growing season aggrevates the limitation of the already short growing period under low temperatures.

- **Low temperatures in combination with organic soils (negative synergy).**

Organic soils are naturally wet soils that have a low bulk density, a low physical stability and a low soil strenght. This results in a poor workability (Pietola et al., 2005). This limits the bearing capacity of the soil. The negative synergy is rooted in the short growing season of the low temperature area in combination with poor soil conditions (wet, poorly accessible) which reduces options for agriculture and delays the start of the growing season.

- **Dryness**

Drought is the inadequate water supply to the crop during the growing season. The availability of water during the growing season depends on a range of factors, among which rainfal maount and distribution, soil factors, among which soil pore volume and geometry, soil texture and soil rootable volume.

- **Dryness in combination with stoniness (negative synergy)**

Stones in the rooted zone of the soil limits rootable soil volume and the capacity of soil to storge and buffer water and nutrients. In arid areas stones in the soil are considered favourable because they limit the upward movement of soil water by capillary rise so that loss of soil water by soil evaporation is reduced (Kosmas et al, 1994). The latter is however considered of less importance than the overall effect of the reduced soil volume on soil available water.

- **Dryness in combination with sand or loamy sand texture (negative synergy)**

Sandy soils are a poor buffer for water. The water retention capacity is generally lower due to the large pore size and lower pore volume as compared to silty or clayey soils. This means that for an establishing and developing crop less soil moisture is available. In combination with an area that has dryness as a limitation this is a negative synergy.

- **Dryness in combination with heavy clay (negative synergy)**

Soils with high clay content, especially those with high swelling and shrinking capacity (smectites), are physically difficult to manage. The topsoil structure is often unstable, deep cracks form in dry conditions and strong swelling in wet conditions. In early rains water may be lost through large macro-pores (cracks) to the deeper subsoil. Once saturated the heavy clay soil becomes low permeable and accessibility and workability are limited (Dudal, 1965). Heavy clay soils have a narrow time window for soil tillage and in dryness prone areas, in which the potential cropping season is already short, this is an added limitation (negative synergy). Still, under adapted management (inlcuding crop selection), heavy clay soils of (semi-)arid regions are often (very) productive.

- **Dryness in combination with rooting depth (negative synergy)**

Shallow soils have a low buffering capacity for nutrients and water because of the limited rooting volume. The soil moisture store is depleted quicker than in deeper soils and crops experience water stress (that curbs growth) sooner. This means that even rainfall distribution and amount is more critical in soils with limiting rooting depth. The overall effect of the reduced soil volume on soil available water in combination with dryness is a negative synergy.

- **Dryness in combination with salinity (negative synergy)**

Semi-arid conditions in combination with salinity are found sporadically in river deltas in the south of Europe and on coastal plains in the Mediterranean and in occasionally on plains of the Danube basin.

Salt accumulation affects plants in two ways (Driessen, 2001): 1) indirectly, by skewing the composition of the soil solution which upsets the availability of plant nutrients, and 2) directly, by inducing physiological drought as a consequence of the high osmotic pressure of the soil moisture. In sodium saturated soils (sodic) the high levels of sodium affect plant performance, either directly (toxicity) or indirectly (deterioritation of soil structure). This provides a negative synergy in drought conditions.

- **Dryness in combination with slope (negative synergy)**

The criterion for evaluation of dryness is based on the ration of precipitation over evapotranspiration and does not take into account the run-on or run-off from or to surrounding landscape positions. Sloping lands do not accumulate water on the soil because of runoff ad lateral seepage/flow of water in the soil. Level lands in drought prone areas therefore have a benefit in accumulating water adding to the water balance. In addition to the limitations for mechanisation of sloping lands, this is considered a negative synergy between dryness and steep slopes.

- **Excess soil moisture**

Excessive soil moisture may result from high annual precipitation amount, low and level landscape position (run-on and high grond water table) and poor internal drainage, causing water to stagnate in the soil and to accumulate on the soil surface. Excess of soil moisture is limting to root development due to lack of oxygen. Furthermore, workability and trafficability are poor in excessively wet soils.

- **Excess soil moisture in combination with organic soils (negative synergy)**

Organic soils are by definition wet, unless drained. The bearing capacity and soil strenght are low. The physical stability for crops is low (especially the case for perennials). Excessively wet soils have a poort accesibility and a limited soil strength. Organic soil have a limited bearing capacity and the soil strenght is also low. The combination of excessive soil moisture and organic soils exacerbates the previously mentioned limitations and provide conditions that are unfarvourable for mechanized farming.

- **Excess soil moisture in combination with rooting depth (negative synergy)**

Shallow soils have a low buffering capacity for nutrients and water because of the limited rooting volume. The soil moisture store is saturated quicker than in deeper soils and will remain saturated longer. Soil saturation affects soil strength, trafficability and availability of oxygen to roots. The overall effect of the reduced soil volume combination with excess soil moisture is therefore considered a negative synergy.

- **Excess soil moisture in combination with slope (positive synergy)**

Water in access of what the soil can store is not accumulated on site but runs off to lower parts of terrain or moves under the force of gravity downward in the landscape through lateral seepage or flow of water in the soil. This means that the extent and duration of excessive soil moisture are reduced. The combination of excess soil moisture and slope is therefore considered to be a positive synergy.

- **Rooting conditions; sand, loamy sand**

Sandy soils are a poor buffer for water. The water retention capacity is generally lower due to the large pore size and lower pore volume as compared to silty or clayey soils. This means that for an establishing and developing crop less soil moisture is available.

- **Sand, loamy sand in combination with organic soil (positive synergy)**

In soils that have combinations of peat with sand, both the limitations of sand and those of peat are less pronounced. Sand added to peat adds to the stability of peat and peat improves the hydraulic properties of sandy soils and, depending on the composition of the peat, may add to the nutrient reserve and buffering capacity. The combination of sandy soils with organic soil is therefore considered to be positive synergy.

- **Sand, loamy sand in combination with rooting depth**

Sandy (and loamy sand) soils are more drought prone and they are a poorer buffer and reserve for nutrients. Soil volume limiting conditions, such as limited rooting depth, adds to this limitation. The combination of sandy soils with limited rooting depth is therefore considered to be negative synergy.

- **Rooting conditions; heavy clay**

Soils with high clay content, especially those with high swelling and shrinking capacity (smectites), are physically difficult to manage. The topsoil structure is often unstable, deep cracks form in dry conditions and strong swelling in wet conditions. In early rains water may be lost through large macro-pores (cracks) to the deeper subsoil. Once saturated the heavy clay soil becomes low permeable and accessibility and workability are limited (Dudal, 1965). Heavy clay soils have a narrow time window for soil tillage and in dryness prone areas.

- **Heavy clay in combination with limited rooting depth**

Heavy clay soils are more saturated in the wet part of season and dry out to a level where soil moisture is no longer available to plants. Furthermore the strong shrinking and swelling of heavy clay soils is a limitation both for crops (roots) and for farming operations. These limitations are aggrevated by limited rooting depth, as a shallow has less buffering capacity for water and nutrients and is also more difficult to cultivate under mechanised operations. It is concluded therefore that the combination of these two limitations are aggravation of the respective limitations and form a negative synergy.

- **Heavy clay in combination with salinity/sodicity**

The presence of salt favours development of strong structures in clay soils under dry conditions, but during the moist winters clay soils become wet, muddy, and impermeable (Driessen et al., 2001).

In heavy clays, soil moisture is clay soils the water is hard to extract by plant roots due to the high matrix suction. Salinity adds to his by increasing the osmotic pressure of the soil moisture and thus inducing physiological drought. Soil sodicity aggrevates the waterlogging and poor aeration in heavy clay soils. Therefore sodic soil combined with high clay content in the topsoil can result in a constraint to agriculture. The limitations of heavy clay soils and salinity/sodicity are aggrevated in the situation where both factors occur and therefore the synergy is considered negative.

- **Heavy clay in combination with very acid or alkaline soils (pH), (negative synergy)**

The availability of nutrients is both limited in alkaline and in acid soils. Soils with pH (0-30 cm) below 4.5 or above 8 are considered (severly) limited. Very acid soils are low in extent in Europe. Acid clay soils have a low nutrient availability (low base saturation) and may problems with aluminium toxicity, such as is the case in Alisols that occur a.o, in humid, temperate climates (WRB, 2015).

Strongly alkaline clays often have a poor soil aggregate stability and a very low permeability under wet conditions.

- **Stoniness in combination with sand, loamy sand (negative synergy)**

Sandy soils already have a poor buffering capacity for water and nutrients and stones in the rooted additionaly limit the rootable soil volume and the capacity of soil to storage and buffer water and nutrients. Stoniness exacerbates the limitations of sandy soils and therefore the synergy is considered negative.

- **Stoniness in combination with organic soil (positive synergy)**

The limitations of organic soils is poor trafficability, limited soil strenght and low bearing capacity. The presence of gravel and stones, alone or mixed in the finer textured mineral compounds, is thought to increase the soil strength and thus trafficability of organic soils. Yet stones in the topsoil area limitation for mechanised practices. The synergy is rated as positive by Terres et al. (2014), although they indicate that that is for grass land and grazing land, due to the effect on trafficability mainly. For arable farming the synergy is neutral at best, if not negative.

- **Stoniness in combination with limiting rooting depth (negative synergy)**

The rootable volume in limiting in shallow soils and thus the capacity to store for water and nutrients is limited. Stones further limit the rootable volume and therewith the availabity of nutrients and water to the crop during the growing season. Furthermore the growth of roots and tubers may be hampered by stones in the soil. The synergy between stoniness and shallow rootingdepth is considered negative.

- **Stoniness in combination with steep slopes (negative synergy)**

Water availability is reduced in stony soils. On sloping land water does not accumulate on the soil but runs off to lower parts of terrain or moves under the force of gravity downward in the landscape through lateral seepage or flow of water in the soil. Sloping land thus negatively impacts on the water balance of stony soils (negative synergy).

- **Limited rooting depth in combination with in combination with salinity/sodicity**

The limitations of lower availability of nutrients and water in shallow soils is aggrevated by salinity due to increased osmotic pressure of the soil moisture. The skewed composition of the soil solution upsets the availability of plant nutrients. High levels of sodium (sodic) affect plant performance in sodic soils (toxicity) and causes soil structure deterioration, affecting soil stability and soil permeability and infiltration capacity (development of a soil crust). The synergy of this combination is considered negative because the limitations from shallow rooting depth are exacerbated by salinity and sodicity and in addition other soil conditions are negatively affected (i.e, soil nutrient status and physical stability).

- **Limited rooting depth and slope (negative synergy)**

Drainage and run off will increase on sloping land and therewith further reduce the water availability in soils of limited rooting depth. Land slip of shallow soils on slopes is a significant risk and therefore there is an enhanced risk of soil loss. Mechanisation is hampered both in shallow soils and on sloping land. The synergy of this combination is negative.

Integration of maps into one final map of marginal lands

As explained in the former the biophysical limitations were clustered in 6 groups of limitations. For mapping the marginal lands according to biophysical constraints, the 6 cluster maps are integrated into one map showing the lands falling within the marginal threshold limits for one or more of the 6 biophysical limitation clusters.

3.3 Land management and biophysical constraints

Land management can have an important influence on the current agronomic suitability of land. Basically, we can distinguish 3 forms of land management that needs to be addressed in the mapping and classification of marginal lands in MAGIC (see also Table 4):

Firstly, land improvement measures can help to neutralise the natural constraints and enable converting marginal lands into productive lands (e.g. cropland and improved grasslands). This category refers to lands where agriculture was clearly constrained by biophysical factors, but through technical measures the most important limitations were removed (e.g. through irrigation, fertilisation, drainage, terraces) converting these lands in (often intensive) high productive croplands or grasslands. In the approach to mapping in MAGIC these category of lands can no longer be regarded as marginal as the biophysical constraints by which these lands are identified no longer apply. The aim is therefore to map these so-called ‘improved’ marginal lands and exclude them according to the approach and data inputs presented in Table 4.

Secondly, there are lands with biophysical limitations where agricultural does take place. However, the use is tuned with the limitations. This often applies to grazing activities or extensive and traditional forms of cropping activities such as with low productive cereals, permanent crops (e.g traditional orchards, olives, vineyards) or in agro-forestry systems (e.g. Dehesas, Montados).

Thirdly, land management can also be stopped, particularly if biophysical and socioeconomic constraints limit the economic returns. It is relevant to classify the marginal lands further according to this use, or rather unused status, because developing industrial crops on abandoned lands will provide for new income activities and for these lands indirect land use changes and competition with food production will be avoided. Furthermore, in rural areas with remote location where abandonment of land is taking place, there is need to find alternative income opportunities to boost rural development.

Another category of land very much determined by unsustainable land management is that of degraded marginal lands. On these lands, which in general are characterised by biophysical constraints making the land more sensitive to degradation in case of intensive agricultural use, the productive capacity is partly or fully disappeared. This goes together with a loss of ecosystem functions. Although this land degradation is caused by land management it will not be mapped in this step, but will indirectly addressed in the step where marginal lands will further be classified according to ecosystem services and threats (see Chapter 5). The classification of threats to soil functions are seen as particularly relevant in this context as industrial crops can be selected and developed to particularly turn around these degradation processes and by doing so create win win solutions in which feedstock production is combined with for example erosion control or fire risk decline. For further details on which threats are relevant and how these are to be mapped as classifying factor read Chapter 5 and 6 in this report.

In the following it is discussed how to map improved marginal lands and current (lack of) land use situation on marginal lands with biophysical constraints (see Table 4):

1) When focusing on how to map marginal land improvements that have led to the conversion of marginal lands can help converting unused lands into productive lands. The most important improvement measures that are applied to convert marginal lands into productive lands are through: fertilization, irrigation, drainage and terraces (see Table 4). Every improvement measure is a response to a specific natural constraint. For the mapping of marginal lands, areas need to be identified where the natural constraints no longer limit agronomic use. These areas no longer limited need to be excluded for the marginal land class. In table 4 an overview is made of how the main improvement measures and how the effect in terms of neutralizing the natural constraint situation can be spatially detected with existing data sources.

2) Another category is the lack of land management leading to abandonment of land. Given the preference to grow industrial crops on lands where low risk is for competition with food production, it is important to classify marginal lands according to abandonment status. However, reliable high resolution data about abandonment status are difficult to find, although several mapping approaches and data sets have become available in recent years of which the Estel et al. approach seems to provide the best estimates which have also been well validated. It is proposed to map abandonment status of the biophysically constrained marginal lands further by overlaying with: Active managed cropland & grassland and abandoned lands (Estel et al. (2015) based on NDVI index from MODIS data 2000-2012). Estel produced maps on abandonment and re-cultivation of cropland areas and also managed grasslands (fertilized and/or grazed) and abandoned grasslands by checking changes in vegetation estimated from satellite information (Modis data) collected for 12 years (2001-2012). The vegetation index calculated from the satellite information is the Normalized Differenced Vegetation Index (NDVI). For further information see Box 1.

Table 4: Natural constraints and land management to convert marginal lands into productive lands and suggestions to best map the land management situation.

<table>
<tr><th>Natural constraint</th><th>Land management improvement measure</th><th>Data sets used to detect & validate (directly/indirectly) the land management improvement measures</th><th>Mapping rules applied</th><th>Validation</th></tr>
<tr><td>Adverse climate - dryness</td><td>Irrigation</td><td>1) Irrigated areas by crop. European Irrigation map aggregated to a grid of 100 m x 100m. (JRC, Wriedt, et al. 2009).
2) CLC irrigated areas (2012)</td><td>1) Select lands mapped as marginal because of limiting factor dryness
2) Overlay lands limited by dryness with irrigated lands in JRC irrigation map
3) Classify lands coinciding as ‘ímproved marginal lands’</td><td>1) Google maps, different point validations over southern Europe
2) Check against economically marginal croplands in Spain (Ciria et al.)
3) Validation later in MAGIC project</td></tr>
<tr><td>Excessive wetness - Limited soil drainage</td><td>Drainage</td><td rowspan="2">1) Active/managed cropland & grassland (Estel et al. (2015) based on NDVI index from MODIS)
2) CLC land cover map 2012
3) Combine CLC agricultural classes with Estel et al. classes identified as active management (≥ 8 times in 12 NDVI disturbances) and generate separate CLC management combinations: active cropland/active crops & grasslands/ active grassland/low productive cropland/low productive grasslands classes.
4) Land use intensity maps gridded in PEGASUS based on Perez-Soba et al., (2015), high, medium and low intensity farmland</td><td>1) Select lands mapped as marginal because of limited soil drainage
2) Overlay land limited by soil drainage with active cropland and grassland & mixed classes from 3) and high intensity farmland from 4). The classes that coincide are classified as ‘improved marginal lands’.</td><td>1) Google maps, different point validations over Europe
2) Check against economically marginal croplands in Spain (Ciria et al.)
3) Validation later in MAGIC project</td></tr>
<tr><td>Limiting soil fertility (Low SOM) and/or limitations in rooting</td><td>Soil fertility management & mulching</td><td>1) Select lands mapped as marginal because of soil fertility and or limitations of rooting
2) Overlay land limited by low soil fertility and limitations in rooting with active cropland and grassland & mixed classes from 3) and with Land use intensity class ‘high intensity’ from 4). The classes that coincide are classified as ‘improved marginal lands’.</td><td>1) Google maps, different point validations over Europe
2) Check against economically marginal croplands in Spain (Ciria et al.)
3) Validation later in MAGIC project</td></tr>
<tr><td>Adverse terrain (slope)</td><td>Terraces & other slope management measures (mulching?)</td><td>1) Identify areas with slopes > 15˚ - to 25˚
2) CLC land cover map 2012
3) Combine CLC agricultural classes with Estel et al. classes identified as active management (≥ 8 times in 12 NDVI disturbances) and generate separate CLC management combinations: active cropland/active crops & grasslands/ active grassland/low productive cropland/low productive grasslands classes.</td><td>1) Select lands mapped as marginal because of slope > 20 ˚
2) Overlay land limited by slope with active cropland from 3) and with Land use intensity class ‘high intensity’ from 4). The classes that coincide are classified as ‘improved marginal lands’.</td><td>1) Google maps, different point validations over Europe
2) Check against economically marginal croplands in Spain (Ciria et al.)
3) Validation later in MAGIC project</td></tr>
</table>

Natural constraint	Land management improvement measure	Data sets used to detect & validate (directly/indirectly) the land management improvement measures	Mapping rules applied	Validation
All constraints	Establishment of green houses or other (intensive) agricultural buildings (e.g. mega-stables)	Overlay all areas with natural constraints with: • The Global Human Settlement Layer (2014) (Pasaresi et al., 2016) (30 m resolution)	1) Select agricultural lands mapped as marginal 2) Overlay marginal lands with human settlement layer and identify marginal lands that are now covered with buildings (50% coverage by buildings per 100 m grid) within agricultural mask. The classes that coincide are classified as urban or 'improved marginal lands'.	1) Google maps, different point validations over Europe, particularly in Spain and Netherland where many green- houses are. 2) Validation later in MAGIC project

Box 1: Explanation as to how Estel et al. (2015) determined 'active management'and 'fallow' to classify agricultural lands in a time series of 12 years into 1) actively managed farmland, 2) abandoned farmland and 3) recultivated farmland:

Estel et al. (2015) defines:

1) 'fallow' farmland as 'land without management: i.e., not sown, cropped, or plowed in the case of cropland, or not mown or intensively grazed in the case of grassland. Phenological profiles of fallow land (unmanaged cropland and grassland) spectrally correspond with natural grassland. Phenological profiles of such unmanaged farmlands are characterized by a smooth, bell-shaped temporal NDVI profile.
2) 'managed' farmland as land where management takes place such as grazing or mowing on grassland or plowing on cropland. It leads to abrupt changes in the temporal phenological profiles. Active farmland is therefore characterized by more irregular temporal NDVI profiles with one or more narrow peaks, with the highest peak often shifted substantially compared to the peak of natural vegetation and fallow land (Figure 1). Intensively grazed or mowed grasslands differ from the smooth, bell-shaped fallow profiles by their plateau-shaped form, often with multiple peaks (Figure 1). Active cropland and managed grassland also result in profiles with substantially smaller growing season NDVI integrals (i.e., area under the curve), deviating strongly from the smooth, bell-shaped profile of fallow fields (Figure 1).

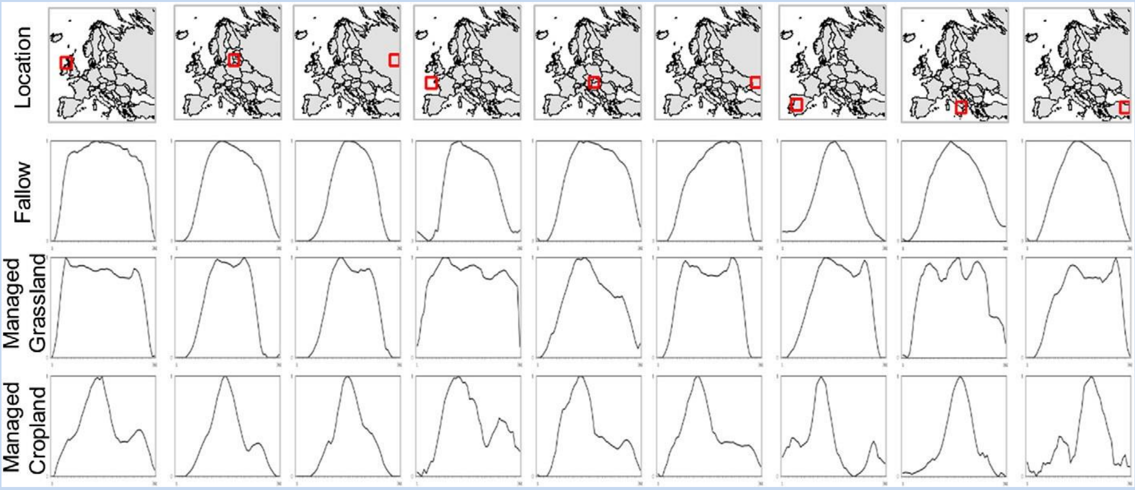


Figure 3 Examples of NDVI indices for fallow, managed grassland and managed cropland (Estel, 2015, p. 315)

(*Copied from Estel et al., 2015, p 215-216*)

The further classification of M-AEZ according to abandonment will be particularly addressed in year 2 of the project and incorporated in the end of year 2 version of the M-AEZ. The Estel et al.,(2015) data will be an important source, besides other data sources which will be further identiefd in year 2 (see also Chapter 6).

4. Results: marginal lands according to biophysical limitations

4.1 Introduction

In this chapter the results are presented of the marginal lands mapped according to the 6 clusters of biophysical constraints and the correction for improved marginal lands according to management. As discussed in the former the final marginal lands map in MAGIC excludes lands where agriculture was clearly constrained by biophysical factors, but through technical measures the most important limitations were removed (e.g. through irrigation, fertilization, drainage, terraces) converting these lands in (intensive) high productive croplands or grasslands. In the approach to mapping in MAGIC these category of lands can no longer be regarded as marginal as the biophysical constraints by which these lands are identified no longer apply. There are also marginal lands where agricultural does take place, but the use is tuned with the biophysical limitations. These categories of lands are included in the marginal lands as mapped here.

4.2 Results for marginal lands mapped according to biophysical limitations

In this Section the result maps and statistics are presented of the marginal land mapped according to biophysical limitations. Every time the results presented refer to all biophysically constrained lands but corrected for the part of the lands that have experienced serious land improvements and are now highly productive.

In Maps 1AB the total marginal land area is presented showing the lands falling within the marginal threshold limits for one or more of the 6 biophysical limitation clusters. In Tables In Annex IV fact sheets are presented for all 6 biophysical limitation clusters showing maps and statistics.

<u>Marginal land areas in Europe</u>

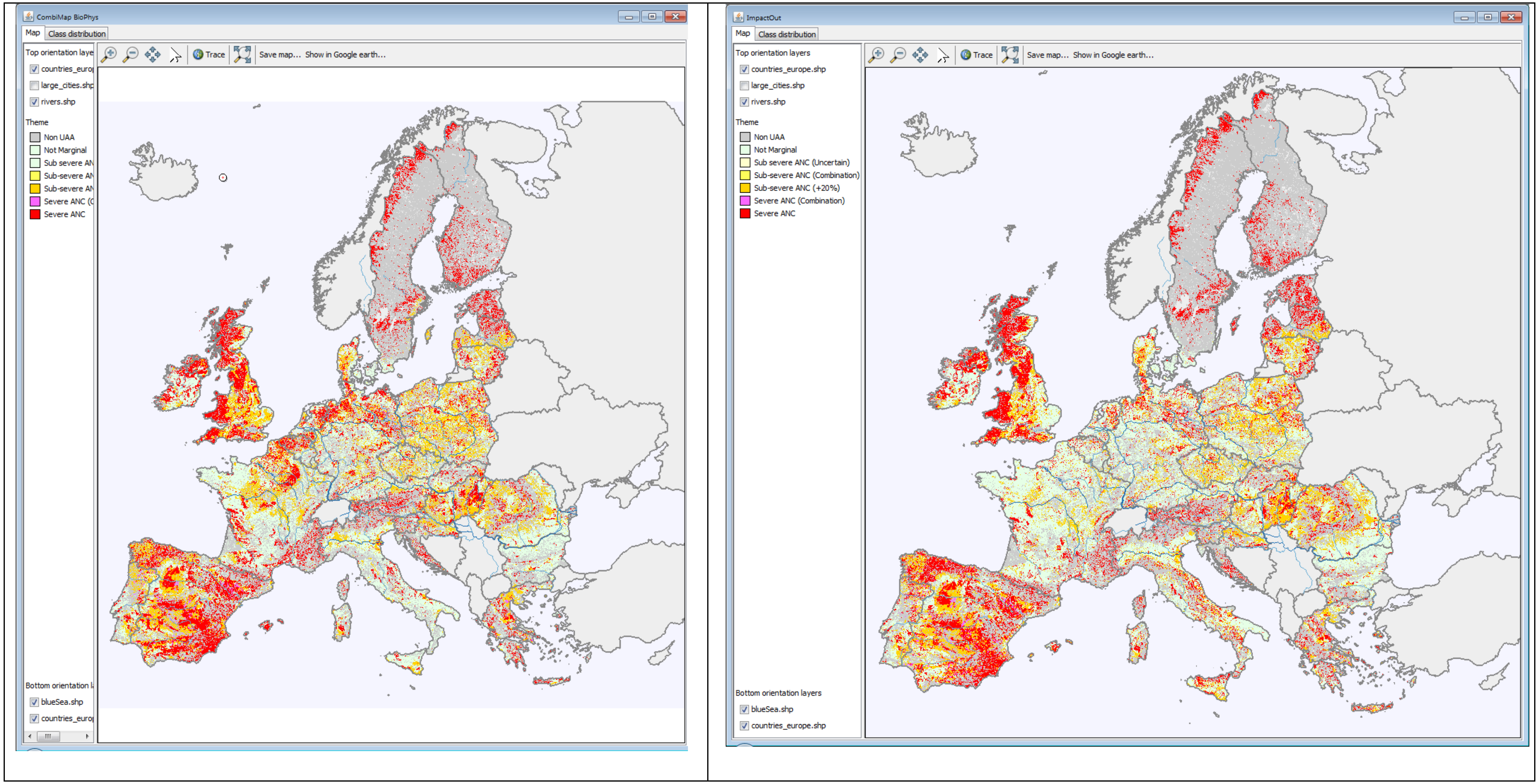
Map 1 presents the marginal land areas in Europe based on levels of severely limiting (clustered) biophysical factors under natural conditions and with exclusion of marginal land that has been improved by management. The total area coverage for all biophysical limitation clusters is also presented in Table 4 (km2) and in Table 5 (in percentage of agricultural land area mask).

In total 27% of the agricultural area is marginal. This share is expressed as percentage of the land that can be regarded 'agricultural' as it has been in continuous or discontinuous agricultural use according to Corine Land Cover (CLC)) between 1990 and 2012. Countries with high proportions (>50%) of their agricultural land classified as marginal land (with exclusion of land improved by management) are all in the Nordic countries and include Estonia (100%), Finland (100%), Sweden (81%), Latvia (56%) and United Kingdom (53%). In these countries the most influential limitation is adverse climate, particularly short growing season.

The most common limitation over the whole of Europe is rooting limitations, with 12% of the agricultural area after correction for improvement. This is followed by adverse climate and excessive soil moisture occurring in respectively 11% and 8% of the agricultural land respectively. It should be mentioned that the largest part of the marginal lands are defined by one of the 6 clustered limitations while in a much smaller part the marginal land combinations of the clustered limitations occur. In the following the marginal lands are further discussed per limitation cluster group.

<u>Adverse climate (see Annex 1, Map 1):</u>
Of the overall marginal land classification, 11% of the agricultural area is severely limited by adverse climate. Areas with severely low temperatures and short growing seasons are concentrated in northern Europe (Sweden, Finland, Estonia). Furthermore the mountainous areas of the Alps, Pyrenees and the Carpathians are severely limited by cold temperatures. This constraint accounts for ≥75% of land classified as agricultural in Estonia, Finland and Sweden (Table 6). Dryness is severely limiting in Spain mainly, and (smaller) parts of Italy and Greece. The largest difference between natural conditions and improved is seen in Spain (5% decrease of the area to 24% through irrigation in areas with dryness).

Management: Irrigation can help to overcome the dryness limitation in the adverse climate cluster, but for severely low temperatures and short growing seasons less measures can be taken to overcome these. Therefore only irrigation has been a measure applied in southern Europe that has lowered the extent of especially arable land that is classified marginal. The decline in severe constrained units for dryness is clearly seen in Spain and Greece after correction for irrigation.



Map 1 Marginal lands based on biophysical constraints in EU-28 (marginal lands are in the 2 severe classes= Severe ANC and Severe ANC (combination)(red and purple)). Left map shows marginal lands without correction for improved lands/Right map show final map of marginal lands after correction for improved lands

Table 5 Land area (km2) coverage* by 6 clusters of biophysical constraints making up marginal lands (mapped as severe and severe by pair-wise combination)

Country	1. Adverse climate	2. Excessive soil moisture	3. Adverse chemical comp.	4. Low soil fertility	5. Adverse rooting cond.	6. Adverse terrain	Total marginal**
Austria	9892	6038	0	457	8415	10916	15271
Belgium	1482	0	873	1933	818	88	2656
Bulgaria	0	4	0	46	1996	2929	5643
Croatia	105	3968	0	36	6053	1358	10061
Czech Republic	617	1356	63	1865	103	752	4585
Denmark	151	2116	0	11	2302	13	4585
Estonia	14510	5102	0	82	267	70	14510
Finland	32195	2295	0	1457	3084	171	32195
France	7789	5448	5156	796	27475	14386	43385
Germany	1146	19666	3	1166	11546	3395	33896
Greece	2854	4	1109	482	15400	11340	23108
Hungary	0	3731	6596	2165	1359	3032	15022
Irish Republic	236	16646	0	247	4662	982	17928
Italy	8819	3966	1693	1999	13614	29025	38722
Latvia	14799	3686	0	42	1537	256	16736
Lithuania	364	1326	0	112	10717	109	12308
Luxembourg	0	0	0	9	58	8	71
Netherlands	0	1699	0	421	2719	277	4874
Poland	519	11778	0	1816	13289	1423	27372
Portugal	371	76	1666	1	11191	4356	13726
Romania	3433	4823	5565	565	11274	8592	23130
Slovakia	606	216	610	269	4432	1928	6532

Country	1. Adverse climate	2. Excessive soil moisture	3. Adverse chemical comp.	4. Low soil fertility	5. Adverse rooting cond.	6. Adverse terrain	Total marginal**
Slovenia	227	996	26	5	1431	695	2007
Spain	80862	5430	3565	33645	100527	33375	167680
Sweden	51043	11864	0	3658	7164	4400	51758
United Kingdom	31690	78493	0	3831	32314	14919	106508
Total	**263751**	**190730**	**26925**	**57116**	**293763**	**148845**	**694320**

** Area refers to total marginal land area in Europe that can be regarded 'agricultural' as it has been in continuous or discontinuous agricultural use (according to Corine Land Cover (CLC)) between 1990 and 2012.*

***Total marginal land is not equal to the total of all cells per country because the 6 marginal limitations can occur simultaneously in the same location (e.g. steep slope and rooting limitations etc.)*

Table 6 Land area share (%/agricultural area)* of total and for 6 clusters of biophysical constraints making up marginal lands (mapped as severe and severe by pair-wise combination)

	1. Adverse climate	2. Excessive soil moisture	3. Adverse chemical comp.	4. Low soil fertility	5. Adverse rooting cond.	6. Adverse terrain	Marginal	Not marginal
Austria	27%	16%	0%	1%	23%	30%	**41%**	59%
Belgium	8%	0%	5%	10%	4%	0%	**14%**	86%
Bulgaria	0%	0%	0%	0%	3%	5%	**9%**	91%
Croatia	0%	15%	0%	0%	23%	5%	**39%**	61%
Czech Republic	1%	3%	0%	4%	0%	2%	**9%**	91%
Denmark	0%	6%	0%	0%	7%	0%	**13%**	87%
Estonia	100%	35%	0%	1%	2%	0%	**100%**	0%
Finland	100%	7%	0%	5%	10%	1%	**100%**	0%
France	2%	1%	1%	0%	8%	4%	**12%**	88%
Germany	0%	8%	0%	0%	5%	1%	**14%**	86%
Greece	5%	0%	2%	1%	25%	18%	**37%**	63%
Hungary	0%	5%	10%	3%	2%	4%	**22%**	78%
Irish Republic	0%	32%	0%	0%	9%	2%	**34%**	66%
Italy	5%	2%	1%	1%	7%	16%	**21%**	79%
Latvia	50%	12%	0%	0%	5%	1%	**56%**	44%
Lithuania	1%	3%	0%	0%	26%	0%	**29%**	71%
Luxembourg	0%	0%	0%	1%	4%	1%	**5%**	95%
Netherlands	0%	6%	0%	2%	10%	1%	**18%**	82%
Poland	0%	6%	0%	1%	6%	1%	**13%**	87%
Portugal	1%	0%	3%	0%	21%	8%	**26%**	74%
Romania	2%	3%	4%	0%	7%	6%	**15%**	85%
Slovakia	2%	1%	2%	1%	17%	7%	**25%**	75%
Slovenia	3%	15%	0%	0%	21%	10%	**30%**	70%
Spain	24%	2%	1%	10%	30%	10%	**49%**	51%

	1. Adverse climate	2. Excessive soil moisture	3. Adverse chemical comp.	4. Low soil fertility	5. Adverse rooting cond.	6. Adverse terrain	Marginal	Not marginal
Sweden	84%	19%	0%	6%	12%	7%	**85%**	15%
United Kingdom	16%	39%	0%	2%	16%	7%	**53%**	47%
GrandTotal	11%	8%	1%	2%	12%	6%	**29%**	71%

** area share of the total marginal area in Europe that can be regarded 'agricultural' as it has been in continuous or discontinuous agricultural use (according to Corine Land Cover (CLC)) between 1990 and 2012.*

Table 7 Land area (km^2) coverage* clustered by 6 clusters of biophysical constraints making up marginal lands (mapped as severe and severe by pair-wise combination) clustered according to Environmental zone

ENZ	1. Adverse climate	2. Excessive soil moisture	3. Adverse chemical comp.	4. Low soil fertility	5. Adverse rooting cond.	6. Adverse terrain	Marginal	Not marginal
ALPINE	31314	16290	33	1243	34929	36676	47562	30519
ATLANTIC	32199	104130	4037	7619	85019	34168	192302	538855
CONTINENTAL	6424	40809	13981	6735	35670	17551	108155	653119
MEDITERRANEAN	82506	4394	9198	36071	114823	55455	218962	422565
NORTH	111383	25182		5448	23396	5063	127414	51699
Grand Total	**263826**	**190805**	**27249**	**57116**	**293837**	**148913**	**694395**	**1696757**

** Area refers to total marginal land area in Europe that can be regarded 'agricultural' as it has been in continuous or discontinuous agricultural use (according to Corine Land Cover (CLC)) between 1990 and 2012.*

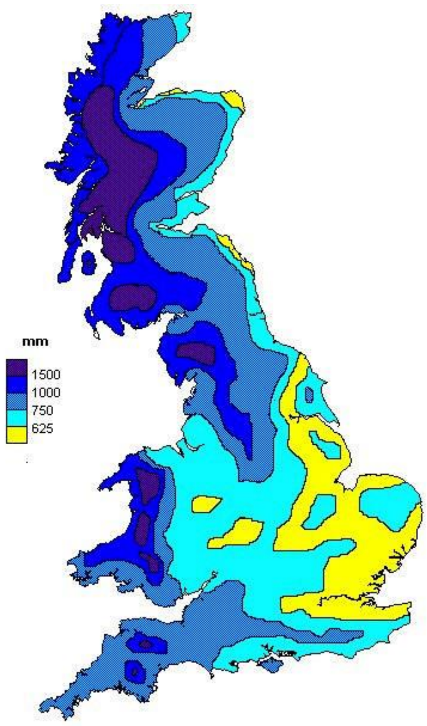
Table 8 Land area share (%/agricultural area)* of total and 6 clusters of biophysical constraints making up marginal lands (mapped as severe and severe by pair-wise combination) according to Environmental zone

	1. Adverse climate	2. Excessive soil moisture	3. Adverse chemical comp.	4. Low soil fertility	5. Adverse rooting cond.	6. Adverse terrain	Marginal	Not marginal
Alpine	40%	21%	0%	2%	45%	47%	**61%**	39%
Atlantic	4%	14%	1%	1%	12%	5%	**26%**	74%
Continental	1%	5%	2%	1%	5%	2%	**14%**	86%
Mediterranean	13%	1%	1%	6%	18%	9%	**34%**	66%
North	62%	14%	0%	3%	13%	3%	**71%**	29%
Grand Total	**11%**	**8%**	**1%**	**2%**	**12%**	**6%**	**29%**	**71%**

** area share of the total marginal area in Europe that can be regarded 'agricultural' as it has been in continuous or discontinuous agricultural use (according to Corine Land Cover (CLC)) between 1990 and 2012.*

Excessive wetness (see Annex 1, Map 2):

Of the total marginal land 8% of the agricultural area is severely limited by excessive moisture. Severely limiting excessive wetness is most expressed in the United Kingdom, Ireland, Estonia. The pattern of which in the United Kingdom and Ireland is related to topography (uplands and mountains) and zones of high annual precipitation (>1000 mm) (See Map 2).



Map 2 Annual precipitation over Great Britain (source: Atmosphere, Climate & Environment (ACE) Information Programme)

The countries where this limitation has been strongly corrected by reclamation and drainage measures are: the Netherlands (-10%), Slovenia (-7%), and Finland, Germany and the Irish Republic (-4%).

Excessive wetness is indicated by soils within the groups of Podzols (poor sandy soils, sometimes with impeding layers), Gleysols (soils with high groundwater table) and Histosols (wet, organic soils). Limitation of excessive wetness is also observed in the Scandinavian mountains, the back swamps of river- and coastal plains of Northern Europe and the Baltics, the mountains of the Pyrenees, the Alps and the Carpathians and the river plains in Hungary. In central Southwestern Spain, part of the river plains of the Guadalquivir, Guadiana and Tagus rivers.

Management: It is assumed that where land with intensive agricultural use (a.o. use of machanisation and fertilizer) overlaps land with excessive wetness, drainage has been applied. This is especially seen in the Netherlands, North Germany, Finland, Hungary, Spain and part of France.

Adverse chemical conditions (See Annex 1, Map 3):

The limitations under adverse chemical conditions are evaluated by excess of salts (salinity and sodicity), natural toxicity (e.g. Aluminium, Sulfur), and toxicity by pollutants. For the latter no accessible database was found for use in this study. Soils with high content in aluminium are more typical for the tropical zones. Although they occur in humid temperate areas and in part of the Meditereanean, based on the available data they do not show in any significant extent as a limitation. Adverse chemical composition (including salinity) conributes only a very small (1%) percentage to the agricultural land classified as marginal. There is no difference in natural and improved (management) conditions for this limitation.

Salinity and sodicy are a severe limitation in East Romania, the Great Hugarian Plain and parts of Spain (south of the Pyrenees, and in some coastal zones in the south) and in smaller areas in Portugal, France, Bulgaria and Greece.

As to management no management correction is mapped for reclamation of saline soils (see Table 4).

Low soil fertility (See Annex 1, Map 4):

Poor conditions for soil nutrient status is evaluated by two factors: acid and alkaline soils and soils with a very low content in organic carbon. Some areas with severe limitations for alkalinity in northern Spain and in cenral Hungary. Very acid soils were not mapped for Europe on the basis of the data available. The other severely limiting units are areas with very low organic carbon. In most cases this is associated with sandy soils (Podzols and Arenosols), especially in Belgium and northern France and in Spain.

Land areas with poor soil fertility conditions (alkaline or very acid soils and/or low organic carbon containing soils) cover only 2% of area contributing to classifying land as marginal. They are found in Belgium (10%), Spain (10%) and Sweden (6%). Mostly in Belgium the statistics show a difference between natural and improved land with this limiting conditions: 41% (natural) decreased to 10% of agricultural land by applying corrections for improvement measures.

Management: Some of the identified sandy, organic carbon poor areas in Belgium, northern France and the southern part of the Netherlands are under intense agricultural use. Large quantities of organic manure is applied on these sandy soils to dispose of this by-product of intense animal farming, thereby fertilizing the poor sandy soils for production of maize that is used for fodder. Therefore biomass production is ultimately high on these (naturally) marginal soils.

Limited rooting conditions (See Annex 1, Map 5):

Limiting rooting conditions are evaluated by five factors: 1) unfavourable texture, 2) content of coarse fragments, 3) presence of histic (organic) soil material, 4) presence of surface stones or rocks, and 5) shallow rooting depth. Shallow soils that cause severe limitations in rooting conditions are found in mountainous areas such as the Pyrenees, the Alps, the Carpathians in Romania, and otherwise also on the Iberian Peninsula (except for the sandy soils in the north-west), Italy, Greece and France. In the norther part of Europe (the Netherlands, Belgium, Germany, Denmark, Great Britain, Lithuania, Sweden and Finland) and the northwestern part of the Iberian Peninsula the factor causing severe limitation for rooting conditions is an unfavourable soil texture, mainly sandy soils. A 12% share of the total agricultural land in Europe has severe limitation of 'adverse rooting conditions' (and 16% in natural conditions without corrections for improvement measures). Countries with adverse rooting conditions that have share of 20% or more of the agricultural land in Europe are: Austria (23%), Croatia (23%), Greece (25%), Lithuania (26%), Slovenia (21%), Portugal (21%) and Spain (30%).

Where the sandy soils combine with intense agricultural use land management methods are assumed that overcome this limitation, such as a high level of organic manure applications (see previous comments under soil fertility). The largest areas within the marginal lands class where the limitation of adverse rooting conditions have been improved by management (e.g. by adding organic manure to sandy soils) are: Belgium (-7%), Greece (-8%), France (-9%), Spain (-10%), and the Netherlands (-11%). In the South of Spain some of these severely limited soils (coarse fragments and/or shallow) are planted with olive trees and are therefore under productive agriculture. In the area Southwest of Barcelona a mosaic pattern of agriculture exists where arable land alternates with tree plantings.

Adverse terrain conditions (see Annex 1, Map 6):

Steep slopes and high risk of flooding are limiting conditions for agriculture. Severe limitations on adverse terrain conditions is limited in extent. Land with severe limitations occur is moutainous areas (slopes), in the Alps and Pyrenees. Flooding risk is found in the plains of river landscapes, such as in the Great Hungarian Plain, and some localised areas in Nothern Europe. Conditions of 'adverse terrain', that includes steep slopes and high risk of flooding, contributes 6% of the land area with severe biophysical limitations. Austria (30%), Greece (18%), Italy (16%), Slovenia (10%) and Spain (10%) stand out in adverse terrain condition area share in the overall marginal land classification.

Management: Little effect is seen of management on number of pixels with severe limitations on adverse terrain conditions. This could be the case for instance when terracing is implemented.

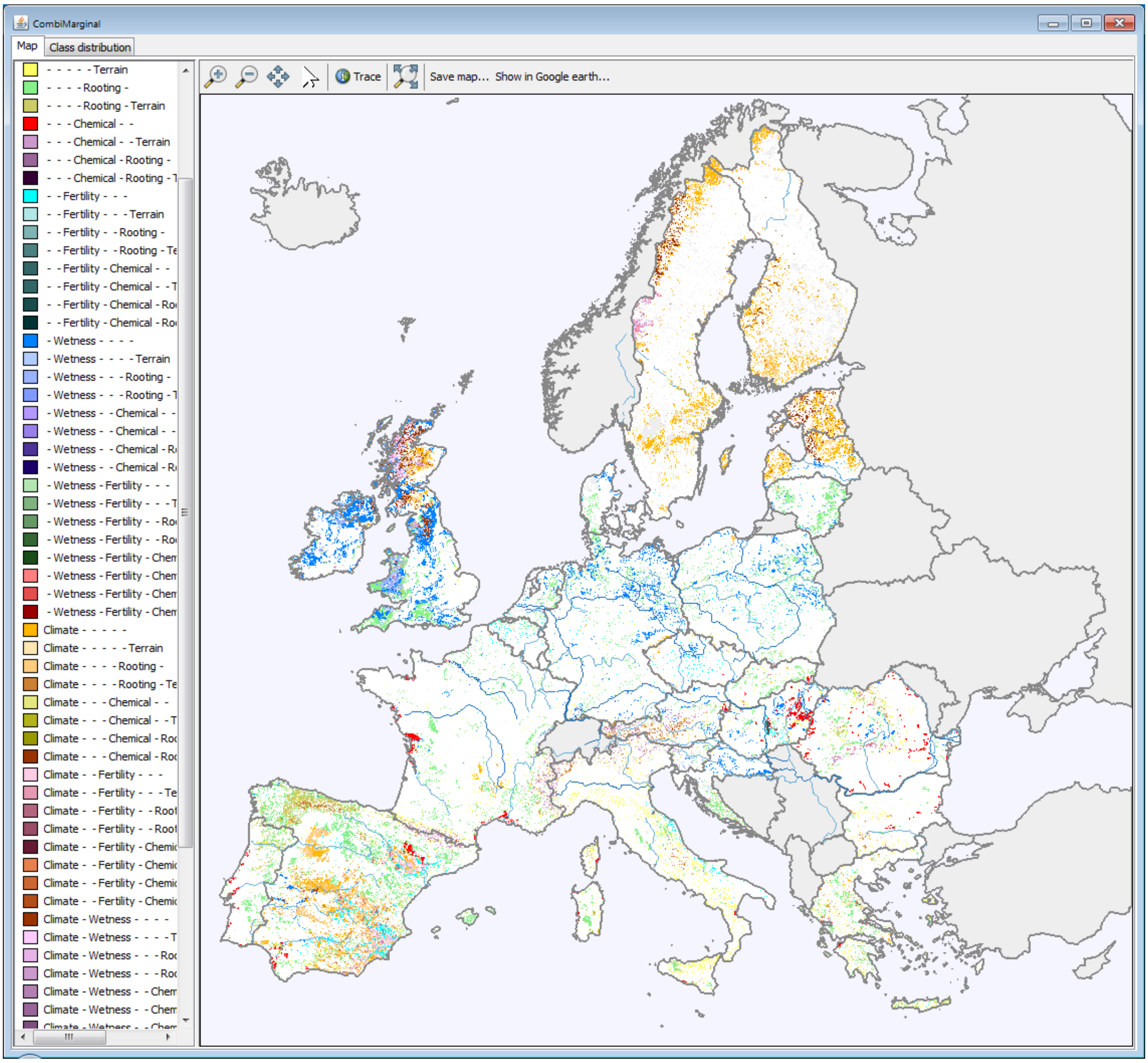
Limiting biophysical factors and marginal land over environmental zones

Severe limitations for adverse (cold) climate (with exclusion of improved land) is most expressed in the agri-environmental zones (AEZ) Alpine areas (40% of agricultural land) and the North (62%). Dryness is expressed most in the Mediterranean zone with 13% of agricultural land being severely limited and thus marginal (improved land excluded). In the North, the Atlantic and the Alpine AEZ, excessive soil moisture is most limiting within the marginal land (14%, 14% and 21% respectively, land improved by management excluded). Low soil fertility does not occur in more than 2% of the agricultural area. This is not surprising as this limitation is generally most easy to overcome through management measures. Adverse rooting conditions (improved land excluded) is most limiting in the Alpine (45%) and the Mediterranean (18%). Adverse terrain conditions contributes more to the marginal limitations in Alpine (47%) and in Mediterranean (9%).

Overall the largest marginal land share in agricultural land is found in the North and the Alpine zone. The AEZ with the lowest marginal land share is Continental (14 % of agricultural area).

Combinations of limiting factors

Maps 3 and 4 show the number of severely limiting (clustered) factors having contributed to the classification of specific marginal land areas. It shows that the much more land is classified as marginal because of the occurrence of one single factors than because of occurrence of multiple factors. This also becomes clear from Tables 9 and 10 where the largest area shares are generally seen for the single factors limitations in rooting (23% of marginal land) and excessive wetness (16% of marginal land). In total 55% of the marginal land is classified as such because of occurrence of one of the 6 clustered factors. Combined factors have generally a lower area share. There are however a couple of regions where this is not the case as becomes clear from the Maps 3 and 4. These areas where one or more (clustered) limiting factors come together are for example found more often in southern Europe especially in Spain where 2 or more factors are severely limiting (e,g, rooting conditions and dryness). Various mountainous areas have more than one severe limitations, such as excessive wetness and adverse rooting conditions, see for example Wales, Sweden, the Alps, Pyrenees and Carpathians.



Map 3 Combination of marginality factors (Marginal land corrected for improvement measures)

Table 9 Land area (km2) coverage by 6 clusters and combinations of biophysical constraints making up marginal lands (mapped as severe) (excluding improved marginal lands)

	1. Adverse climate	2. Excessive wetness	3. Adverse chemical composition of soil	4. Low soil fertility	5. Limitations in rooting	6. Adverse terrain	**Total**
1. Adverse climate	121138	73683	1441	28889	69558	5734	**260282**
2. Excessive wetness	73683	115747	422	7104	44015	3561	**210895**
3. Adverse chemical composition of soil	1441	422	22062	230	52	11	**1441**
4. Low soil fertility	28889	7104	230	24009	9056	288	**58614**
5. Limitations in rooting	69558	44015	52	9056	185310	4307	**69558**
6. Adverse terrain	5734	3561	11	288	4307	11733	**5734**
Total	**260282**	**210895**	**1441**	**58614**	**69558**	**5734**	**646627**

Table 10 Marginal land area share covered by the 6 clusters and combinations of biophysical constraints

	1. Adverse climate	2. Excessive wetness	3. Adverse chemical composition of soil	4. Low soil fertility	5. Limitations in rooting	6. Adverse terrain	**Total**
1. Adverse climate	2%	4%	0%	3%	5%	2%	16%
2. Excessive wetness	4%	16%	0%	0%	2%	0%	23%
3. Adverse chemical composition of soil	0%	0%	3%	0%	0%	0%	4%
4. Low soil fertility	3%	0%	0%	3%	0%	0%	7%
5. Limitations in rooting	5%	2%	0%	0%	23%	5%	36%
6. Adverse terrain	2%	0%	0%	0%	5%	8%	16%
Total	16%	23%	4%	7%	36%	16%	100%

Current land use in marginal lands

To understand what the main land use is in marginal lands (corrected for improvement) a classification was made according to Corine land cover (CLC) classes (see Table 10). The largest share of marginal lands occurs in non-irrigated arable lands, pastures, moors and heathlands and natural grasslands and the two mixed CLC classes 'Land principally occupied by agriculture, with significant areas of natural vegetation' and 'Complex cultivation patterns'. This is not a surprise as these are also the largest agricultural CLC classes, making up together 78% of the total agricultural land in CLC (2012).

The CLC classes most strongly dominated by marginal lands are moors and heathlands, natural grasslands, peat bogs and sclerophyllous vegetation. This is no surprise, given that biophysical limitations such as excessive wetness or low fertility and limitations in rooting are inherent characteristics of these type of land cover classes. Furthermore, one can argue whether all these classes should be regarded agricultural (and therefore included in the agricultural mask). Part of these CLC types will be (extensively) grazed, but not all.

Table 11 Distribution of marginal lands in EU-28 over Corine Land Cover (CLC) classes 2012

CLC class 2012	Non-marginal agricultural km2	Marginal agricultural km2	Total UAA km2	% marginal of marginal	% marginal of CLC class
Non-irrigated arable land	840578	180398	**1020976**	26%	18%
Pastures	250849	**103860**	**354709**	15%	29%
Moors and heathland	7386	**71847**	**79233**	10%	91%
Natural grasslands	29024	**70448**	**99472**	10%	71%
Land principally occupied by agriculture, with significant areas of natural vegetation	88591	**47118**	**135709**	7%	35%
Complex cultivation patterns	130863	**34045**	**164908**	5%	21%
Peat bogs	1042	**18978**	**20020**	3%	95%
Permanently irrigated land	22674	**11492**	**34166**	2%	34%
Olive groves	30725	**12943**	**43668**	2%	30%
Transitional woodland-shrub	18396	**14567**	**32963**	2%	44%
Vineyards	28121	**8859**	**36980**	1%	24%
Sclerophyllous vegetation	11239	**13009**	**24248**	2%	54%
Agro-forestry areas	23869	**6984**	**30853**	1%	23%
Fruit trees and berry plantations	20000	**7117**	**27117**	1%	26%
Crops associated with permanent crops	3929	**1042**	**4971**	0%	21%
Rice fields	4958	**959**	**5917**	0%	16%
Salines	56	**130**	**186**	0%	70%
Other (no longer agricultural CLC in 2012)	184457	90599	275056	13%	33%
Total		**694395**	**2391152**	**100%**	**29%**

4.2.1 First evaluation of marginal lands mapping

Google Earth (GE) and Google Street View (GSV) were used for verification of the marginal land map. The high resolution images of GE allow the study of various features that are relevant to the mapping of different layers that make up the final marginal land map (Marginal Agri-environmental Zonation (MAEZ)). These include features such as landform and slope conditions, land cover, crop systems, soil drainage (poorly versus well drained soils), presence of drainage ditches, parcel size, land uses and urbanization degree.

Method

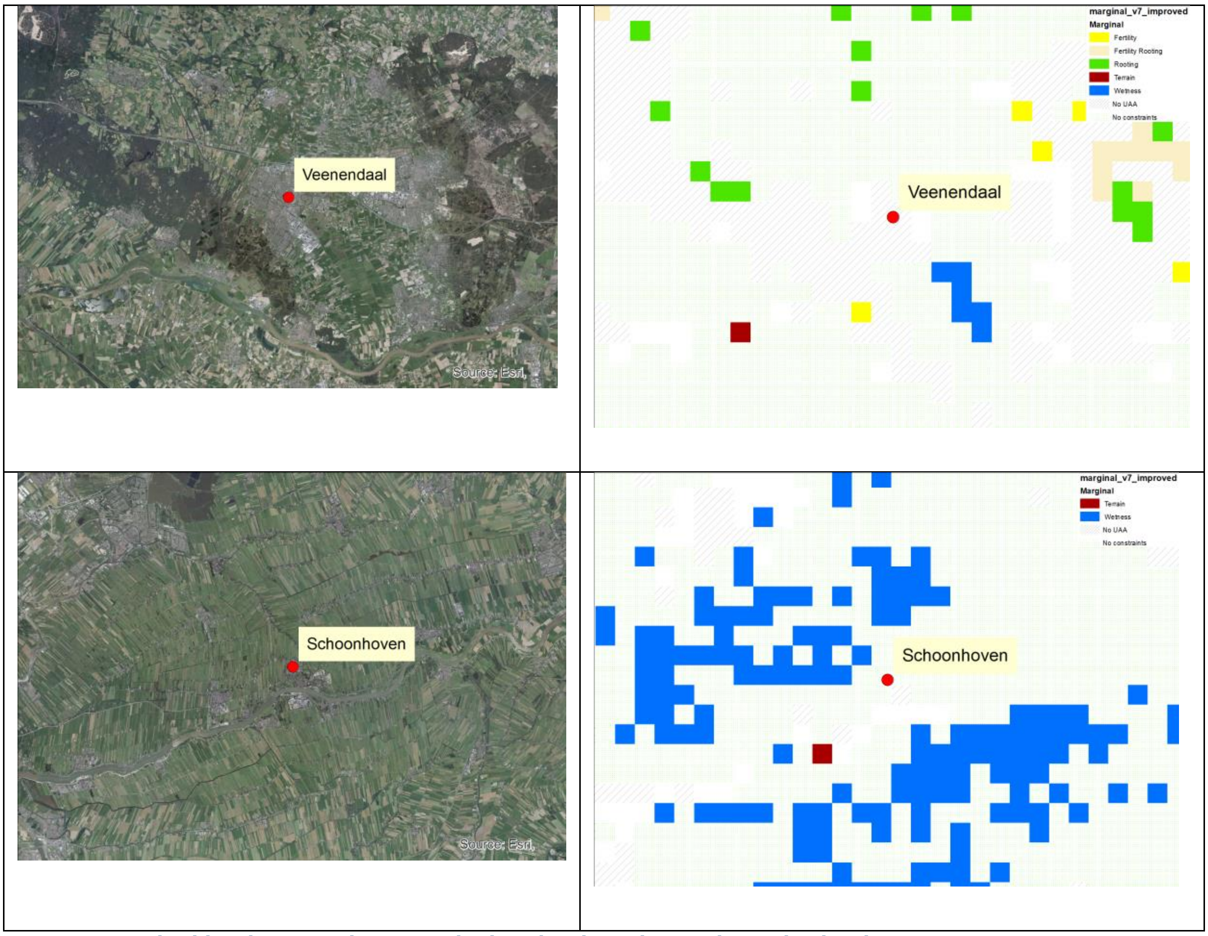
A transparent layer of the Marginal Agri Environmental Zonation (MAEZ) was superimposed on Google Earth for checking selected areas. We focused on those issues and geographical areas where management has changed the local conditions to overcome naturally occurring limitations to land use. The data (mainly soil data), that formed the basis for the MAEZ classifications, do not reflect anthropogenic changes. To generate the MAEZ, the areas that have biophysical limitations were first corrected for management measures that have been applied to overcome the biophysical limitations (See Section 3.3, Table 4). The rule followed for making that correction was that where land with severe limitations is indicated, but where there is still intensive land use (using different data on land use and intensity for the EU), management measures (e.g. drainage, fertilization, irrigation) are assumed that compensate for the natural limitations (see Table 4 in Section 3.3). For an overview of the evaluation sites see the Map 4. It shows all 18 sites where the evaluations were done which will be discussed in the following.

Map 4 Overview of evaluation sites in Europe to validate the mapped MAEZ result map

Evaluation of selected sites

Areas with excessive wetness limitations

Many swamps and poorly drained areas in the Netherlands have been drained for agriculture or for pastures. The regional soil information, used in the MAEZ assessment, classifies most of these areas as poorly drained. The area near Veenendaal, in the central part of the country, and the area around Schoonhoven, in the western part of the Netherlands, were chosen for verification of MAEZ mapping results (see Map 5). Veenendaal is bordered by an ice-pushed ridge (Utrechtse Heuvelrug) in the west. To the east of that ridge a poorly drained area with peat lands and cover sand with mainly grasslands are found. Schoonhoven is located in a peatland area that has been drained and is currently under intensively managed pastures.



Map 5 Marginal lands around Veenendaal and Schoonhoven in Netherlands

Around Schoonhoven part of the intensively managed grasslands are classified as 'marginal' and part of the area (with the apparent same conditions judged in Google Earth) have been classified as 'non-marginal'. The area is classified partly as 'extensive grasslands' and partly as 'intensively managed grassland'. The source map (Active/managed cropland & grassland from Estel et al. (2015) based on NDVI index from MODIS, see Table 4 in Section 3.3) is not discriminating adequately between 'extensively' and 'intensively' managed grassland for the area around Schoonhoven to correct the marginal land classification

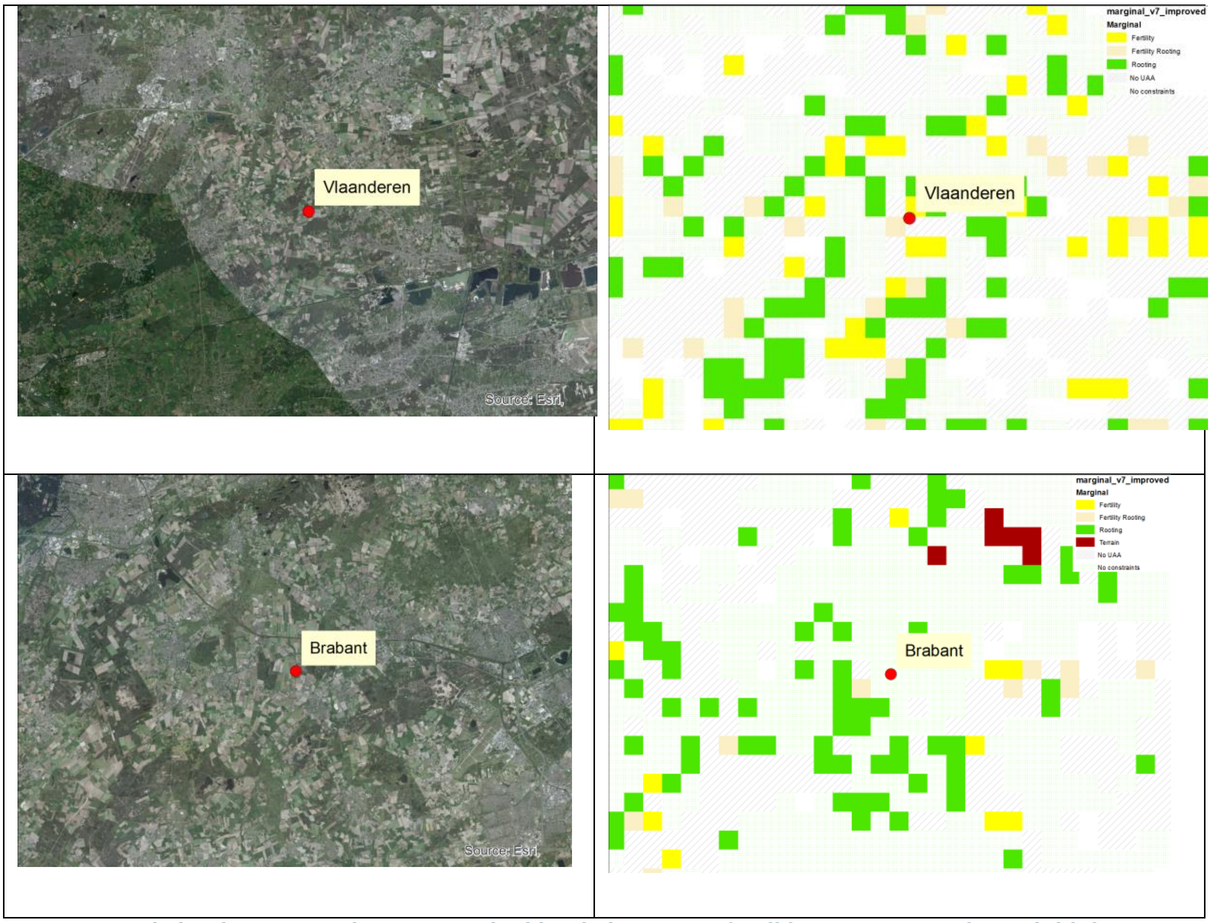
The poorly drained area to the west of Veenendaal is covered with MAEZ pixels that indicate marginal land (severely limited due to excessive wetness), confirming the overall classification. When zoomed in, the pattern leaves out some poorly drained areas. Base map resolution, compiled at a regional scale, is the cause of this.

In many other areas the classification with severe limitations for drainage on the MAEZ, such as parts of the UK, the land management correction did not affect the 'severely limited' and 'marginal' classification as these areas are dominantly extensively managed grasslands. So farming is 'tuned' with the severe limitations in the verification sites chosen in UK.

Local drainage measures seem not to be reflected in the classification of land management in most EU databases. The differentiation between ‘medium intensive use’ and ‘intensive use’ for intensively managed pastures under drainage in the database by Levers et al. (2015) is not always adequate. This causes some areas to be classified as ‘marginal’ while in reality the marginality factors have been overcome by management. This is a data related limitation rather than an error in the classification criteria. Even though more land should be excluded from the marginal class, at the regional scale, the correction for land management seems to work.

Low fertility in sandy soils

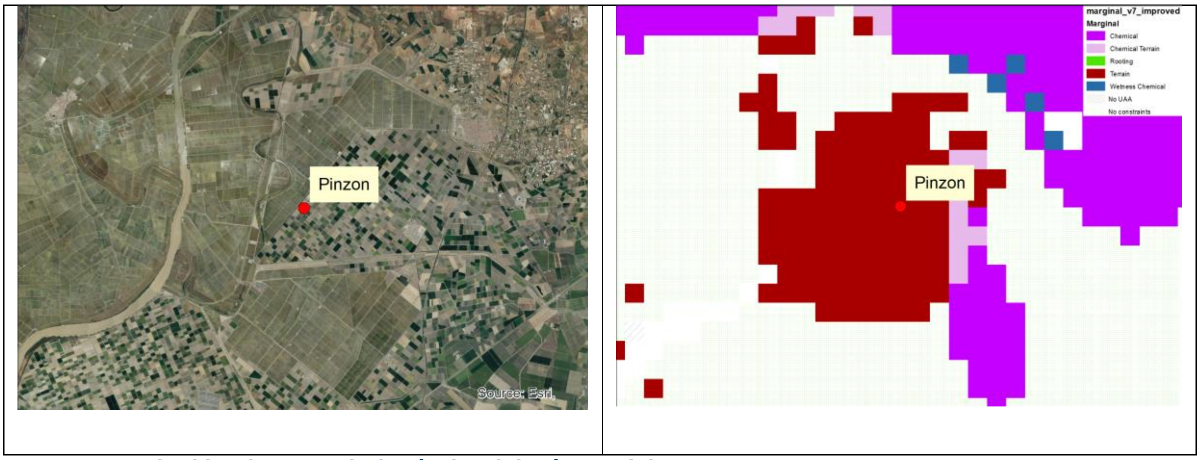
Sandy landscapes are found in Flanders region of Belgium and the southern part of the Netherlands (see Map 6). Part of those areas are under forest and heathland vegetation, but also farming is practiced in these landscapes. These sandy soils were all classified initially as ‘marginal’ due to severe limitations for low soil fertility. This limitation has been overcome in large parts of this area by high fertilization rates related to intensive animal production systems. The pattern remains rather similar, but the intensity decreased after the correction for land use intensity.



Map 6 Sandy landscapes no longer marginal lands because of soil improvements through high fertilisation in Flanders and Southern parts of Netherlands (Brabant)

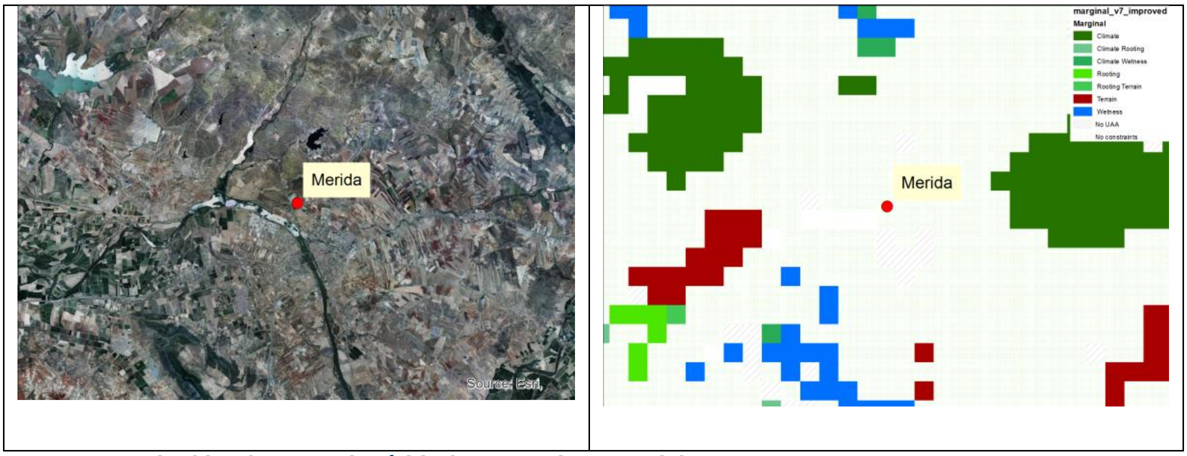
Selected sites in Spain

The area east of the village of Pinzón is located south of Seville in a river plain, near the mouth of the Guadalquivir river, is indicated as severely marginal because of flooding risk (in terrain conditions). West of Pinzón is a large area of wetland rice fields (See Map 7). The use intensity is indicated as low intensity use, yet the area is under intensive land use (irrigated annual crops and horticulture). The flooding risks is assessed to be severe because of topographic conditions, but drainage ditches and canals were observed when inspecting with Google Earth. The flooding risk is significantly reduced with counter measures in this area. This implies that the mask for correcting for improved marginal lands according to land use intensity works well in general, but does not capture all areas under intense land management. It excludes the neighboring rice field area but it does not recognize the rather intense use of area around Pinzón (irrigated field crops). This is due to erroneous classification in the base map for land use intensity by Levers et al., (2015).



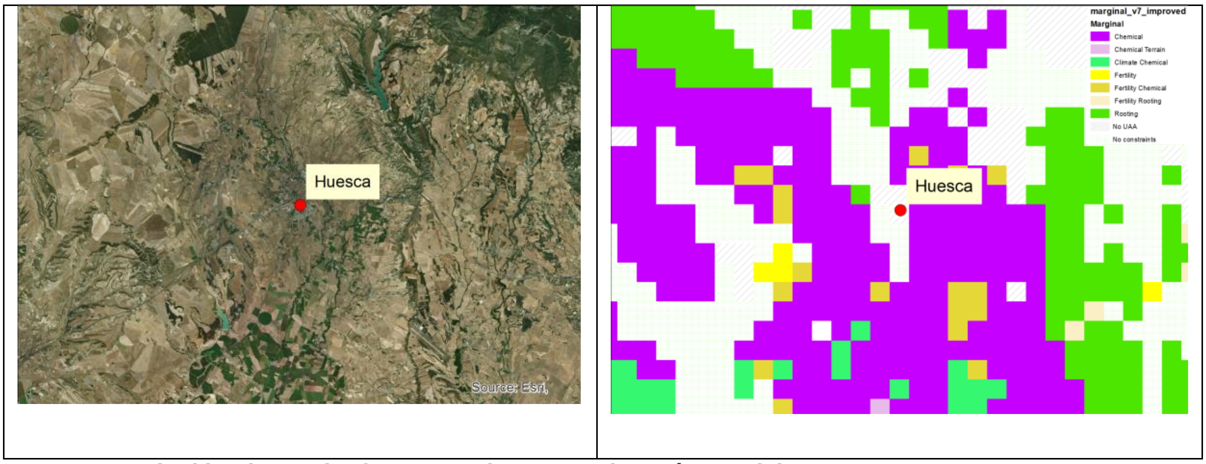
Map 7 Marginal lands around Pinzón (Andalucía, Spain)

The area east and south of Merida in Extremadura, near Calamonte, is classified to be severely limiting for the factor ‘wetness’. On Google Earth and Google Streetview no drainage problems can be observed however. Annual (e.g. irrigated maize) and perennial crops (e.g. grapes) are cultivated. The severe limitation for wetness in the area is derived from the soil types map that indicates a ‘Gleyic Acrisol’ for this area with ground water at 40 cm. This does not match with field conditions assessed through Google Earth and streetview (no poorly drained field). Thus the data quality for soils is limiting the MAEZ classification in this case. It is likely to be related to the (too low) resolution of the soil map and the land use intensity map.



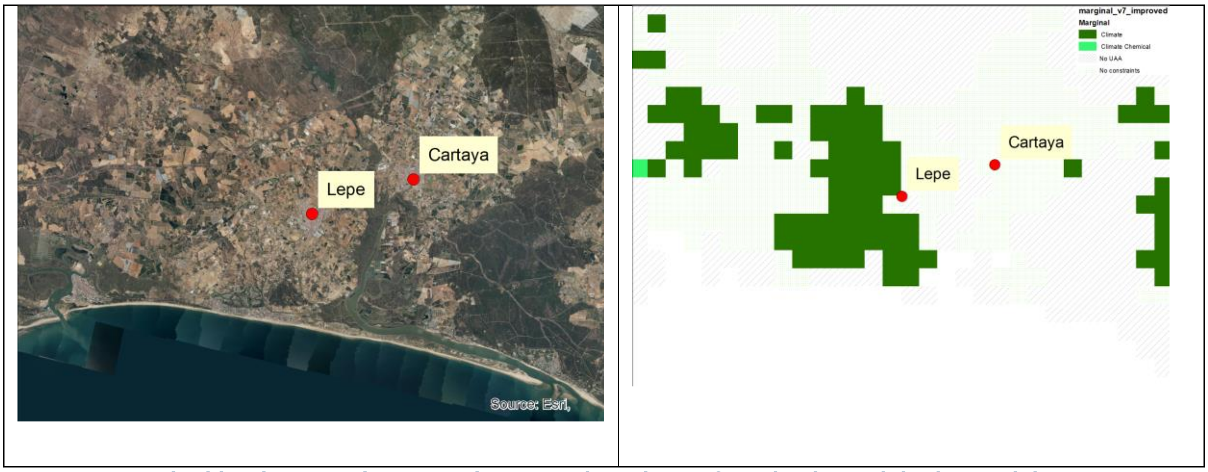
Map 8 Marginal lands around Mérida (Estremadura, Spain)

North of Zaragoza, the area near Huesca is classified as marginal on the basis of ‘chemical properties’. This seems consistent with the indicated soil saline types (solonchaks). The Google streetview check shows a low intensity use: grassland and overgrown area, intermittent with irrigated fields. Sandy soils (to the east of Huesca) have been classified as marginal on soil fertility and rooting conditions (texture). The ground check using Google Street View is consistent with this.



Map 9 Marginal lands North of Zaragoza in Huesca (Aragón, Spain)

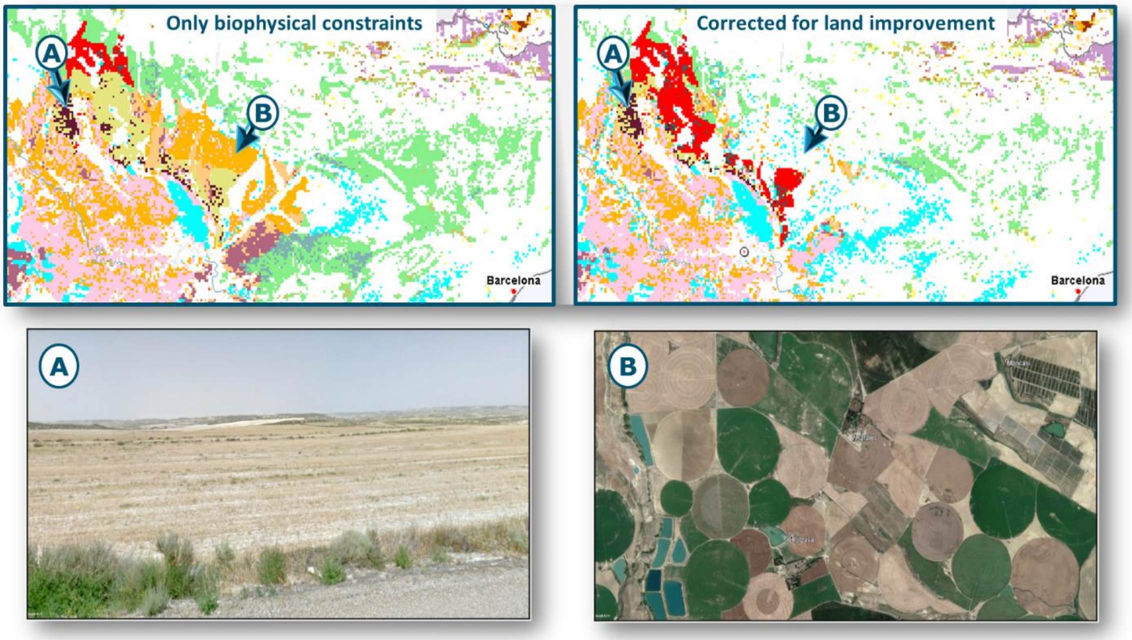
In the coastal area in the province of Huelva, near the Portuguese border around the villages of Lepe and Cartaya a mosaic pattern of land is observed. These areas have access to irrigation and land use is intense (dominantly strawberry cultivation) in seasonal cultivation (part of the year the land is bare). Part of this area is classified as marginal and the land use intensity is not well represented on the map of Levers et al. (2015).



Map 10 Marginal lands around Lepe and Cartaya (Province of Huelva in Andalucia, Spain)

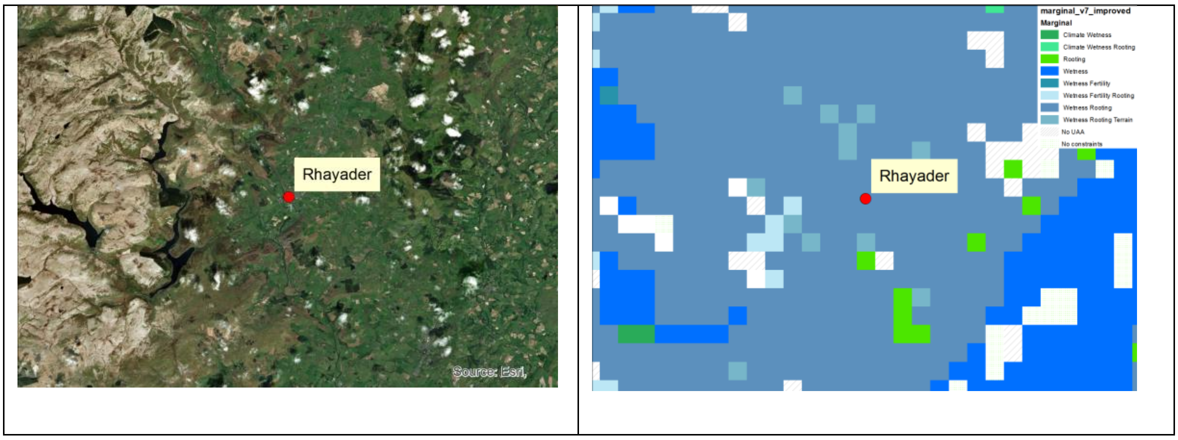
Other selected sites:

In the Ebro valley in Spain two sites were evaluated (see Map 11). In point A marginality is determined by salinity, and limitations on rooting and fertility. This area shows pictures of very extensive low productive arable lands. The area B (see Map 11) was initially mapped as marginal because of climate limitations for dryness. After correction for management this area was excluded again as is made visible in the right hand map in Map 11. This correction was indeed right which was clearly confirmed by the presence of large scale centre-pivot irrigation as is visible on the Google street view picture (right picture in Map 11)



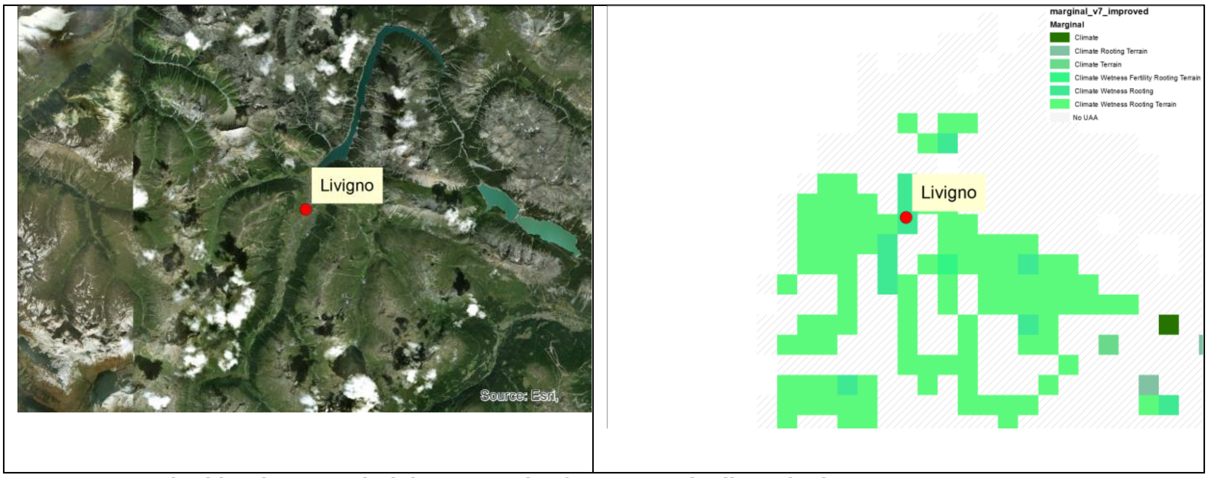
Map 11: Marginal lands in the Ebro Valley, Cataluña, Spain.

For Rhayader, Mid Wales, UK the MAEZ map indicates wetness, rooting and cold climate as marginality factors (see Map 12). The soil data layer indicates peat land. On inspection of the area with GE/GSV a wet landscape of higher altitude was observed with foggy conditions and evidence of peat and cattle raising (a coral was visible). This is consistent with the marginality factors identified.



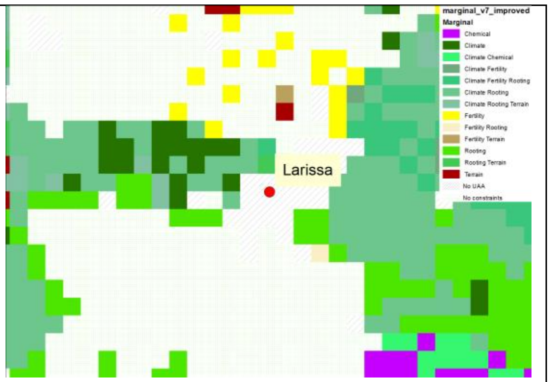
Map 12 Marginal lands around Livigno- North of Bergamo (Italian Alps)

Near Livigno, in the Italian Alps and at about 1800 m above sea level, long stretched fields were visible that appear to be slopes of touristic or recreational space, such as skiing (see Map 13). The grasslands seem to be mowed for fodder, but grazing is not visible. The dominant use of land seems to be skiing. Skiing is a form of intense land use, but the agricultural land use does no longer apply as the land has been converted to recreation.



Map 13 Marginal lands around Livigno- North of Bergamo (Italian Alps)

In the mountains of North Bergamo typical alp meadows are grazed under a low intensity management (see Map 13). The limiting factors indicated on the MAEZ are wetness, climate, rooting and terrain. These factors can be confirmed after inspection with GE/GSV. Yet, we noted that the information for intensity of use is not adequate for distinguishing between managed (low intensity) pastures and natural grasslands. The information on land use intensity does barely discriminate between low intensity pastures and natural grassland in the Alps.

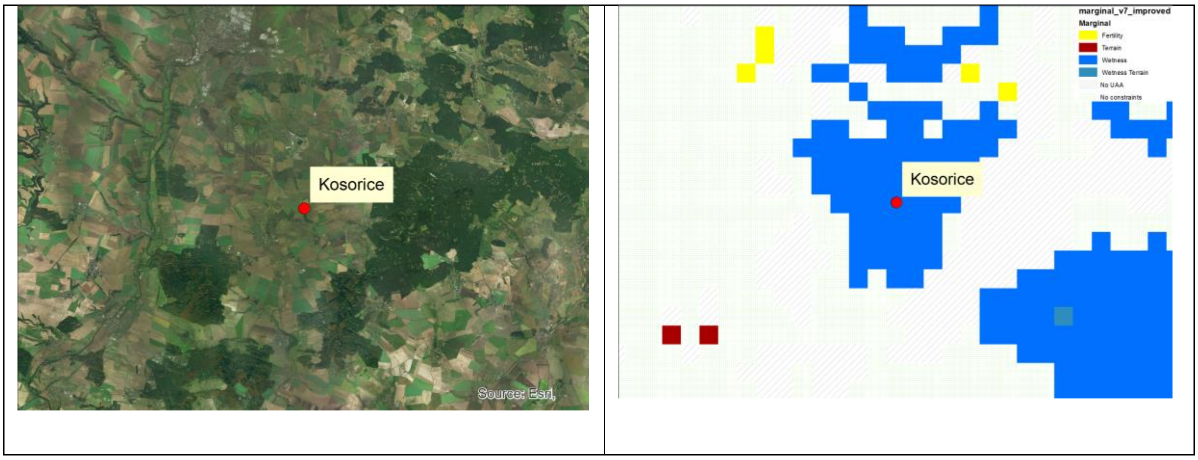


Map 14 Marginal lands around Larissa (Greece)

For Larissa, Greece, the MAEZ map indicates low fertility (see Map 14), which is explained by the soil pH factor (above 8). The soil types indicated are chromic Luvisols and Vertic Cambisols. Also, climate is a indicated to be limiting (drought) contributing to inclusion in the MAEZ classification. The climate is dry; crops are irrigated. The virtual field check shows that the area around Larissa is under arable farming (ploughed fields are observed). In some of the area evidence of harvested cotton is seen. Literature on the Larissa region[1] confirms that the area is under irrigated maize and cotton and that soils have a pH (H_2O); above 8. Locally salinity is a problem, a.o. in the cotton fields.

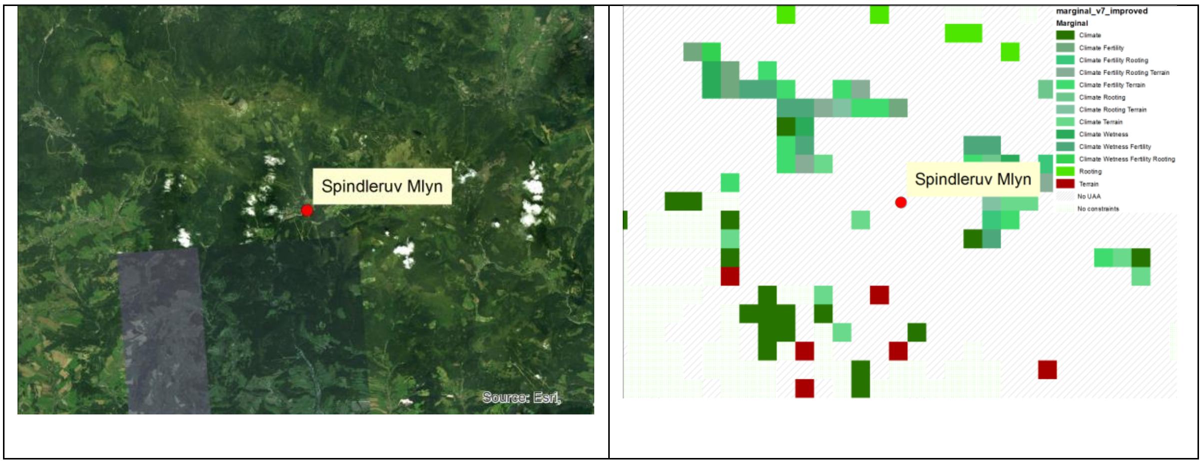
North of Kosorice Czech republic (between Kosorice and Dobrovice) (see Map 15), wetness is indicated as limiting factor. The soils indicated in the MAEZ information layers are fertile, but with high ground water (Phaeozems; soils with an organic matter rich topsoil and Luvisols; fertile and clayey soils, but both soils have the gleyic qualifier indicating poor drainage). The wetness was confirmed on inspection with Google Earth, although the variability is high (even within fields). Soil drainage conditions locally depends on the landscape position (plain) and distance to the natural drainage system (stream).

[1] Quantified analysis of selected land use systems in the Larissa region, Greece, PhD thesis of N.G. Danalatos



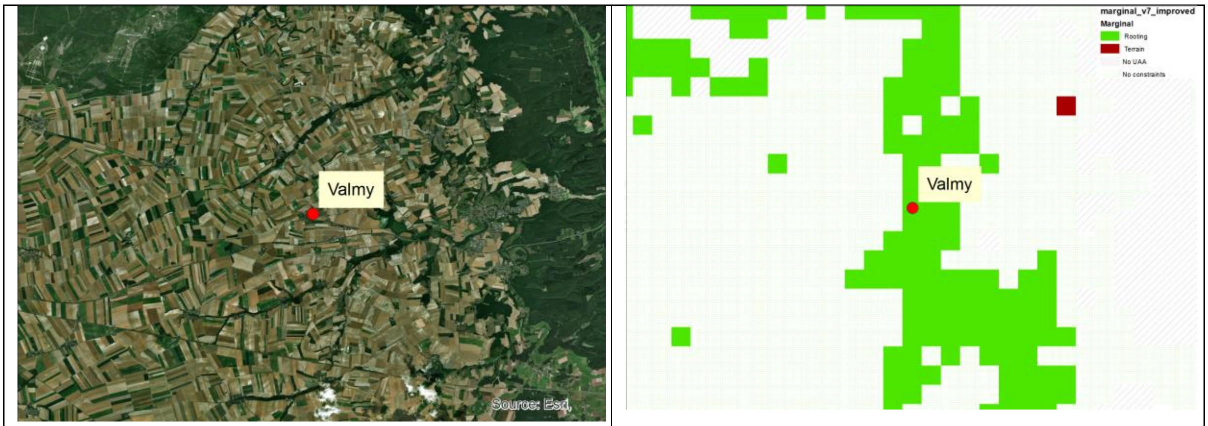
Map 15 Marginal lands around Kosorice (Czech Republic)

For Spindleruv Mlyn northern Czech republic (see Map 16), (severly) limiting factors indicated are climate (low temperatures) and terrain (steep slope). Views with GE confirms this as no farming practices were observed. Yet, managed and fenced pastures were observed. The pattern is patchy though; where slopes are too steep, forest dominates over pastures.



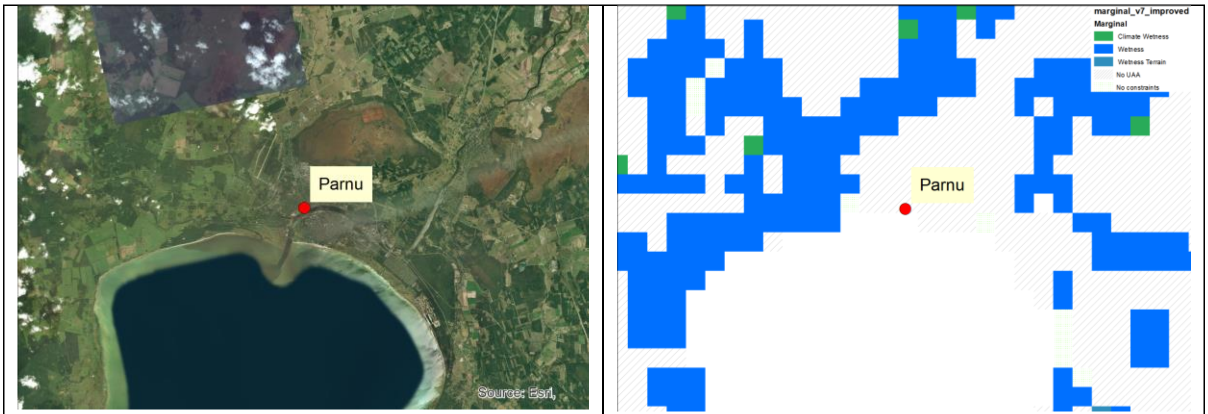
Map 16 Marginal lands around Spindleruv Mlyn (Czech Republic)

In the MAEZ, rooting conditions are indicated to be limiting in the Champagne area, Valmy, west of Paris, France. The soils are indicated to be shallow (Rendzic Leptosols) (see Map 17). Wheat and maize field are observed in GE inspections. The intensity of land use is indicated to be of ‘medium intensity’. Most of the land use in this region is excluded from the MAEZ through the land use intensity layer. The verified area has medium intensity land use, which proves not to be a strict enough filter for management. Therefore in this area the medium land use (in the map of Levers et al., 2015) should have been excluded from the marginal land classes on the basis of indicated management.



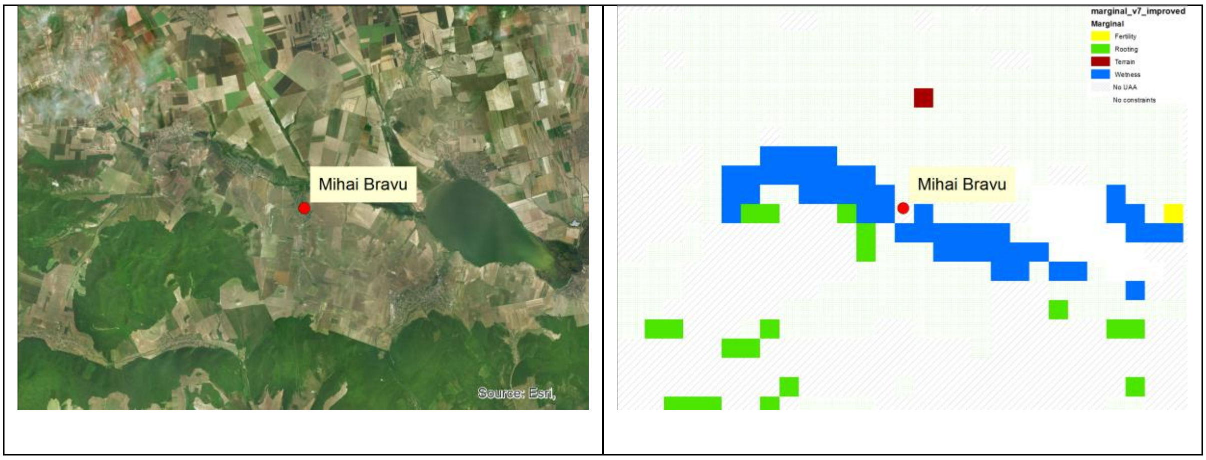
Map 17 Marginal lands in Champagne area, around Valmy, west of Paris (France)

Climate and wetness are limiting factors in the MAEZ north of Pärnu in Estonia (see Map 18). The area is under managed but unimproved grasslands. Mowed grass packs are observed on fields. Relatively wet soils are indicated in the database (Eutric Gleysols; soils with high groundwater level) and flooding is indicated, which seems correct as the area is part of the Pärnu river plain.



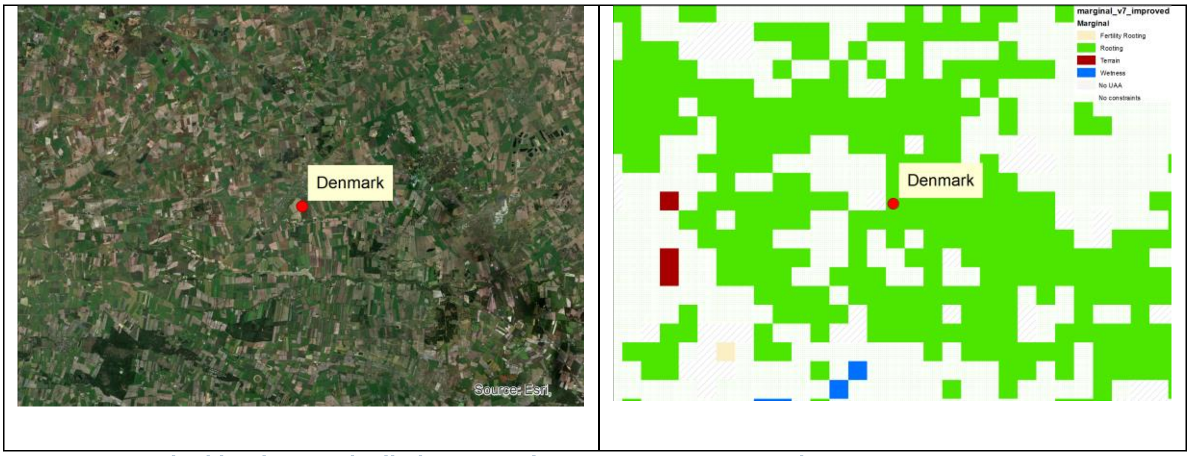
Map 18 Marginal lands north of Pärnu in Estonia

The area around Mihai Bravu, Giurgenu county, Romania is classified as marginal land because of one limiting factor (soil chemical conditions) (See Map 19). Inspection in GE shows soils with a low intensity use. Indicated soils are Gleyic Solonetzes (soils high in sodium and with a high groundwater table). Consistent with this, fields show a patchy and whitish pattern. It seems that salt tolerant vegetation types grow on the border with the road.



Map 19 Marginal lands round Mihai Bravu, Giurgenu county, Romania

In Denmark large areas are indicated as marginal due to ‘wetness’ (see Map 20). The soils in those units are indicated are soils with a high groundwater table (Eutric Gleysols). Still there are arable fields and managed pastures visible. Also here, the land use intensity mask seems not strict enough to exclude areas that are under management (drainage in this case).



Map 20 Marginal lands round Mihai Bravu, Giurgenu county, Romania

Conclusions

The correction of the marginal land map (MAEZ) for management on the basis of land use intensity works well in general, but it does not always correctly exclude enough land for management. This is mostly due to quality of the land use intensity data used to make the correction (from Levers et al., 2015), that does not include all intensively managed lands. In some of the mapped areas the MAEZ classification is limited by data quality, data resolution (e.g. soil map) and the uncertainties in the data layers used. It seems that for the land units for which multiple limiting factors were identified (e.g. climate, soil fertility, chemical soil properties), the MAEZ classification reliability increases. Even though more land should be excluded from the marginal class, at the regional scale, the correction for land management seems to work.

4.2.2 Reflection on JRC criteria and final mapping approach

As explained in Chapter 2, the approach to mapping marginal lands builds on the JRC approach to mapping areas of natural constraints (van Oorschoven et al., 2014, Terres, et al., 2014). The JRC approach was followed as much as possible, although the freedom was taken to critically evaluate the threshold setting for individual indicators, the completeness of the indicator set and the integration of the sub-indicators into a final set of 6 clustered indicators.

It should be realized that the JRC approach to mapping areas of natural constraints is based on expert knowledge and the main outcome of it is to provide guidelines to EU member states on how to map the areas of natural constraints that can be targeted through CAP support. Sofar the guidelines exist, but the mapping itself has not been done as part of the JRC study. Furthermore, the JRC approach does not provide guidance on what data to use. The mapping results in this report can therefore be seen as the first EU wide attempt to map marginal lands according to the factors for areas of natural constraints. An important challenge for the mapping of the biophysical constraints was good quality data availability. In MAGIC the different data sources to map the biophysical constraints were collected and evaluated. It was regarded as more important to use high quality data for mapping marginal lands then to follow strictly the JRC mapping guidelines. The selection of the appropriate indicator and the mapping of the marginality factor according to the threshold has to be scientifically robust, but also needs to be operational given data quality and availability. Sometimes it was decided that certain sub-indicators being part of one of the 6 clusters could not be reliably mapped and/or that other sub-indicators needed to be included. The overlap and differences between guidelines from JRC on mapping areas of natural constraints and final indicators and threshold levels used for mapping marginal lands in this study is presented in Table 12.

Table 12 Indicators and thresholds used for mapping marginal lands and overlap and differences with JRC indicators and thresholds for mapping areas of natural constraints

Cluster	Sub- factor	Selection based on JRC?	Indicator and threshold suggested by JRC for mapping Areas of Natural Constraints (ANCs) with severe and sub-severe limitations	Indicators and thresholds used for the final mapping of marginal lands in MAGIC
1.Adverse climate	Low temperature	JRC (Van Oorschoven et al, 2014)	LGPt ≤ 180 days Or Degree days <= 1500 days (<= 1575 = sub-severe)	Indicators and thresholds as in JRC ANCs mapping approach
	Dryness	JRC (Van Oorschoven et al, 2014)	P/PET ≤ 0.5 (< 0.6 = sub-severe)	Indicators and thresholds as in JRC ANCs mapping approach
2.Excessive wetness	Excess soil moisture	JRC (Van Oorschoven et al, 2014)	Oorschoven et al. (2014) proposed a threshold for severe of 230 days of water content in the soil exceeding field capacity (and >184 days for sub-severe). Terres et al. (2014) proposed 210 days for subsevere instead of 184 days (which is the 20% trheshold) as that was considered too lenient to constitute a severe agricultural constraint	For the sake of mapping >210 days was taken for severe. >190 days was taken for sub-severe as mapped data are only available in 10 days rounded classes. So indicators as in JRC ANCs mapping approach with slight adaptation in sub-severe threshold level.
	Limited soil drainage	JRC (Van Oorschoven et al, 2014) but with adapted thresholds/selections from the Reference Soil Groups (RSGs) of the World Reference Base for Soil Resources	Van Oorschoven et al (2014) proposes to select for severe and sub-severe class Gleysols, Histosols, Stagnosols, Planosol, Soils with primary qualifiers Histic, Gleyic and Stagnic and marshlands.	Soil types selected are similar to those proposed in JRC approach: Gleysols, Histosols, Stagnosols, Planosol, Soils with primary qualifiers Histic, Gleyic and Stagnic and marshlands.
3.Adverse chemical conditions	Salinity (Ec)	Toth et al. (2008) and Van Oorschoven et al (2014)	Van Oorschoven et al (2014) proposes :Salinity: ≥ 4 deci-Siemens per meter (dS/m) in topsoil (and > 3.2 dS/m for sub-severe)	For mapping purposes soil types and soil qualifiers were chosen with high salt content but the threshold values as suggested exactly in JRC ANCs mapping approach could not be mapped. Instead marginal lands were mapped according to a selection of Solonchaks and soils with a salic qualifiers. For these soils salt levels are estimated > 15 dS/m and they were selected when they had a dominant soil coverage (> 50% of the mapping unit area (of the soil mapping unit in the soil map)). No distinction was made between severe and sub-severe.
	Sodicity (Na – ESP)	Toth et al. (2008) and Van Oorschoven et al, (2014)	Van Oorschoven et al (2014) proposes:Sodicity: ≥ 6 Exchangeable Sodium Percentage (ESP) (and 4.8 ESP for sub-severe)in half or more (cumulatively) of the 100cm soil surface layer	For mapping purposes soil types and soil qualifiers were chosen with high sodic content: Solonetz, 'natric' soils, or 'Sodic' soils. These have a saturation with exchangeable sodium of more than 15% (ESP), and they were selected when they had a dominant soil coverage (> 50% of the mapping unit area (of the soil mapping unit in the soil map)). No distinction was made between severe and sub-severe.
	Natural toxicity (e.g. Al, S)	No indicator suggested by JRC for mapping ANCs. The natural toxicity was added as meaningful sub-indicator for 'adverse chemical condition'.	No JRC indicator suggested	Soils with high content of sulfur that have acidification potential upon drainage (Thionic qualifier for soils) were selected for marginal land mapping.
	Toxicity by pollutants	No indicator suggested by JRC for mapping ANCs. The natural toxicity was added as meaningful sub-indicator for	No JRC indicator suggested	NOT INCLUDED YET AS INDICATOR FOR MAPPING MARGINAL LANDS, BUT PLANNED IN LATER STAGE. Reason is that data on toxicity were not yet available to the project: Tóth, G., et al. (2016). "Heavy metals in agricultural soils of the

Cluster	Sub- factor	Selection based on JRC?	Indicator and threshold suggested by JRC for mapping Areas of Natural Constraints (ANCs) with severe and sub-severe limitations	Indicators and thresholds used for the final mapping of marginal lands in MAGIC
		'adverse chemical condition'.		European Union with implications for food safety." Environment International 88(Supplement C): 299-309. doi.org/10.1016/j.envint.2015.12.017
4.Low soil fertility	Soil reaction (pH)	JRC (Van Oorschoven et al, 2014) (with adapted threshold values)	Soil Acidity: pH $\leq$ 5 (in water) in topsoil	For mapping marginal lands this threshold was adapted to soils with pH below 5 or pH above 8 (at depth 0-30 cm). No distinction was made for severe or sub-severe.
	Soil organic carbon (%)	No indicator suggested by JRC for mapping ANCs. The low % OM was added as meaningful sub-indicator for low soil fertility	No JRC indicator suggested	For mapping marginal lands a % OM in topsoil < 0.5% was taken (<0.75% for sub-severe). The thresholds were selected based on Mantel et al. (2010).
5.Limitations in rooting	Unfavourable soil texture	JRC (Van Oorschoven et al, 2014) but with adapted thresholds/selections	Texture class in half or more (cumulatively) of the 100 cm soil surface is sand, loamy sand defined as: silt% + (2 x clay%) ≤ 30% (= Max 70% sand) (max 60% sand = sub-severe)	Indicators and thresholds as in JRC ANCs mapping approach
	Coarse fragments & surface stones & impeding layers	JRC (Van Oorschoven et al, 2014) but with adapted thresholds/selections	Overall the rooting needs to be < 35 cm. Reasons for shallow rooting need to be as follows: Course material at depth: 0-35 cm covering a surface of >35% and/or > 15% coverage with coarse material, including rock outcrop and boulder (> 25% and/or > 10% respectively for sub-severe)	Indicators and thresholds as in JRC ANCs mapping approach except for impeding layer: so rule applied for marginal land mapping also follows presence of course material (30 cm depth covering surface of at least >35% (>25% surface for sub-severe).
	Organic soils	JRC (Van Oorschoven et al, 2014) (with adapted threshold values based on Mantel et al (2010)	Organic matter (OM) ≥ 30% of topsoil (30/100 cm)	Mapping according to exact 30% OM level was not possible. Instead for mapping marginal lands a selection was made of soil types in soil map (ESDB) with high OM content. The soils selected were all Histosols.
	Shallow rooting depth	JRC (Van Oorschoven et al, 2014) but with adapted thresholds/selections	< 30 cm rooting depth possible. Suggested soils for mapping (Terres et al., 2014): Leptosols, Albeluvisols, Lithic, Petrocalcic, Fragipans, Duripans, Petroferric (no distinction between severe and sub-severe)	The mapping of marginal lands based on impeding layers was done following JRC but with slight additions in soil type selection: The soils that are typically shallow selected for the mapping were: Lithic , Petrocalcic, Duripans, Albulivisol, mollic cambisols, Leptosol & Fragipans (for sub-severe only Albulivisol, mollic cambisol were selected and for severe: Lithic , Petrocalcic, Duripans, Leptosol & Fragipans)
6.Adverse terrain conditions	Steep slope	JRC (Van Oorschoven et al, 2014) but with adapted thresholds/selections	Slope of > 15% for severe and > 12% for sub-severe	For mapping marginal lands the threshold of JRC for ANCs is taken but an extra rule was added regarding average area coverage by this slope as this was necessary to make the mapping. For severe it was assumed >80% of area has a slope of > 15% . For sub-severe the slope % was not lowered, but the area coverage with the slope moved to > 60% of the area and the slope remained >15%.
	Flood risk	No indicator suggested by JRC for mapping ANCs. The flood risk was added as it was also suggested in Meuncheberg et al. (2011)	No JRC indicator suggested	For mapping marginal land for severe the threshold is > 2 m flood in 2yrs return time (For sub-severe >1-2 m flood in 2 yr return time)

For the climate related limitations we mapped the marginal lands following exactly the indicators and threshold values as recommended for mapping ANCs by JRC. For some soil indicators it was not always possible to map exactly according to the thresholds specified by JRC because the thresholds indirectly refer to soil characteristics/qualifiers and the only way to map these is to identify the soil types in the soil map that have these qualifiers. These qualifiers do not always match with the threshold levels (for severe and sub-severe) as suggested by JRC for ANCs. This is for example the case for salinity, sodicity, Low PH and soil drainage. We selected soil types with qualifiers that certainly qualify as limiting according to the indicators, but not necessarily fit entirely with the thresholds for severe and sub-severe (see Table 12).

There are also some more differences between the JRC recommendations for ANCs and the final mapping of marginal lands caused by incorporation of some additional limiting factors. These additional factors were natural toxicity as a sub-indicator for adverse chemical composition and a very low organic matter level as an extra indicator for low soil fertility and finally one extra sub-factor was added for mapping adverse terrain referring to flooding risk (see Table 12).

5 Integrated approach to classifying marginal lands according to socio-economic constraints and ecosystem service compatibility

5.1 Introduction

As to the socio-economic constraints linked to marginal lands the literature is not conclusive (see D2.1). Socio-economic indicators indicative for marginal lands mentioned in literature were low economic returns on land, absence of markets, difficult accessibility and bad infrastructure'.

It is clear that there are several approaches (see D2.1, chapter 2 and section 3.2) in which socio-economic factors such as negative returns are seen as key factors for catergorising land as marginal (Barlow, 1986 & Strijker 2005) But if the perspective is agricultural land use, the low or negative returns are often caused (amongst others) by biophysical constraints. Furthermore, economic return from marginal lands is considered dynamic (Pollard, 1997 & Strijker, 2005). Particularly in MAGIC dynamics in economic returns are relevant since it will be investigated if using this land for production of industrial crops will deliver a positive economic return while when using it as a food crop it will not. Given the strong link between biophysical limitations and economic returns and the dynamic nature of economic returns because of market and policy drivers, an unfavourable input output ratio on land does not seem to be a stable factor for identifying marginal lands, but for further characterisation of it it is.

Factors such as absence of markets, difficult accessibility, bad infrastructure, low population density and declining population were identified as drivers for farmland abandonment particularly when occuring in combination with natural constraints (see van Oorschoven, Terres et al., 2013 and Ioffe & Nefedova, 2004). On the other hand the FAO-CGIAR land classification also pointed out that the chance for land degradation is larger in areas where there is higher population pressure and demand for land. Degraded marginal lands are therefore likely to occur more often in central locations then in the remoter ones, unless degradation occurs through land abandonment and encroachment of shrubs increasing chances for forest fires.

From the above discussion is can be concluded that socio-economic limitations have a clear influence on the development opportunities of regions, particularly where they occur in combination with biophysical limitations. Furthermore, the more remote/decentral regions are located, the higher chance there is for abandonment of farmland with biophysical limitations. What is clear however is that the distance factor is not a key characteristic of all lands limited by biophysical factors. Remote location should more be seen as an additional complicating factor for part of the marginal lands. Biophysical limitations can be a reason for abandoning lands also when located in the centre (near a city/market), particularly when they are also affected by degradation, while lands with good soils located in isolated locations can still be used for agricultural production, in spite of their relative accessibility limitations. Overall, it is therefore concluded that socio-economic limitations will be used only to classify marginal lands identified by biophysical limitations further.

5.2. Characterizing marginal lands in terms of socio-economic constraints

As to the socio-economic limitations the FAO-CGIAR definition and the literature is not conclusive, particularly because it also to covers characteristics typical for marginal lands outside Europe. Overall there seems to be consensus about the fact that on marginal lands the input/output relationship is unfavourable making it difficult to obtain a positive income return from these lands when used for food production. However, at the same time it is acknowledged that this economic margin constraint is very dynamic in time under influence of changes in technologies, markets and policies. In the MAGIC project the evaluation of economic returns obtained from marginal lands when used for industrial crops and food crops will certainly be evaluated extensively, particularly to establish whether industrial crops are options for these lands while avoiding competition with food production. However, given the dynamic nature of this constraint and the fact that economic returns are part of the sustainability evaluation in the project, this economic return constraint will not be used to identify marginal lands initially.

As to socio-economic constraints regarding 'limited access to markets, difficult accessibility and bad infrastructure' it can be concluded that many marginal lands have these characteristics, but these are less uniformly applicable then the bio-physical constraints. In other words marginal lands are indeed often located in decentral locations, but it does not mean that all decentrally located lands are marginal. On the other hand, the more decentral marginal lands are the higher the chances are for negative returns on cropping activities given higher cost to reach, process and transport harvested products to markets. Marginal lands in decentral locations also have a higher chance to remain unused for food production and therefore the chance to compete with food production on these lands is lower when industrial crops are introduced. Because of this it is concluded that locational factors like accessibility and bad infrastructure can be used to further classify marginal lands identified according to biophysical constraints for the purpose of MAGIC.

Often there is a strong relationship between several of the socio-economic factors which implies that a rural multidimensional typology would be the best approach to classifying marginal lands further.

An example of such a typology is the one developed in the FARO project (Van Eupen et al., 2012) which has as an advantage that it is more dimensional as it combines indicators on agricultural land use, accessibility, population and economic activity density, developed with high resolution data and has been generated through a robust statistical clustering. The clustering of factors takes account of environmental zone specific ranges and averages per factor to map the 3 typology classes of peri-urban, rural and deep rural areas per environmental zone (see Figure 3 and also Section 3.2 in D2.1).

For the further classification of marginal lands in MAGIC according to socio-economic constraints the FARO classification is used (see Figure 4).

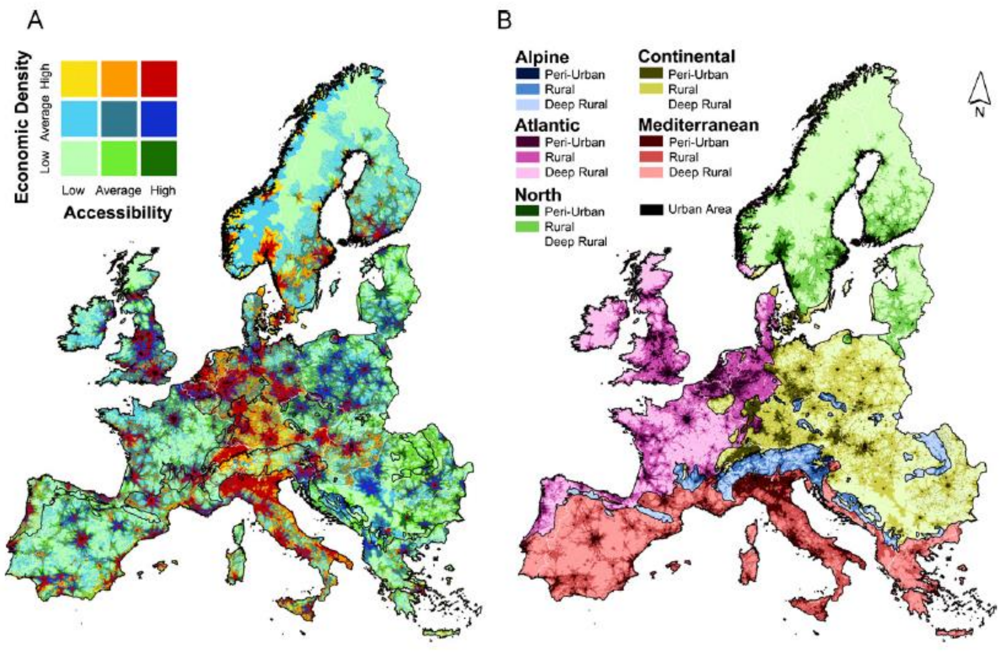


Figure 4 FARO rurality classes (Van Eupen et al., 2012). Map A show nine rurality classes based on economic density and accessibility for each aggregate Environmental Zone (AEZ) (Alpine, Atlantic, Continental, Mediterranean and North (=Boreal & Nemoral)) derived from the Environmental zones of Metzger et al. (2005). Map B shows the resulting 3 rural typology zones: Peri-urban, rural and deep rural within the five aggregate Environmental zones.

5.3 Marginal lands and ecosystem services determining use options for industrial cropping

Since the aim of MAGIC is to identify options for the use of marginal lands for industrial non-food cropping **sustainability is a critical issue**. The sustainability impacts of growing industrial crops in marginal lands can be positive and negative, but depends on three aspects:

1) whether other land uses are replaced by the industrial crops (leading to direct and indirect land use changes and potentially competition with food production);

2) whether biodiversity and other ecosystem service will be affected;

3) what industrial crops and management systems are to be used.

In the identification it therefore needs to be ensured that marginal lands identified are classified according to factors that can be taken into account in developing best sustainable industrial cropping solutions. There are 2 types of factors of relevance in this respect:

Ecosystem services that can be negatively affected through the introduction of industrial cropping activities. It is important to know what type of ecosystem service are particularly occuring in marginal lands sothat industrial cropping solutions are developed that can be combined without negatively affecting the service. There could also be services present that cannot be combined with industrial cropping.

Threats to ecosystem services that can be neutralised/taken away through the introduction of industrial cropping. A good understanding of these threats and how they coincide with marginal lands will help identify industrial cropping options that create win-win solutions bringing threats down while producing feedstock for non-food products.

Initially it is proposed to focus on the following 3 types of ecosystem services and threats:

Provisioning service for food and feed; in MAGIC competition between industrial crops for non-food purpose with food production should be avoided. This implies that marginal lands that show evidence of abandonment are of more interest to develop industrial cropping systems for then lands used for food production. The aspect of land use and abandonment was already addressed in Chapter 3 (Section 3.3 on land management) and will not be further discussed here. However a further understanding of marginal lands in relation to current uses and abandonment is planned in next steps in year 2 and 3 of the MAGIC project.

Biodiversity service: in Europe the risk for biodiversity loss is a factor that certainly needs specific attention particularly because it has been shown that High Nature Value (HNV) farmlands often coincide with areas of natural constraints which are typically overlapping with marginal lands (Andersen et al. 2003; Paracchini, 2008). This does not imply that industrial cropping and presence of habitats and species of conservation value cannot be combined, but a careful tuning is certainly required to not destroy biodiversity values. It is well known that intensification of the farming activities in these lands may lead to land degradation and loss of biodiversity. There is a clear coincidence between the places where farmland biodiversity has remained relatively stable and where the relative extensive traditional farming systems have continued to exist, while the opposite is true for the decline in farmland biodiversity and the shift towards more intensive and efficient farming systems (e.g. EEA, 2005; Heath et al., 2000). On the other hand farmland abandonment is an important cause for loss of HNV farmland and thus biodiversity in more marginal areas of Europe. The introduction of industrial crops in marginal lands needs to be tuned with the present biodiversity values. It may help to bring farmland abandonment down, but certain many types of biodiversity values cannot be combined with intensive forms of cropping and monocultures (.

Threats to soil function that are particularly relevant in croplands. These relate to high input uses in the form of heavy machinery, fertilisation and pesticides, irrigation and intensive rotational cropping. Particularly in marginal lands such pressures can form a larger threat to the ecosystem functions and the biophysical constraints present.

5.3.1 Biodiversity values and compatibility with industrial crops

The introduction of industrial crops in marginal lands can have adverse effects on biodiversity. This is particularly a risk where marginal lands contain high biodiversity values. It is clear that the impacts on biodiversity of changing some extensive land uses to intensive arable or biomass production would be severe, but from an economic and technical point of view, these changes are not always very likely to occur particularly within the EU. For example, changing wetlands to intensively used arable of perennial land is not likely because of the high cost of drainage and because of legislation to protect them. Growing short-rotation coppice on wetlands would be more economically viable but in many cases the sites would still be protected by law. Biodiversity values that are more challenging to conserve against land use changes are those not protected by conservation sites. In Europe the concept of HNV farmland was therefore developed. It is 'farmland that comprises of those areas in Europe where agriculture is a major (usually the dominant) land use and where agriculture supports or is associated with either a high species and habitat diversity or the presence of species of European conservation concern or both' (Andersen, et al. 2003 and EEA/UNEP, 2004). HNV farmlands are both complementary to protected sites, included in the Natura 2000 network of the EU, and also overlap with protected sites.

he direct and indirect pressures exerted by introduction of industrial crops in marginal lands could further encourage intensification in they are introduced at the expense of traditional farming practices, but could also help to prevent land abandonment. Direct impacts on biodiversity include habitat fragmentation, habitat loss and diversification, changes in canopy structure and soil cover; indirect impacts include all environmental effects both negative and positive, such as eutrophication, acidification, water depletion, and soil improvement or degradation. The last of these may lead to overall changes in habitat quality and have impacts on broader areas including adjacent land (ETC-SIA, 2013).

In the approach to identifying marginal land for industrial cropping we propose to use the HNV farmland likelyness map (see Box 1) to characterise marginal lands furthr according to the key ecosystem value which is occurence of high biodiversity value. The advantage of using the HNV farmland indicator is that it should cover all agricultural lands in the EU that have high biodiversity value irrespective whether it is protected or not. In Box 1 further explanation is given of HNV farmland and how it was mapped at EU level.

The overlap of marginal land with HNV farmland does not necessarily imply that this land should not be used for industrial cropping at all, however it does imply that if it is introduced this should be tuned with maintenance of biodiversity values present. Abandoned HNV farmlands are also losing their biodiversity values because the traditional agricultural management on which specific biodiversity values rely for their subsistence has disappeared. The introduction of industrial crops on these type of abandoned lands may be an option to maintain the low intensity management. Impacts on biodiversity that occur directly or indirectly due to land-use changes are not known for the mostly new industrial crops on which MAGIC focusses. Cropping systems can be designed with different impacts. The main variables are cropping patterns (e.g. mono-cropping or diverse rotations), management intensity, the scale of the industrial crop plantation and crop choice. The choice of management options is therefore crucial for the effects on biodiversity and the wider environmental impacts of industrial cropping.

For the classification of the Marginal lands we will therefore present to which extend marginal lands overlap with HNV farmland.

Box 1: HNV farmland concept and EU wide map

High Nature Value (HNV) farmland areas have become an important policy target in the new Rural Development Programme (EAFRD) (Council Regulation 1698/2005). In response to this, the Community's Strategic Guidelines for rural development, 2007 –2013, encourage Member States to put in place measures to preserve and develop HNV farming systems.

In order to meet the objective of preserving and enhancing HNV farming, MS are obliged to apply the baseline indicator 18 on HNV farmland area (as part of the Common Monitoring and Evaluation Framework) at the start of the Rural Development Programme and to introduce own indicators to measure the extent and quality of their HNV farmland annually as from 2010 onwards. Mapped information from MS is available for some EU countries, but not all and the approach to mapping it nationally is different (see e.g. Opperman et al., 2012). However, mapping of HNV farmland has been done by the EEA and JRC at EU-28 level. the IRENA indicator of HNV farmland (EEA, 2005) and the further elaboration of this indicator by Paracchini et al. (2008) where it has been identified using three categories of information:

Land cover (e.g. Corine LC) (e.g. semi-natural vegetation classes such as semi-natural grasslands, agro-forestry, scrub, woodland-pastures, land use mosaics, etc.) (an up-date is presently done with newest CLC information)

Farming characteristics (e.g. stocking density, extent of semi-natural and extensive arable, grassland and/or permanent crop land uses, high number of mixed/mosaic land uses, proportion of fallow land, fertiliser application, use of common grazing lands, etc.) for as far as national and regional data are available.

Species (e.g. indicative farmland birds (e.g. Dupont's Lark (Chersophilus duponti), Common Quail (Coturnix coturnix)) and/or farmland habitats linked to extensive farmland management (e.g. lowland or mountain hay meadows, Nordic alvars, calcareous grasslands etc.).

This spatial database of HNV farmland (Parrachini, et al., 2008) is available and can be used as an EU wide database for the farmland areas of high biodiversity. They were mapped using agricultural Natura 2000 areas overlapping with a selection of CORINE agricultural land cover classes, combined with ecological data sources on species numbers linked to farmland (e.g. birds and butterflies). The result is a likeliness score for HNV farmland has been determined per region (Nuts 2/3) for arable and permanent grassland. It is assumed that the HNV farmland share for released agricultural land is similar to the average share for a region. The resulting map is presented underneath.

Map 21 High Nature Value farmland likelyhood

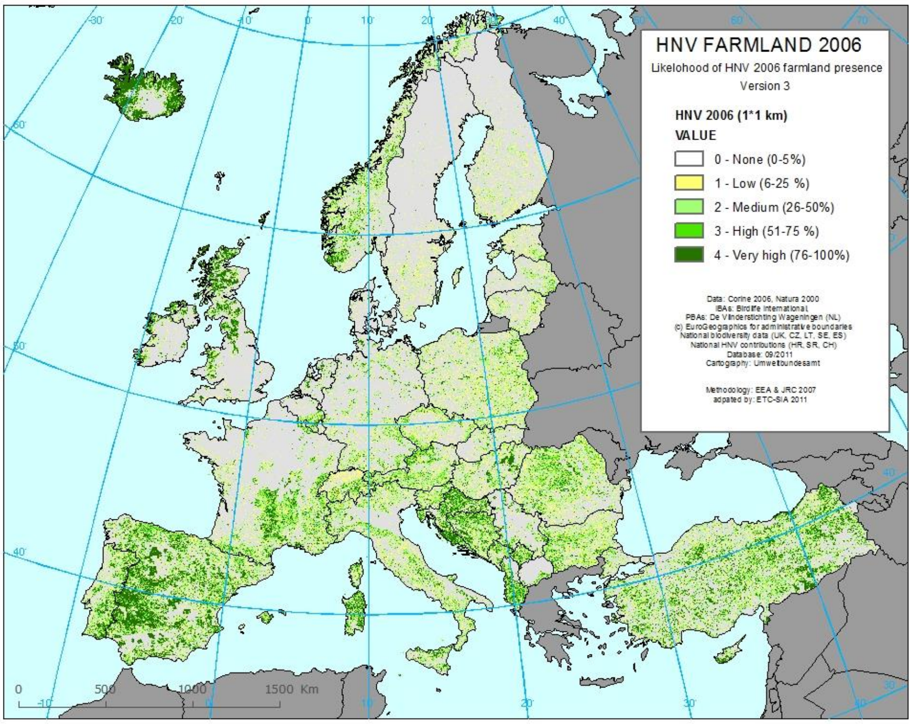


Table 13 HNV agricultural area share (Schweiger et al., 2011)

Country	Area share of HNV (col1/col2) in %
Albania	80.4
Austria	64.1
Bosnia and Herzegovina	93.1
Belgium	24.4
Bulgaria	38.2
Switzerland	46.0
Cyprus	54.5
Czech Republic	25.7
Germany	15.1
Denmark	5.6
Estonia	33.1
Spain	55.8
Finland	42.4
France	22.8
Croatia	88.9
Hungary	28.6

Ireland	20.2
Iceland	100.0
Italy	33.7
Liechtenstein	1.4
Lithuania	16.0
Luxembourg	9.7
Latvia	20.0
Montenegro	99.1
FYR of Macedonia	17.0
Malta	6.6
Netherlands	15.2
Norway	90.4
Poland	22.7
Portugal	58.5
Romania	36.3
Serbia	20.6
Sweden	27.0
Slovenia	75.6
Slovakia	19.9
Turkey	46.1
United Kingdom	27.9
Kosovo (under UNSCR1244/99)	81.5
Total	**41.2**

5.3.2 Soil function threats and industrial cropping options

Efficient land use, the conservation of available land resources and the reduction of annual land take are listed as the most important challenges for land and soil of the European Union . There is however major concern in the EU (and also worldwide) about conservation of soil functions because there are major threats to soils . The Roadmap to a Resource Efficient Europe puts soil as a central factor in reaching efficient use of available resources. The Roadmap specifies three policy targets for soil conservation and sustainable land management: contain soil erosion, conserve soil organic matter and reduce land take. In EU policy these are the key soil targets for the soil resource.

The EU RECARE and SOILCARE projects lists 12 soil threats (see Table 15). It is likely that several of these soil threats are occuring in marginal lands and it would be important to take account of these threats when designing industrial cropping systems for these lands. The focus should be on

identifying components of industrial cropping systems which may be used to prevent or minimize soil threats, through three mechanisms (Wezel, 2014): (i) changes in input-output ratio's, (ii) substitution, and (iii) redesign of the current land use or cropping system. The review by Oenema et al (2017) shows that for each soil threat components of cropping systems exist that can be adjusted to prevent or reduce soil threats. These components include crop types and rotations and a selection of agro-management techniques (see table 14 from Oenema et al. (2017) below.

Table 14 Components of cropping systems that can be adjusted to create soil improving cropping systems (source: Oenema et al. (2017).

Nr	Components of cropping systems
A	Crop rotations, including cover crops, etc.
B	• Nutrient management, techniques and inputs
C	• Irrigation management, techniques and inputs
D	• Drainage management and techniques
E	• Tillage management, techniques and inputs
F	• Pest management, techniques and inputs
G	• Weed management, techniques and inputs
H	• Residue management, techniques and inputs
J	• Mechanization management, including planting and harvesting machines
K	• Landscape management techniques and inputs

In Table 15 an overview is given of the main soil threats occurring in EU soils. The threats that are likely to be most relevant in marginal lands and which have potential to be mitigated through the introduction of appropriate industrial cropping systems are shaded in green.

Table 15 Components of industrial cropping systems which may be used to prevent or minimize soil threats and indicators of soil threats. Soil threats of particular interest to be addressed by design of industrial cropping systems are shaded in green.

1. Soil threat	Considered in RECARE	Considered in SOILCARE	2. Components of industrial cropping system to prevent or minimize the soil threat Mechanisms: (i) changes in input-output ratio's, (ii) substitution, and (iii) redesign.	3. Indications by clusters of biophysical constraints (See section 3.1 for 6 clusters)	4. Proposed key indicator	5. Spatial dataset for key indicator
Soil erosion	x	X	[2](ii) (iii) Crop rotations: Permanent cropping or +inter/relay/cover cropping +strip cropping, agroforestry (ii) Tillage management: reduced & contour tillage (ii) Residue management: mulching (iii) Mechanization management: contour traffic Landscape management: agroforestry, terracing, contour treelines	4, 6	Modelled erosion risk for erosion by water >3 t/h/yr Wind erosion susceptibility: moderate or high	Soil Erosion by water– PESERA: http://eusoils.jrc.ec.europa.eu/ESDB_Archive/pesera/pesera_data.html Wind Erosion: http://eusoils.jrc.ec.europa.eu/library/themes/erosion/winderosion/
Soil salinization	x	X	[3]Salinization-specific SICS are highly site-specific, and may involve all three mechanisms. (i) improved drainage through groundwater level control and channelling, reduced evaporation (through mulching), less input of soluble fertilisers, and targeted irrigation with low EC water. (ii) drip irrigation instead of surface irrigation (iii) ridging, (plastic) mulching, and growing tolerant crops.	3	- (unless areas experiencing secondary salinization are not mapped out under the biophysical constraints; in that case: % of area with sodic or saline soils>50)	- (http://esdac.jrc.ec.europa.eu/content/saline-and-sodic-soils-european-union)
Soil compaction	x	x	(i) stimulating biological activity through addition of organic matter (ii) lowering wheel loads and tyre pressures, reduced tillage (iii) controlled trafficking, deep rooting crops and trees	2	Modelled Relative Normalized Density (RND[4])>1 (excluding organic soils) Schjønning et al. (2015)	Dataset not officially available but I have it from the authors.
Soil sealing	x	-	(iii) cultivation of former industrial sites and mining sites or sites to be desealed where substances in the soil prevent the cultivation of food crops or where industrial cropping is competitive with urban or commercial land use types.	-	<to be suggested; possibly % of 'built-up land without active use', e.g. areas of former industrial sites, mining sites and other brownfields>	From combination of HRSL and CLC

[2] J. Stolte, R. Hessel, L. Øygarden, O. Green, A. Ferreira, G. Edwards, J. Poesen and M. Riksen (2017). Soil-improving cropping systems for soil erosion. Chapter 7 in Oenema et al. (2017).

[3] J. Cuevas, J.J. Hueso, F. del Moral, I. Tsanis and I. Daliakopoulos (2017). Soil-improving cropping systems for soil salinization. Chapter 6 in Oenema et al. (2017).

[4] RND: Relative Normalized Density: dimensionless or %; defined as the actual dry bulk density divided by a critical bulk density, the latter being a function of the clay content

1. Soil threat	Considered in RECARE	Considered in SOILCARE	2. Components of industrial cropping system to prevent or minimize the soil threat Mechanisms: (i) changes in input-output ratio's, (ii) substitution, and (iii) redesign.	3. Indications by clusters of biophysical constraints (See section 3.1 for 6 clusters)	4. Proposed key indicator	5. Spatial dataset for key indicator
Desertification	x	x	<to be filled in next report>	<to be filled in next report>	<to be filled in next report>	<to be filled in next report>
Flooding and water logging	x	x	<to be filled in next report>	<to be filled in next report>	<to be filled in next report>	<to be filled in next report>
Landslides	x	x	<to be filled in next report>	<to be filled in next report>	<to be filled in next report>	<to be filled in next report>
Loss of OM in peat soils	x	x	Permanent cropping systems, perennial cropping systems, cereals (iii), minimum tillage (ii), manuring, green manures (i), are known to build-up organic matter. Intensive soil cultivation, growing root crops, and bare fallows are known to decrease SOM levels. Conversion of grassland to arable land is associated with a decrease in SOM; conversion of arable land to grassland into an increase in SOM levels (iii).		stock of peat (Mt); as proxy indicators the water table depth (m), soil moisture content (%), soil temperature (°C) and vegetation type (species) can be considered	<to be suggested>
Loss of OM in mineral soils	x	x	(1) above-ground residue handling; solid recycled organic material (ROM) (2) no-tillage, cover and catch crops (3) conversion to perennial crops	4	- the total carbon stock to 100 cm depth (t ha^{-1}) - the clay: SOC ratio, the topsoil organic carbon content (% or g kg-1) - the topsoil organic carbon stock (t ha^{-1})	<to be suggested>
Soil contamination	x	x	(i) withdrawal of pollutants with phytoremediating (hyper-accumulating) crops (ii) soil amendments which stimulate the biological breakdown or lock-up of organic pollutants (iii) growth of bio-energy crops	3	The top 3 indicators advocated by the ENVASSO project4 are (Huber et al., 2008): - heavy metal contents in soils, - critical load exceedance by sulphur and nitrogen (%) - progress in management of contaminated sites (%). Other possible indicators are: concentration of persistent organic pollutants, topsoil pH, bioavailability of pollutants.	https://esdac.jrc.ec.europa.eu/content/heavy-metals-topsoils New data is available based on the LUCAS Topsoil Survey (2015). The dataset also includes maps of the share of soil samples with heavy metal concentrations above the threshold value.
Soil biodiversity decline	x	x	<to be filled in next report>	<to be filled in next report>	<to be filled in next report>	<to be filled in next report>
Acidification	-	x	<to be filled in next report>	<to be filled in next report>	<to be filled in next report>	<to be filled in next report>

They include soil erosion, salinization, compaction, loss of organic matter (OM) and contamination.

Given the urgency to address soil threats and the opportunity to mitigate some of these threats through the introduction of industrial cropping systems in marginal lands it is logical to further investigate the overlap between M-AEZ and the occurence of soil threats. In this first version of the MAEZ developed in the first year of the MAGIC project we have only classified the marginal lands according to sensitivity to erosion. Erosion is a very important threat for EU soil and in the next is will therefore be discussed to which extend MAEZ overlap with high erosion sensitive areas.

A distinction was made between sensitivity to erosion by by wind and water.

For the wind erosion we used the dataset developed by the JRC (Borrelli et al., 2014). The dataset predicts the susceptibility to wind erosion. The map is based on an Index of Land Susceptibility to Wind Erosion (ILSWE) which was created by combining spatiotemporal variations of the most influential wind erosion factors (See further details in Box 3). For the assessment of understanding the sensitivity to wind erosion of marginal lands it was determined what share of marginal lands overlapped with wind susceptibility classes (in ILSWE) 'High' and 'Very High'

Box 3: Description of the ILSWE dataset predicting wind erosion susceptability of land in Europe (Source: https://esdac.jrc.ec.europa.eu/content/Soil_erosion_by_wind)

The ILSWE is based on the combination of the most influential parameters, i.e. climate (wind, rainfall and evaporation), soil characteristics (sand, silt, clay, CaCO3, organic matter, water-retention capacity and soil moisture) and land use (land use, percent of vegetation cover and landscape roughness). The spatial and temporal variability of factors are appropriately defined through Geographic Information System (GIS) analyses. Harmonised dataset and a unified methodology were employed to suit the pan- European scale and avoid generating misleading findings that could result from heterogeneous input data. The selected soil erosion parameters were conceptually divided into three groups, namely (i) Climate Erosivity, (ii) Soil Erodibility and (iii) Vegetation Cover and Landscape Roughness. Sensitivity to the contributing group of factors was calculated using the fuzzy logic technique, which allows the sensitivity range of each factor in Europe to be unambiguously defined.

Spatial coverage: 28 Member States of the European Union and 8 other European States (three European Union candidate countries (Montenegro, Serbia, the Former Yugoslav Republic of Macedonia), three potential European Union candidate countries (i.e. Albania, Bosnia and Herzegovina, and Kosovo), Norway and Switzerland).

Pixel size: 500m

Projection: ETRS89 Lambert Azimuthal Equal Area

Temporal coverage:1981-2010

For sensitivity for erosion by water the WaTEM/SEDEM spatial database was used which was elaborated by the JRC in collaboration with University of Basel and Universite Catholique de Louvain. To identify the marginal lands with high susceptibility for water erosion we identified which share of the marginal lands overlap with WaTEM class > 100 ton/ha/yr of soil loss. For further details on the WaTEM/SEDEM water erosion risk map see Box 4.

Box 4 Description of the WaTEM/SEDEM dataset predicting water erosion susceptability in Europe (Source: https://esdac.jrc.ec.europa.eu/content/estimate-net-erosion-and-sediment-transport-using-watemsedem-european-union)

The JRC in collaboration with University of Basel and Universite Cathilique de Louvain quantify the potential spatial displacement and transport of soil sediments due to water erosion at European scale. With the WaTEM/SEDEM model long-term averages of annual soil loss and deposition rates were computed. The findings indicate that soil loss from Europe in the riverine systems is about 15% of the estimated gross on-site erosion.

Spatial Coverage: European Union 28 Member States

Resolution: 100m

Time Reference: 2010

Format: Raster (Grid)

Projection: ETRS89 Lambert Azimuthal Equal Area

Input data: RUSLE2015 soil erosion estimates, Digital Elevation Model (DEM) at 25m.

More Information: Sediment transport using WaTEM/SEDEM can be found in: Borrelli et al., 2018.

The estimated sediment yield totals 0.164 ± 0.013 Pg yr-1 (which corresponds to 4.62 ± 0.37 Mg ha-1 yr-1 in the erosion area). The greatest amount of gross on-site erosion as well as soil loss to rivers occurs in the agricultural land (93.5%). The Sediment Delivery Ration (SDR) i.e., the ratio between sediment yield (SY) and gross erosion, indicates that the sediment routed down the hillslopes to the riverine system accounts for 15.3% of the total eroded soil.

5.4 Results

5.4.1 Marginal lands classified according to FARO rurality classes

In Table 13 a distribution is given over the maginal lands distributed over different rural areas types as classified by the FARO typology (Eupen et al., 2012) according to economic density and accessibility.

For the whole of Europe the marginal lands dominate most strongly in the deep rural and rural class. When looking at the distribution of rural classes per environmental zone the same general pattern of strong concentration of marginal lands in deep rural and rural areas is seen (Table 16). In the North ENZ marginal lands are more concentrated in deep rural areas then in rural areas as compared to the distribution in other ENZ. In the Continental ENZ the marginal lands are more concentrated in rural areas then in the deep rural areas which is different in all other ENZs. The ENZs North and Alpine are different from the other ENZs because of the very large dominance of marginal lands in the total agricultural land area.

Table 16 Classification of marginal lands according to rural area types based on FARO typology

Total Europe	Marginal km2	UAA km2	% of marginal area	% marginal of UAA
Deep Rural	358037	934099	52%	15%
Rural	274019	1114129	39%	11%
Peri-Urban	58184	319601	8%	2%
Urban Area	4155	23323	1%	0%
Grand Total	**694395**	**2391152**	**100%**	**29%**

North	Sum of Marginal	Sum of UAA km2	% of marginal area	% marginal of UAA
Deep Rural	69285	87938	54%	39%
Rural	48745	79916	38%	27%
Peri-Urban	8952	10586	7%	5%
Urban Area	432	673	0%	0%
Grand Total	**127414**	**179113**	**100%**	**71%**

Atlantic	Sum of Marginal	Sum of UAA km2	% of marginal area	% marginal of UAA
Deep Rural	108378	304172	56%	15%
Rural	64893	322364	34%	9%
Peri-Urban	17533	96791	9%	2%
Urban Area	1498	7830	1%	0%
Grand Total	**192302**	**731157**	**100%**	**26%**

Alpine	Sum of Marginal	Sum of UAA km2	% of marginal area	% marginal of UAA
Deep Rural	31062	35755	65%	40%
Rural	13402	29574	28%	17%
Peri-Urban	2977	12313	6%	4%
Urban Area	121	439	0%	0%
Grand Total	**47562**	**78081**	**100%**	**61%**

Continental	Sum of Marginal	Sum of UAA km2	% of marginal area	% marginal of UAA
Deep Rural	44763	262430	41%	6%
Rural	53273	403571	49%	7%
Peri-Urban	9004	85329	8%	1%
Urban Area	1115	9944	1%	0%
Grand Total	**108155**	**761274**	**100%**	**14%**

Mediterranean	Sum of Marginal	Sum of UAA km2	% of marginal area	% marginal of UAA
Deep Rural	104549	243804	48%	16%
Rural	93706	278704	43%	15%
Peri-Urban	19718	114582	9%	3%
Urban Area	989	4437	0%	0%
Grand Total	**218962**	**641527**	**100%**	**34%**

5.4.2 Marginal lands classified according to High Nature Value farmland

From the overlay of the marginal lands map with the HNV likelyhood map a statistical summary could be mape per country (see Table 17). It becomes clear that of the marginal land in EU-28 34% is overlapping with HNV farmland. For the nonmarginal land this percentage is only 17%. It implies that when designing industrial cropping systems these need to be tuned in such a way that biodiversity values in an area are respected.

Table 17 Area share of marginal and non-marginal lands overlapping with concentration areas of high nature value farmland in EU-28 countries

	Marginal land	Non-marginal land
COUNTRY	% HNV farmland	% HNV farmland
Austria	63%	36%
Belgium	8%	21%
Bulgaria	61%	19%
Croatia	88%	83%
Czech Republic	19%	15%
Denmark	5%	2%
Estonia	12%	-
Finland	9%	-
France	46%	13%
Germany	17%	9%
Greece*	...	...
Hungary	38%	14%

COUNTRY	Marginal land % HNV farmland	Non-marginal land % HNV farmland
Irish Republic	13%	2%
Italy	53%	15%
Latvia	10%	10%
Lithuania	14%	5%
Luxembourg	1%	4%
Netherlands	32%	7%
Poland	28%	10%
Portugal	48%	44%
Romania	57%	20%
Slovakia	17%	9%
Slovenia	81%	61%
Spain	44%	44%
Sweden	4%	9%
United Kingdom	39%	3%
Grand Total	**34%**	**17%**

*Missing information

There are clear differences in the overlap of HNV farmland with marginal lands between countries. In the countries where the HNV farmland area is large, the share of HNV farmland overlapping with marginal lands is automatically high. The countries with the largest overlap between both marginal and HNV farmlands are Austria, Bulgaria, Croatia, France, Italy, Portugal, Romania, Slovenia and Spain. It is striking that in most countries HNV farmland is strongly overrepresented in marginal land as compared to non-marginal. Exceptions to this are few such as Sweden, Portugal, Luxembourg, Latvia and Belgium.

When looking at the overlap between marginal lands and HNV farmland per environmental zone the largest overlap is found in the Alpine and the Mediterranean zone (Table 18).

Table 18 Area share of marginal and non-marginal lands overlapping with concentration areas of high nature value farmland per Environmental zone

ENRNAME	Marginal land % HNV farmland	Non-marginal land % HNV farmland
ALPINE	75%	61%
ATLANTIC	33%	6%
CONTINENTAL	34%	15%
MEDITERRANEAN	40%	30%
NORTH	8%	7%
Grand Total	34%	17%

When looking at the type of marginality constraints having the largest overlap with HNV farmland (Table 19) it is clear that HNV farmland is most strongly overlapping with areas where a terrain constraint applies. It also becomes clear that the overlap with HNV farmland is higher when multiple marginal constraints apply.

Table 19 Area share of marginal constraints combination overlapping with HNV farmland

Marginal constraints	Sum of KM2	% HNV
Rooting	160526	28%
Climate	113740	21%
Wetness	109254	28%
Terrain	52236	46%
Rooting - Terrain	37753	56%
Climate -Rooting	33424	42%
Climate - Wetness	30395	38%
Fertility	23643	18%
Chemical	22539	26%
Climate -Fertility	18387	26%
Climate - Wetness -Rooting - Terrain	16969	74%
Climate -Rooting - Terrain	14944	66%
Climate -Terrain	13987	59%
Wetness -Rooting	13230	28%
Climate - Wetness -Rooting	5899	37%
Climate - Wetness -Terrain	4741	75%
Climate -Fertility -Rooting	4441	30%
Wetness -Terrain	2975	68%
Fertility -Rooting	2163	21%
Climate - Wetness - Fertility	1959	51%
Wetness -Rooting - Terrain	1382	82%
Wetness - Fertility	1202	60%
Climate -Chemical	1173	19%
Fertility - Chemical	1151	56%
Chemical -Terrain	979	35%
Climate - Wetness - Fertility -Rooting	932	20%
Climate - Wetness - Fertility -Rooting - Terrain	838	69%
Climate -Fertility -Terrain	759	50%
Chemical - Rooting	582	19%
Climate -Fertility -Rooting - Terrain	499	60%
Wetness -Chemical	430	57%
Climate - Wetness - Fertility -Terrain	418	65%
Climate -Fertility - Chemical	244	33%
Fertility -Terrain	226	29%
Wetness - Fertility -Rooting	97	56%
Wetness - Fertility -Terrain	78	63%
Climate -Chemical - Rooting	54	6%
Fertility -Rooting - Terrain	49	47%

Marginal constraints	Sum of KM2	% HNV
Chemical - Rooting - Terrain	44	20%
Climate -Chemical -Terrain	18	44%
Fertility - Chemical -Terrain	18	67%
Fertility - Chemical - Rooting	11	18%
Climate - Wetness -Chemical	5	0%
Wetness - Fertility - Chemical	1	100%
Total	**2391152**	**22%**

5.4.3 Marginal lands classified according to soil threat erosion risk

Marginal lands do not seem to be more sensitive to erosion than non-marginal lands. Actually soil erosion risk by water is higher in non-marginal lands. On average in the whole EU 16% of the marginal lands is classified as high risk for wind erosion and 13% for erosion by water. In some countries the marginal land share overlapping with high erosion risk for water is much higher; e.g. Italy, Greece, Luxembourg, Slovakia. The erosion risk for wind in marginal lands is particularly high in Denmark, Spain, Greece, Bulgaria and France.

Table 20 Overlap between marginal lands and areas sensitive to erosion by water and wind

	Marginal land		Not marginal	
COUNTRY	% sensitive to erosion by water	% sensitive to erosion by wind	% sensitive to erosion by water	% sensitive to erosion by wind
Austria	23%	7%	28%	3%
Belgium	5%	6%	14%	3%
Bulgaria	14%	22%	24%	31%
Croatia	9%	0%	4%	0%
Czech Republic	25%	2%	31%	3%
Denmark	1%	53%	3%	55%
Estonia	0%	0%	0%	0%
Finland	1%	1%	0%	0%
France	16%	21%	17%	9%
Germany	6%	2%	17%	2%
Greece	30%	23%	30%	21%
Hungary	5%	1%	17%	1%
Irish Republic	1%	5%	5%	2%
Italy	54%	12%	41%	11%
Latvia	1%	0%	1%	0%
Lithuania	3%	0%	2%	0%
Luxembourg	35%	0%	28%	0%

COUNTRY	Marginal land % sensitive to erosion by water	Marginal land % sensitive to erosion by wind	Not marginal % sensitive to erosion by water	Not marginal % sensitive to erosion by wind
Netherlands	0%	3%	0%	14%
Poland	5%	1%	12%	1%
Portugal	23%	0%	18%	0%
Romania	20%	14%	33%	31%
Slovakia	34%	6%	34%	2%
Slovenia	22%	0%	21%	0%
Spain	27%	28%	26%	19%
Sweden	3%	12%	5%	72%
United Kingdom	6%	7%	5%	20%
Grand Total	**16%**	**13%**	**20%**	**12%**

When looking at the environmental zones with highest erosion risk land shares in marginal land (see Table 21) this is the Mediterranean zone followed by the Alpine zone. This is not surprising as erosion risk areas are most dominant in general in these environmental zones.

Table 21 Overlap between marginal lands and areas sensitive to erosion by water and wind per environmental zone

ENRNAME	Marginal land % sensitive to erosion by water	Marginal land % sensitive to erosion by wind	Not marginal % sensitive to erosion by water	Not marginal % sensitive to erosion by wind
ALPINE	22%	11%	18%	2%
ATLANTIC	7%	6%	12%	8%
CONTINENTAL	11%	7%	20%	12%
MEDITERRANEAN	33%	27%	32%	17%
NORTH	2%	4%	3%	2%
Total	**16%**	**13%**	**20%**	**12%**

The type of marginal constraints with the largest share of land overlapping with high erosion risk areas are presented in Table 22. It becomes clear that erosion risk by water is particularly large in marginal lands determined by limitations in terrain (steep slopes), which can be expected, but also often in marginal lands where climate is one of the constraints. The latter climate limitation is related to dryness and Mediterranean areas that have higher erosion risk problems often cope with dryness.

Table 22 Overlap between marginal lands and areas sensitive to erosion by water and wind per type of marginal constraint

	Marginal land (km2)	% sensitive to erosion by water	% sensitive to erosion by wind
Rooting	160526	20%	12%
Climate	113740	8%	10%
Wetness	109254	4%	5%
Terrain	52236	38%	10%
Rooting - Terrain	37753	24%	11%
Climate -Rooting	33424	20%	23%
Climate - Wetness	30395	2%	4%
Fertility	23643	25%	25%
Chemical	22539	13%	28%
Climate -Fertility	18387	23%	39%
Climate - Wetness -Rooting - Terrain	16969	23%	22%
Climate -Rooting - Terrain	14944	24%	14%
Climate -Terrain	13987	21%	12%
Wetness -Rooting	13230	6%	1%
Climate - Wetness -Rooting	5899	2%	39%
Climate - Wetness -Terrain	4741	17%	18%
Climate -Fertility -Rooting	4441	28%	52%
Wetness -Terrain	2975	8%	12%
Fertility -Rooting	2163	26%	26%
Climate - Wetness - Fertility	1959	1%	5%
Wetness -Rooting - Terrain	1382	16%	7%
Wetness - Fertility	1202	2%	6%
Climate -Chemical	1173	31%	36%
Fertility - Chemical	1151	5%	11%
Chemical -Terrain	979	15%	7%
Climate - Wetness - Fertility -Rooting	932	1%	48%
Climate - Wetness - Fertility -Rooting - Terrain	838	14%	8%
Climate -Fertility -Terrain	759	14%	6%
Chemical - Rooting	582	19%	25%
Climate -Fertility -Rooting - Terrain	499	19%	7%
Wetness -Chemical	430	4%	7%
Climate - Wetness - Fertility -Terrain	418	22%	21%
Climate -Fertility - Chemical	244	41%	73%
Fertility -Terrain	226	24%	17%
Wetness - Fertility -Rooting	97	3%	4%
Wetness - Fertility -Terrain	78	14%	31%
Climate -Chemical - Rooting	54	41%	61%
Fertility -Rooting - Terrain	49	22%	22%
Chemical - Rooting - Terrain	44	16%	5%
Climate -Chemical -Terrain	18	11%	17%
Fertility - Chemical -Terrain	18	0%	6%
Fertility - Chemical - Rooting	11	0%	0%

	Marginal land (km2)	% sensitive to erosion by water	% sensitive to erosion by wind
Climate - Wetness -Chemical	5	0%	20%
Wetness - Fertility - Chemical	1	0%	0%
Grand Total	**2391152**	**19%**	**12%**

The overlap in erosion risk by wind with marginal lands is again particularly high where climate is one of the limiting factors. This is likely to be related with the fact that extreme climate, too cold or too dry, often overlaps with high wind speed and/or open landscapes.

6 Conclusions and further steps

6.1 Introduction

In MAGIC a first EU wide map is created to assess options for sustainable use of marginal lands to grow industrial crops.

The approach for mapping and presented in this report builds on the JRC work to identify Areas of Natural Constraints (ANCs) (Van Oorschoven et al., 2014 and Terres et al., 2014) and other land evaluation systems for agronomic suitability. The results describe the location and amount of marginal land area across Europe and what the main characteristics are in terms of biophysical and socio-economic limitations. This classification serves as a basis for developing sustainable best-practice options for industrial cropping in Europe on marginal lands.

To come ot thec first mapped result in WP2 the work was organised as follows: a) definition, classification and identification of data was done and best approaches for mapping of marginal land in 2015, 2020 and 2030 were designed b) the second step was the actual mapping of current marginal land and the main characteristics taking into account in natural constraints with regard to soil, climate and topographic factors. The combined outcome is a mapped Marginal Agro-Ecological Zonation (M-AEZ) of Europe.

Additional descriptive characteristics covered sofar in this report include aspects other than natural constrains such as regional rural classification, dominant land cover classes and agricultural activities, overlap with High Nature Value farmland and key soil threats such as erosion by water and wind. In this report the first version of the M-AEZ is presented. Different succeeding versions of a spatially explicit database (MAPDB) will be developed in next year's however. In every new version of the database an increasing amount of characteristics is added to the land strata of the M-AEZ classification. MAP-DB will be uploaded on the project website and will be maintained there during the project lifetime and at least five years beyond the project completion.

6.2 Mapping results sofar

Biophysical factors have been identified for the classification of severe limitations; 18 single factors, grouped into 6 clustered factors:

- Adverse climate (low temperature and/or dryness)

- Excessive wetness (Limited soil drainage or excess soil moisture)
- Low soil fertility (acidity, alkalinity or low soil organic matter)
- Adverse chemical conditions (Salinity or contaminations)
- Poor rooting conditions (low rootable soil volume or unfavourable soil texture)
- Adverse terrain conditions (steep slopes, inundation risks)

The land units were identified with biophysical factors within the 20% margin of the threshold value of severity. This allows to map pair-wise limitations. When two factors are within this 20% margin the land units were classified from sub-severe to severe.

A correction was made by excluding areas where natural constraints were neutralized via measures such as fertilisation, irrigation, drainage and creation of terraces. Different spatial data sources were used to identify the marginal lands where land improvements were made and intensive agricultural production now occurs.

The results of the mapping of marginal lands are presented in Figure 5 and examples are given of marginal land mapping in 3 different regions of the EU. In Scotland the main limitations making up marginal lands are excessive wetness, climate limitations in terms of short growing season and limitations in rooting. The marginal lands in Hungary are characterized by multiple limiting factors both occurring besides or in combination and include high salinity, limitations on fertility, excessive wetness and rooting limitations. The same applies for the selected area of the Ebro region. All six clusters of limitations are very common in this region often occurring in combination in the same location.

In total 29% of the agricultural area is marginal in EU-28. The most common are rooting limitations, with 12% of the agricultural area after correction for improvement. This is followed by adverse climate and excessive soil moisture occurring in respectively 11% and 8% of the agricultural land. The largest share of marginal lands is defined by one of the six clustered limitations, while in a much smaller share multiple limitations occur.

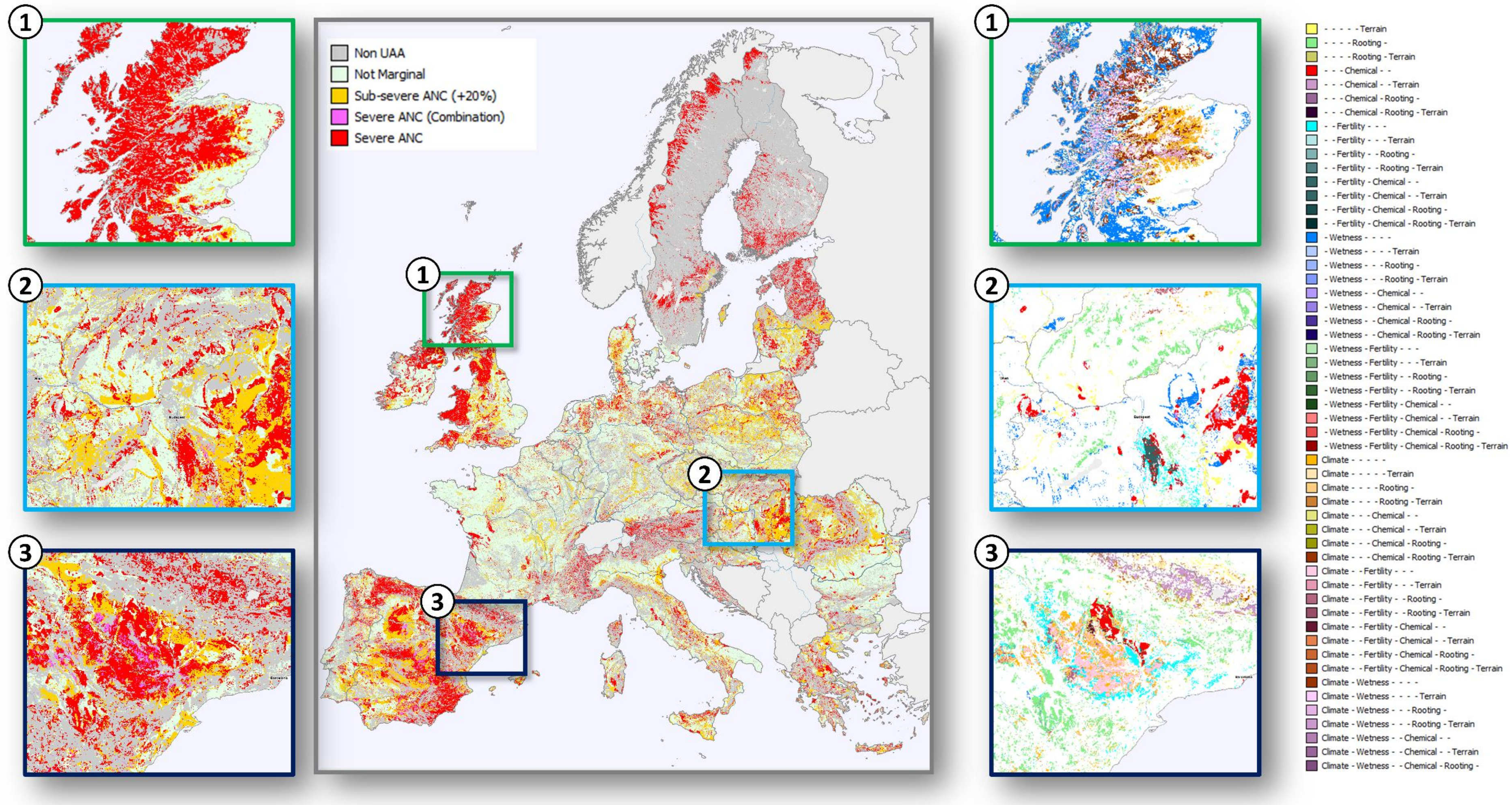


Figure 5 First Map of marginal lands in EU-28. Selected windows: Dominant severe limitations: 1) Scotland; excessive wetness, climate, limitations in rooting. 2) Hungary: multiple limiting factors salinity, fertility, excessive wetness and rooting limitations. 3) Ebro Valley: large concentration of multiple overlapping limitations (all six factors).

6.3 Further development of a spatially explicit database on Marginal lands in Europe

This report presents the first version of the marginal land for the EU-28. The combined outcome is a mapped Marginal Agro-Ecological Zonation (M-AEZ) of Europe based on biophysical limitations in land.

In every new version of the M-AEZ the quality of the data contained will improve and grow as more evaluation and validation of results has been done and an increasing amount of characteristics is added to the marginal land strata. The current M-AEZ is made available to WP1 and 4 and is accessible in an ESRI viewing tool and the M-AEZ will also be up-dated with further validated and refined results in years 2, 3 and 4 of the project.

MAP-DB of the M-AEZ is made accessible in the project website and through the development and incorporation into MAGIC-DSS in WP 1 of the project. Currently the MAP-DB is already made available for internal use through the ESRI data viewer. This enables clicking on marginal land polygons to obtain information on the biophysical constraints determining the marginal land denomination. The same information is also made available to user outside the project at the level of Nuts 3 regions. This enables obtaining information on any region of the EU on the area of marginal land and the contribution of the different biophysical limitations.

There are 4 activities planned for the next year to further improve and refine the M-AEZ:

1) The first next step is to extend the current map to include marginal lands in Ukraine. Sofar this was postponed because not all data layers used to map the marginal lands in EU-28 were available for the Ukrainian territory. Currently the data gaps are being filled and the Ukraine marginal lands will soon be included in the M-AEZ.

2) The second step that is currently implemented simultaneously with the former is the inclusion of chemical limitation factors by metals which can both have a natural and a human origin. For further details on approach and needs see separate section underneath.

3) For the identified mapped marginal lands further evaluation and validation will be done to determine the quality of the current mapped result and to further improve the mapping. This will be addressed in several ways. Firstly through validation of segments (grids) of the M-AEZ. This will be done by different partners in the project using national and regional high resolution data (including satelite based

information) to overlay with the M-AEZ. From this overlay it can be established how well the different biophysical limitation layers and land management improvement layers are representing the real situation on the ground. Secondly, we will involve in WP1 citizen science. The M-AEZ will be made available through the ESRI viewing tool and in a GEO-WIKI. Citizens are then asked delivering reality checked information back on a specific site selected regarding type of soil limitations occurring and types of current land uses occurring through which directly and indirectly the correctness of the M-EAZ can be established.

4) For the identified marginal lands, further characterization and stratification particularly in relation to current land uses and state of abandonment should be done. This is necessary to better understand the sustainable options for using the lands for industrial cropping. Additional descriptive characteristics will cover aspects other than natural constrains (demographic regional characterization, dominant agricultural activities, etc.) also by using assessments done for the Agri-environmental Indicators (Eurostat, EEA) and the mapping of ecosystem services (MAES).

5) The changes in marginal land in Europe between 2015 and 2020 and 2030 will be assessed by using a large variation in already modelled scenario studies with the GLOBIOM model. This however, will happen in the third year in the project and is not discussed further in this report.

As to 4) further ideas exist the meaningful further stratification of marginal lands in relation to understanding better sustainable industrial cropping options. In the Table 23 suggestions are given for descriptive characteristics that support a risk evaluation and identification of co-benefits of industrial cropping options on marginal lands in relation to the sustainability aspects mentioned above. It is also indicated in the Table 23 when this aspect is to be addressed in the project.

Table 23 Descriptive characteristics according to which marginal lands identified in MAGIC need to be classified in order to support the analysis of their sustainable use for industrial crops

Sustainability aspect	Relevant classification factor	Why relevant?	When and how addressed
Risk for competition with food production and direct and indirect land use changes	Current uses	Avoid competition with food	Year 2: collect as spatially detailed information from national and EU sources and satellite information providing better understanding on land uses, intensity of uses, absence of uses
	Abandonment status	Avoid competition with food	Idem, as above
	Access to markets	Lower transport cost in delivery chain or focus on feedstock delivery to local markets instead of urban markets	Year 1, already done through overlay with FARO rural typology. Further attention in WP7 in logistical case studies
	Accessibility		Idem, as above
	Status of infrastructure present in region		Idem, as above
	Access to land, land ownership	Reaching large enough and secure feedstock delivery chains to make it economically feasible	Year 2/3: Through collection of data on land ownership ditribution. Likely to be accessible in a selection of regions not EU-wide
Risk for negative & potential positive effects of land conversion to industrial crops on biodiversity and other ecosystem services	Presence of protected nature areas (e.g. Natura2000, wetlands)	Loss of biodiversity through industrial cropping should be avoided	Year 1 & 2: Further data overlays will be made with protected area sites and detailed sptaily explicit information on sites of high biodiversity value.
	Presence of HNV farmlands		Overlay with HNV farmland was already made in year 1 (see this report)
	Erosion risk	Industrial cropping solutions should not adversely affect but rather positively contribute improving soil and water resources.	Overlay with erosion risk areas was already made in year 1 (see this report)
	Water protection areas		Spatially detailed information on water protection areas will be collected and overlayed with current M-AEZ
	Leaching risk		Idem as above
	Water depletion risk		Year 3: Spatial Assessments will be made with spatial information on current water use levels and options for additional sustainably available water resources to indicate where industrial crops can be grown with and only without irrigation

Sustainability aspect	Relevant classification factor	Why relevant?	When and how addressed
Type of industrial crops and management systems to be used	Bio-physical constraints (climatic, soil and terrain limitations as mentioned above)	Industrial crop types and management systems need to be designed that are best adapted to the soil and climatic characteristics in marginal lands. This requires detailed data on soil and climate per marginal land class in every environmental zone in Europe.	Outcome of the current M-AEZ in year 1 (see this report). M-AEZ already used for the selection of crop types and testing sites (see D4.1 Cossel et al., 2018)
	Relative accessibility	The infrastructural circumstances have important influence on the organisation of the logistics in a feedstock delivery chain	Further attention in WP7 in logistical case studies
	Infrastructure present		Further attention in WP7 in logistical case studies
	Population development & ageing	Regions with declining and ageing populations need new sources of income to stop population decline	Year 2: Further refinement of classification according to FARO typology by adding demographic indicators based on regional statistics
Contribution to rural development	Employment opportunities	In regions with limited economic activities the need for finding alternative income options is larger	Year 2: Further refinement of classification according to FARO typology by adding demographic indicators based on regional statistics
	Dependency on agricultural sector, agricultural income & dependency on subsidies	If a region has a large dependency on agriculture and income is low there is need for alternative income opportunities with higher returns	Year 2: Further refinement of classification according to FARO typology by adding demographic indicators based on regional statistics
	Land abandonment	Abandonment is indicator for declining agricultural sector and indicates toward the need to find alternative income opportunities and also indicates towards opportunity gaps for industrial cropping.	Idem as above

6.3.1 Marginal lands identified according to metal contaminations

In MAGIC contaminated soils and sites will be included in the M-AEZ classification. In the first instance we will focus on metals in agricultural soils, these can be natural background contaminations, but can also be caused by humans as a result of mining and municipal and industrial wastes (Toth, et al., 2015; Reiman et al., 2014). In the second step (to be implemented in 2019, contaminated sites outside agricultural lands will also be mapped.

The metal content of agricultural soils will be included in the M-AEZ as an extra variable in the group of adverse chemical composition limitation group. High metal content in agricultural soils can be seen as a soil limitation, even though the source maybe human induced.

GEMAS data (Reiman et al., 2014) together with LUCAS soil data are likely to be the best data to be used for the mapping of metal levels and/or contaminations in agricultural. Since these data are all point source data we will need to work with extrapolated data. Extrapolated data are available to the MAGIC project and are currently collected.

WP 4 will work on trials with industrial crops to bring down metal contamination in soils. WP4 needs a further understanding of where the main contamination areas are for four main metals (and in what combination with soil characteristics they occur. Focus will therefore be on cadmium, zinc, lead and nickel as is already decided in WP4. Cadmium has several more anthropogenic sources. It is a wide spread contamination problem as it occurs where too intensive phosphate fertilization has taken place. It can be seen as a large contamination problem worldwide. Hyper-accumulation in plants applies more to nickel.

For WP 4 an overview will be generated of what are the top metal contaminations (for these four metal types) in Europe in terms of area share in marginal agricultural lands and in terms of type of metals and contamination levels.

Since the focus in WP 4 on bioremediation options with industrial crops it will also need to be decided what type of soils are most commonly occurring in the main contamination areas. Soil characteristics are very influential on whether plants can take up the metals easily. Particularly the pH level is important which is strongly influenced by the presence of calcium.

Soil characteristics in combination with metal contaminations are very relevant to understand better the behavior of bioremediation options and will therefore be mapped in combination.

In year 3 of the project the mapping of marginal lands outside agricultural lands will obtain more attention in WP2 and this implies that data will also be collected to identify contaminated sites. In these contaminated sites the biophysical constraints do not have a natural cause, but are caused by waste disposal, industrial and mining activities such as for oil extraction and production, and power plants, military sites and war affected zones, storages of chemical substances like oil and obsolete chemicals, transport spills on land (oil spill sites and other hazardous substance spills sites), nuclear sites and other sources. Some of these site may be interesting to be used for industrial crops, particularly for crops that can also be used for bioremediation on these sites (Fernando, 2005, Lewandowski et al. 2016, Cadoux et al., 2011; Hartley et al., 2009; Técher et al., 2012).

It is however a challenge to obtain a complete picture of contaminated sites in Europe as not all countries have provided data to the survey request organised through the EEA EOINET and the ESDAC and the data refer to point information and do not provide area estimates. However, the coverage is improving every year. Panagos et al. (2013) reported the status based on reports from 33 European countries and extrapolated the results to all 38 European countries. In our next steps toward mapping marginal lands outside agricultural lands we will certainly build on the data sources described above.

References

Alcantara, C., Kuemmerle, T., Baumann, M., Bragina,E., Griffiths, P., Hostert, P., Knorn, J, Muller, D., Prishchepov A., Schierhorn, F., Sieber, A. & Radeloff, V. (2013). Mapping the extend of abandoned farmland in Central and Eastern Europe using MODIS time series satellite data. Environ. Res. Lett. 8 (2013) 035035 (9pp). doi:10.1088/1748-9326/8/3/035035

Andersen, E., Baldock, D., Bennett, H., Beaufoy, G., Bignal, E., Brouwer, F., Elbersen, B., Eiden, G., Godeschalk, F., Jones, G., McCracken, D.I., Nieuwenhuizen, W., van Eupen, M., Hennekens, S. & Zervas, G. 2003. Developing a high nature value indicator. Report for the European Environment Agency. Copenhagen. Further work of the EEA and JRC is documented under: http//eea.eionet.europa.eu/Public/irc/envirowindows/hnv/library.

Bai, Z. G.; Dent, D. L.; Olsson, L.; Schaepman, M. E. Proxy Global Assessment of Land Degradation. Soil Use Manage. 2008, 24 (3), 223–234.

Berge, H.F.M. ten, Schroder, J.J., Olesen, J.E. and Giraldez Cervera, J.V. 2017, Research for AGRI Committee – Preserving agricultural soils in the EU, European Parliament, Policy Department for Structural and Cohesion Policies, Brussels.

Borrelli, P., Panagos, P., Ballabio, C., Lugato, E., Weynants, M. Montanarella, L (2014). Towards a pan-European assessment of land susceptibility to wind erosion. Land Degradation & Development, In Press. DOI: 10.1002/ldr.2318

Borrelli, P., Van Oost, K., Meusburger, K., Alewell, C., Lugato, E., Panagos, P. 2018. A step towards a holistic assessment of soil degradation in Europe: Coupling on-site erosion with sediment transfer and carbon fluxes. Environmental Research, 161: 291-298.

Cai, X., Zhang, X., & Wang, D. (2011). Land availability for biofuel production. Environmental Science and Technology, 45(1), 334e339. http://dx.doi.org/10.1021/es103338e.Dankers, R. and L. C. D. Feyen (2009). "Flood hazard in Europe in an ensemble of regional climate scenarios. Journal of Geophysical Research: Atmospheres 114(D16). DOI 10.1029/2008JD011523

EC-Eurostat (2017). Statistics Explained (http://ec.europa.eu/eurostat/statisticsexplained/) - 02/06/2017

European Commission, Eurostat (2017). Regional typologies overview. Statistics Explained (http://ec.europa.eu/eurostat/statisticsexplained/) - 02/06/2017

Elbersen, B., Van Eupen, M., Verzandvoort, S., Boogaard, H., Mucher, S., Cicarreli, T., Elbersen, W., Mantel, S., Bai, Z., MCallum, I., Iqbal, Y., Lewandowski, I., Von Cossel, M., Carrasco, J., Ramos, C.C., Sanz, M., Ciria Ciria, P., Monti, A., Consentoni, S., Scordia, D., Eleftheriadis, I., 2018a. Methodological approaches to identify and map marginal land suitable for industrial crops in Europe (EU deliverable-not published yet) (No. 2.6). WUR, Wageningen, Netherlands.

Elbersen, B., Van Verzandvoort, M., Boogaard, S., Mucher, S., Cicarelli, T., Elbersen, W., Mantel, S., Bai, Z., MCallum, I., Iqbal, Y., Lewandowski, I., Von Cossel, M., Carrasco, J., Ramos, C.C., Sanz, M., Ciria, P., Monti, A., Consentino, S., Scordia, D., Eleftheriadis, I., 2018b. Definition and classification of marginal lands suitable for industrial crops in Europe (EU deliverable-not published yet) (No. 2.1). WUR, Wageningen, Netherlands.

Esch Van der S, ten Brink B, Stehfest E, Bakkenes M, Sewell A, Bouwman A, Meijer J, Westhoek H and van den Berg, M (2017). Exploring future changes in land use and land condition and the impacts on food, water, climate change and biodiversity: Scenarios for the Global Land Outlook. PBL Netherlands Environmental Assessment Agency, The Hague. http://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2017-exploring-future-changes-in-land-use-and-land-condition-2076.pdf

Eupen, M., Metzger, M.J.; Perez-Soba, M; Verburg, P.; van Doorn, A. & Bunce, R.G.H. (2012). A rural typology for strategic European policies. Land use Policy 29 (2012) p. 473-482.

Fernando, A. (2005). Fitorremediacao por Miscanthus x giganteus de solos contaminados com metais pesados, PhD Thesis, Universidade Nova de Lisboa, Lisbon.

Fischer, G., Velthuizen, H., Shah, M., and Nachtergaele, F. (2002). Global agro-ecological assessment for agriculture in the 21st century. Methodology and results. International Inst. for Applied Systems Analysis, Laxenburg, Austria.

Fischer, G., Hizsnyik, E., Prieler, S., Shah, M., and Velthuizen, H. (2009). Biofuels and food security – implication of accelerated biofuels production. Summary of the OFID study prepared by IIASA, Vienna, Austria.

Fischer, G., Prieler, S., Velthuizen, H., Berndes, G., Faaij, A., Londo, M., and Wit, M. (2010). Biofuel production potentials in Europe. Sustainable use of cultivated land and pastures, Part II: Land use scenarios. Biomass and Bioenergy, 34, 173-187.

Food and Agricultural Organisation (FAO), Consultative Group on International Agricultural Research (CGIAR), (1999); Research Priorities for Marginal Lands, the Framework for Prioritizing Land Types in Agricultural Research, the Rural Poverty and Land Degradation: A Reality Check for the CGIAR; CHAPTER 2 - DEFINITIONS AND CONTEXT. Document No.:SDR/TAC:IAR/99/12

Hengl, T., Mendes de Jesus, J., Heuvelink, G. B.M., Ruiperez Gonzalez, M., Kilibarda, M. et al. (2017) SoilGrids250m: global gridded soil information based on Machine Learning. PLoS ONE 12(2): e0169748. doi:10.1371/journal.pone.0169748

Jannes Stolte, Mehreteab Tesfai, Lillian Øygarden,Sigrun Kværnø (NIBIO); Jacob Keizer, Frank Verheijen (University of Aveiro); Panos Panagos, Cristiano Ballabio (JRC); Rudi Hessel (Alterra WUR) Soil threats in Europe, 2016. Status, methods, drivers and effects on ecosystem services. EUR 27607 EN. https://esdac.jrc.ec.europa.eu/public_path/shared_folder/doc_pub/EUR27607.pdf

Lewandowski, I., 2016. The Role of Perennial Biomass Crops in a Growing Bioeconomy, in: Perennial Biomass Crops for a Resource-Constrained World. Springer International Publishing AG, Cham, pp. 3–13.

Lewandowski, I., Clifton-Brown, J., Trindade, L.M., Van Der Linden, G., Schwarz, K.-U., Müller-Sämann, K., Anisimov, A., Chen, C.-L., Dolstra, O., Donnison, I.S., 2016. Progress on optimizing miscanthus biomass production for the European bioeconomy: Results of the EU FP7 project OPTIMISC. Front. Plant Sci. 7, 1620.

Lewandowski, I., Lippe, M., Castro-Montoya, J., Dickhöfer, U., Langenberger, G., Pucher, J., Schließmann, U., Derwenskus, F., Schmid-Staiger, U., Lippert, C., 2018. Primary Production, in: Bioeconomy. Springer, Cham, pp. 95–175. https://doi.org/10.1007/978-3-319-68152-8_6

Louwagie, G., Gay, S., and Burrell, A. (2009). Addressing soil degradation in EU agriculture: Relevant processes, practices, and policies. Report on the project "Sustainable agriculture and soil conservation (SoCo)." JRC Scientifi c and Technical Reports. Office for Official Publications of the European Communities, Luxembourg.

Mantel, S., Kauffman, J.., 1995. Agricultural suitability of reference soils (The automated land evaluation system applied to ISRIC soil information system).

Mantel, S. and J. H. Kauffman (1995). Agricultural suitability of reference soils. The Automated Land Evaluation System applied to ISRIC Soil Information System. Working Paper and Preprint 95/13. ISRIC. Wageningen ISRIC. p.27.

Mantel, S., Bindraban, P., DeHeu, B. (2010). Background document for comitology with a proposal for a clear, unambiguous and practical definition of 'severely degraded land' and 'heavily contaminated land'. Task 3, degraded land, final Report. Project Support Activities for the Development of Practical Measures to Facilitate the Implementation of the Biofuels Sustainability Scheme. Wageningen, ISRIC, Ecofys: 26.

Metzger, M.J., Bunce, R.G.H., Jongman, R.H., Mücher, C.A., Watkins, J.W., 2005. A climatic stratification of the environment of Europe. Glob. Ecol. Biogeogr. 14, 549–563.

Meuller, L., Schindler, U., Behrendt, A., Eulenstein, F. & Dannowski, R. (2010). The Meuncheberg Soil Quality Rating (SQR). Field manual for detecting and assessing properties and limitations of soils for cropping and grazing. Leibniz-Centre for Agricultural Landscape Research (ZALF) e. V., Muencheberg, Germany

Montanarella, L., Tóth, G., 2008. Desertification in Europe, in: 15th International Congress of the International Soil Conservation (ISCO Congress) Soil and Water Conservation, Climate Change and Environmental Sensitivity. Citeseer.

OECD, 2006. The New Rural Paradigm, Policies and Governance. OECD Rural Policy Reviews. OECD Publishing, Paris, 168 pp.

OECD, 2007. OECD Regions at a Glance: 2007 Edition. OECD Publishing, Paris, 252 pp.

OECD, 2009. OECD Regions at a Glance: 2009 Edition. OECD Publishing, Paris, 196 pp.

Oenema, O. , M. Heinen, R. Rietra and R. Hessel (eds.), 2017. Review of soil-improving cropping systems (SICS). Deliverable 2.1 of the EU SOILCARE project (in pub.).

Panagos, P., Van Liedekerke, M., Jones, A., Montanarella, L., 2012. European Soil Data Centre: Response to European policy support and public data requirements. Land Use Policy 29, 329–338. https://doi.org/10.1016/j.landusepol.2011.07.003

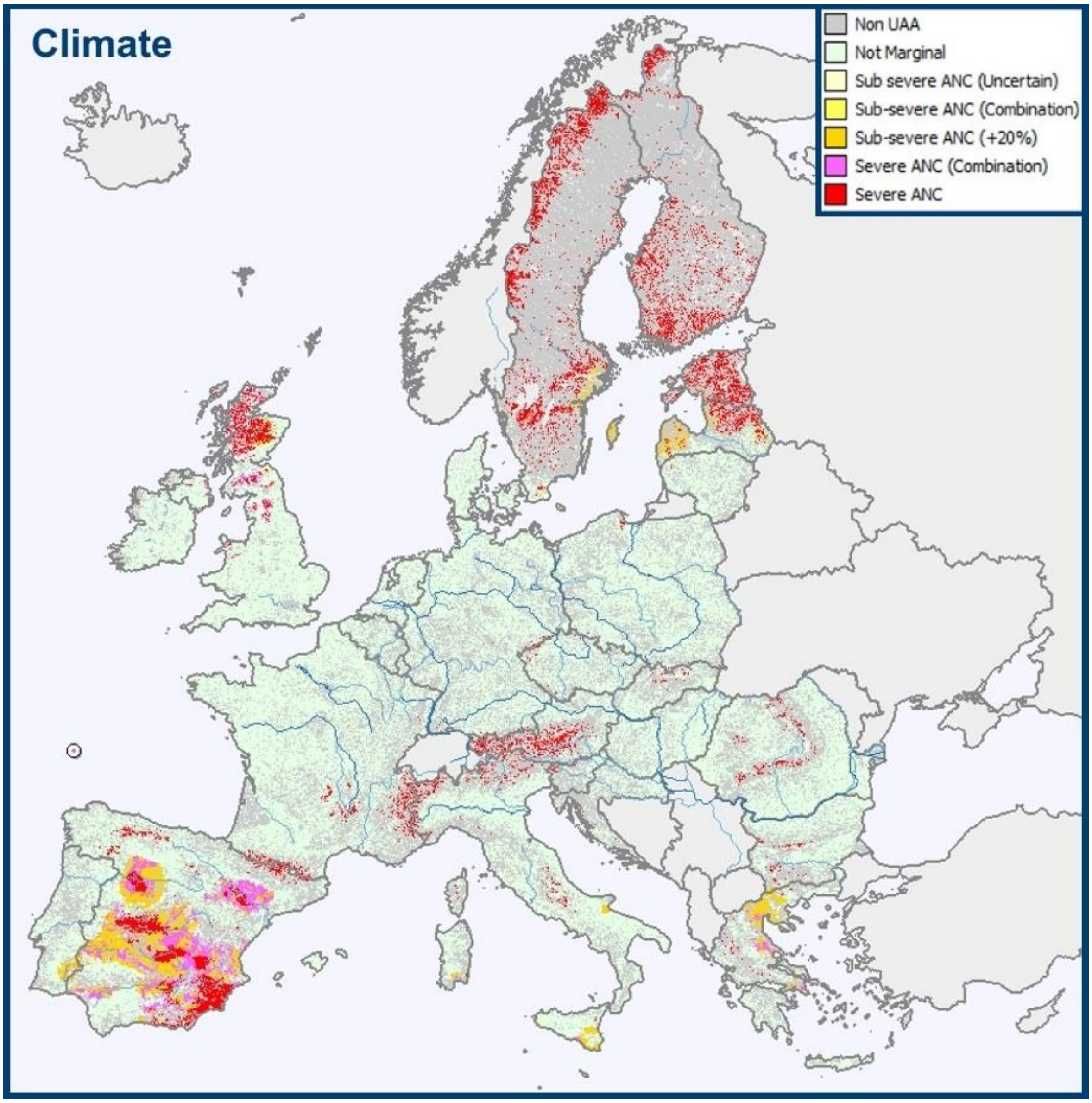
Paracchini, M. L.; Petersen, J.-E.; Hoogeveen, Y.; Bamps, C.; Burfield, I. and van Swaay, C., 2008. High Nature Value Farmland in Europe. An estimate of the distribution patterns on the basis of land cover and biodiversity data.

JRC Scientific and Technical Reports. European Communities, Luxembourg http://agrienv.jrc.ec.europa.eu/activities_HNV.htm
Pasaresi, M., Ehrlich, D., Ferri, S., Florcyk, A.J., Freire, S., Halkia, M., Julea, A., Kemper, T. Soille, P. & Syrris, V. (2016). Operating procedure for the production of the Global Human Settlement Layer from Landsat data of the epochs 1975, 1990, 2000, and 2014. JC Technical Reports. EUR 27741 EN.
Pérez-Soba M. · Elbersen B. · Kempen M. · Braat L. · Staristky I. · Wijngaart R. van der · Kaphengst T. · Andersen E. · Germer L. · Smith L. · Rega C. · Paracchini M.L. (2015). JRC Technical Report: Agricultural biomass as provisioning ecosystem service: quantification of energy flows.
Scarlat, N., Dallemand, J.-F., Monforti-Ferrario, F., Nita, V., 2015. The role of biomass and bioenergy in a future bioeconomy: policies and facts. Environ. Dev. 15, 3–34.
Schäfer-Landefeld, L., Brandhuber, R., Fenner, S., Koch, H.-J., Stockfisch, N., 2004. Effects of agricultural machinery with high axle load on soil properties of normally managed fields. Soil Tillage Res. 75, 75–86. https://doi.org/10.1016/S0167-1987(03)00154-5
Terres, J.-M., Hagyo, A., Wania, A., Confalonieri, R., Jones, R., van Diepen, K., Van Orshoven, J., 2014. Scientific contribution on combining biophysical criteria underpinning the delineation of agricultural areas affected by specific constraints: Methodology and factsheets for plausible criteria combinations.
Terres J.M., Anguiano E, Nisini L (2013) Assessing the risk of farmland abandonment in the EU Technical assistance to define key factors and drivers, process data sets and provide results Administrative Arrangement #AGRI-2011-0295 between DG Agriculture and Rural Development and JRC Study on farmland abandonment – Deliverable 1
Toth G, Adhikari K, Varallyay Gy, Toth T, Bodis K, Stolbovoy V. Updated map of salt affected soils in the European Union. in: Toth, G., Montanarella, L. and Rusco, E. (eds.) Threats to Soil Quality in Europe EUR 23438 EN, Office for Official Publications of the European Communities; Luxembourg 2008, p 65-77
Tóth, G., Hermann, T., Da Silva M.R., Montanarella, L. (2016). Heavy metals in agricultural soils of the European Union with implications for food safety. Environment International 88(Supplement C): 299-309. doi.org/10.1016/j.envint.2015.12.017, Fig 1
Tilman, D., Socolow, R., Foley, J.A., Hill, J., Larson, E., Lynd, L., Pacala, S., Reilly, J., Searchinger, T., Somerville, C., 2009. Beneficial biofuels—the food, energy, and environment trilemma. Science 325, 270–271.
Tóth, G., Montanarella, L., Rusco, E., 2008. Threats to soil quality in Europe.
Tyshhenko, O., Tyshhenko, A., Chernychenko, M., 2013. About the salt resistance of alfalfa and the ways to increase it. Collect. Sci. Pap. “Irrigated Agric. 59, 105–107.
Van Orshoven, J., Terres, J.-M., Tóth, T., Jones, R., Le-Bas, C., Nachtergaele, F., Rossiter, D., Schulte, R., Van Velthuizen, H., 2014. Updated common bio-physical criteria to define natural constraints for agriculture in Europe - Definition and scientific justification for the common biophysical criteria. JRC Science and Policy Reports. https://doi.org/10.2788/79958
Van Orshoven, J., Terres, J.-M., Tóth, T., Jones, R., Le-Bas, C., Nachtergaele, F., Rossiter, D., Schulte, R., Van Velthuizen, H., 2012. Updated common bio-

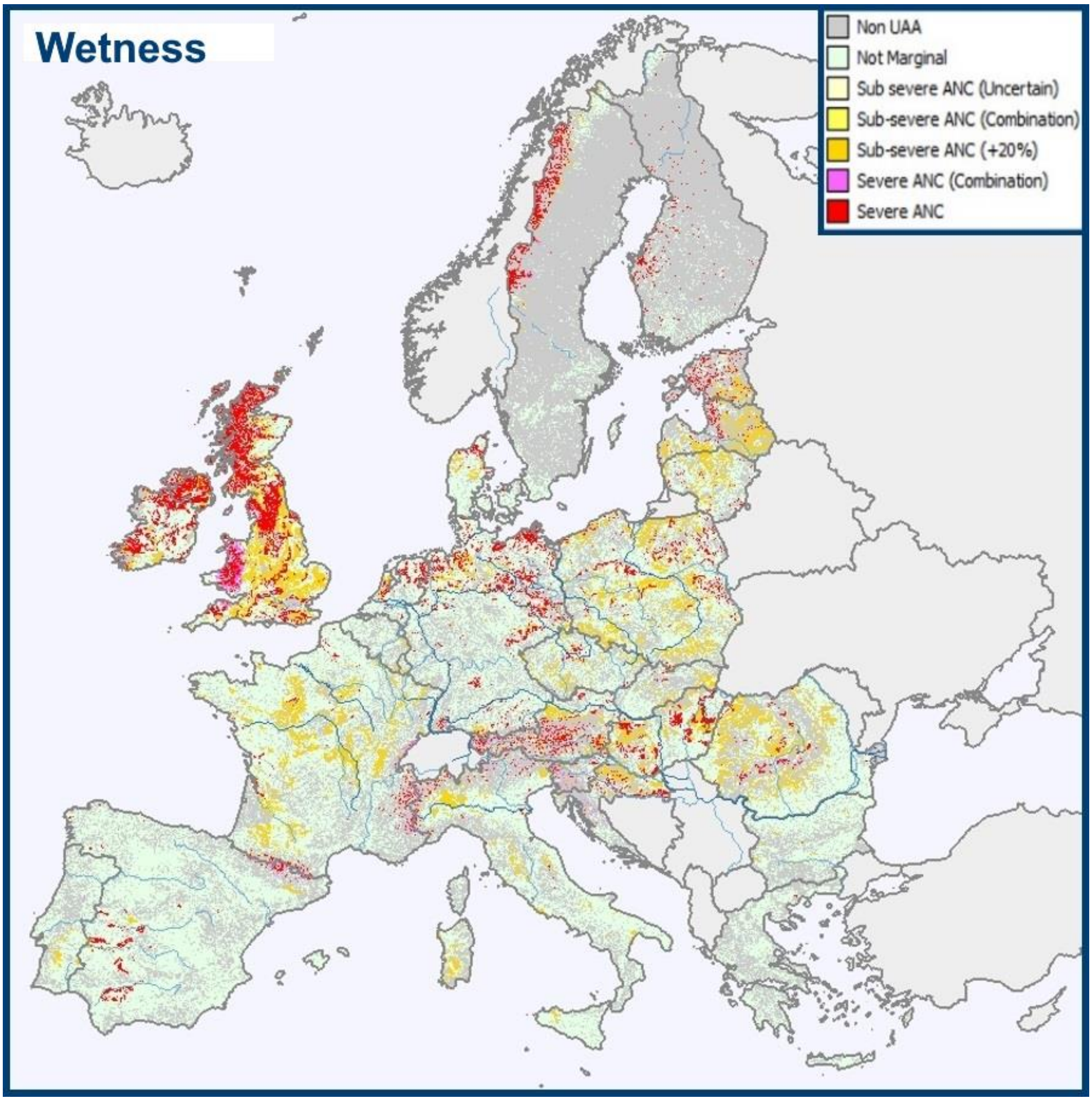
physical criteria to define natural constraints for agriculture in Europe. JRC Sci. Tech. Rep. Eur. Comm. Jt. Res. Cent. Inst. Environ. Sustain.-IES Luxembg. Available Online Httpmembers Iif Hutot3700abstrJVOJMTTT2012 Pdf. https://doi.org/10.2788/91182

von Cossel, M., Lewandowski, I., 2016. Perennial wild plant mixtures for biomass production: Impact of species composition dynamics on yield performance over a five-year cultivation period in southwest Germany. Eur. J. Agron. 79, 74–89. https://doi.org/10.1016/j.eja.2016.05.006

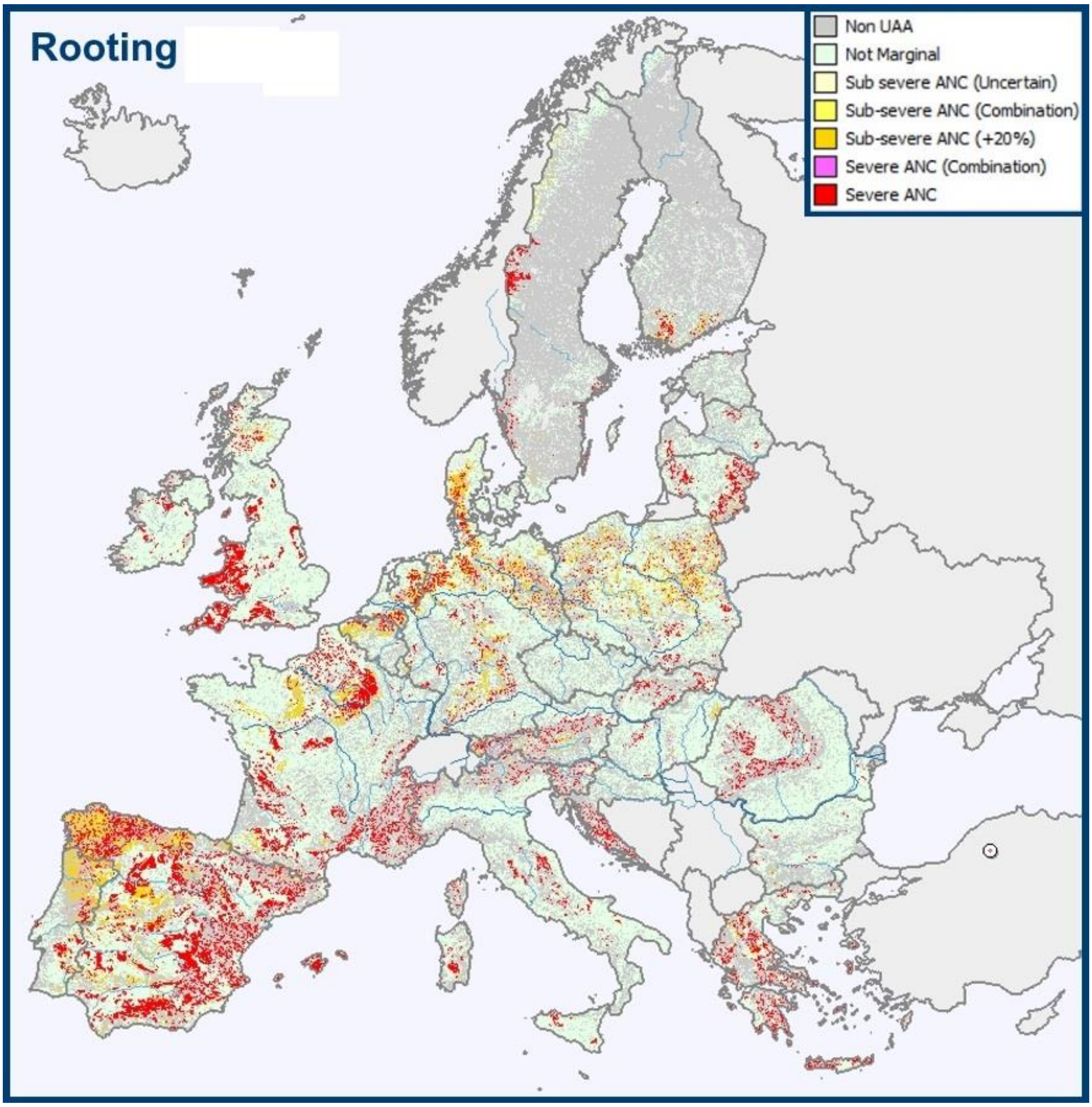
Annex 1 6 Mapped groups of biophysical constraints making up marginal lands



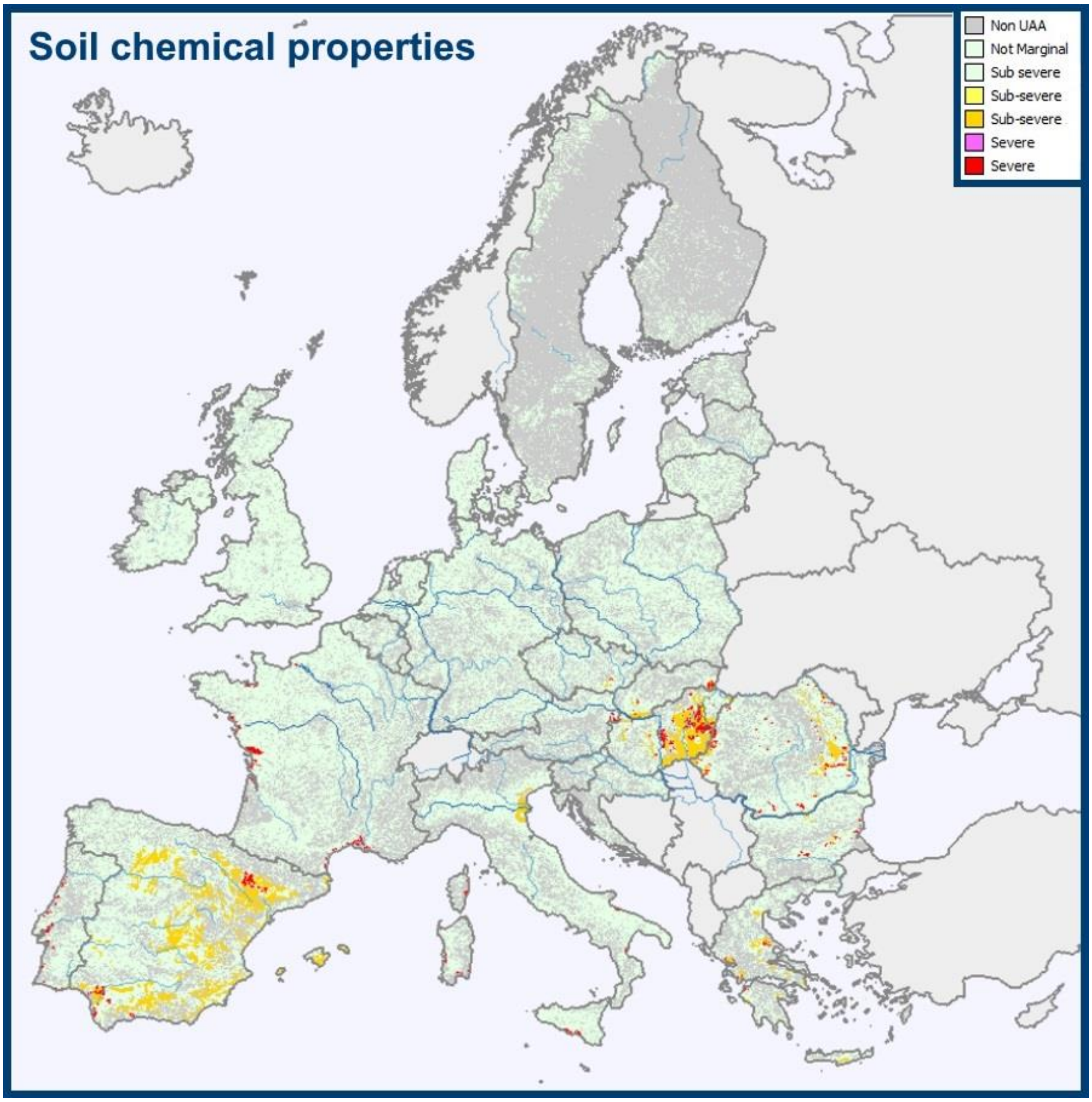
Map 1 : Spatial distribution of adverse climate (low temperature and/or dryness) across Europe



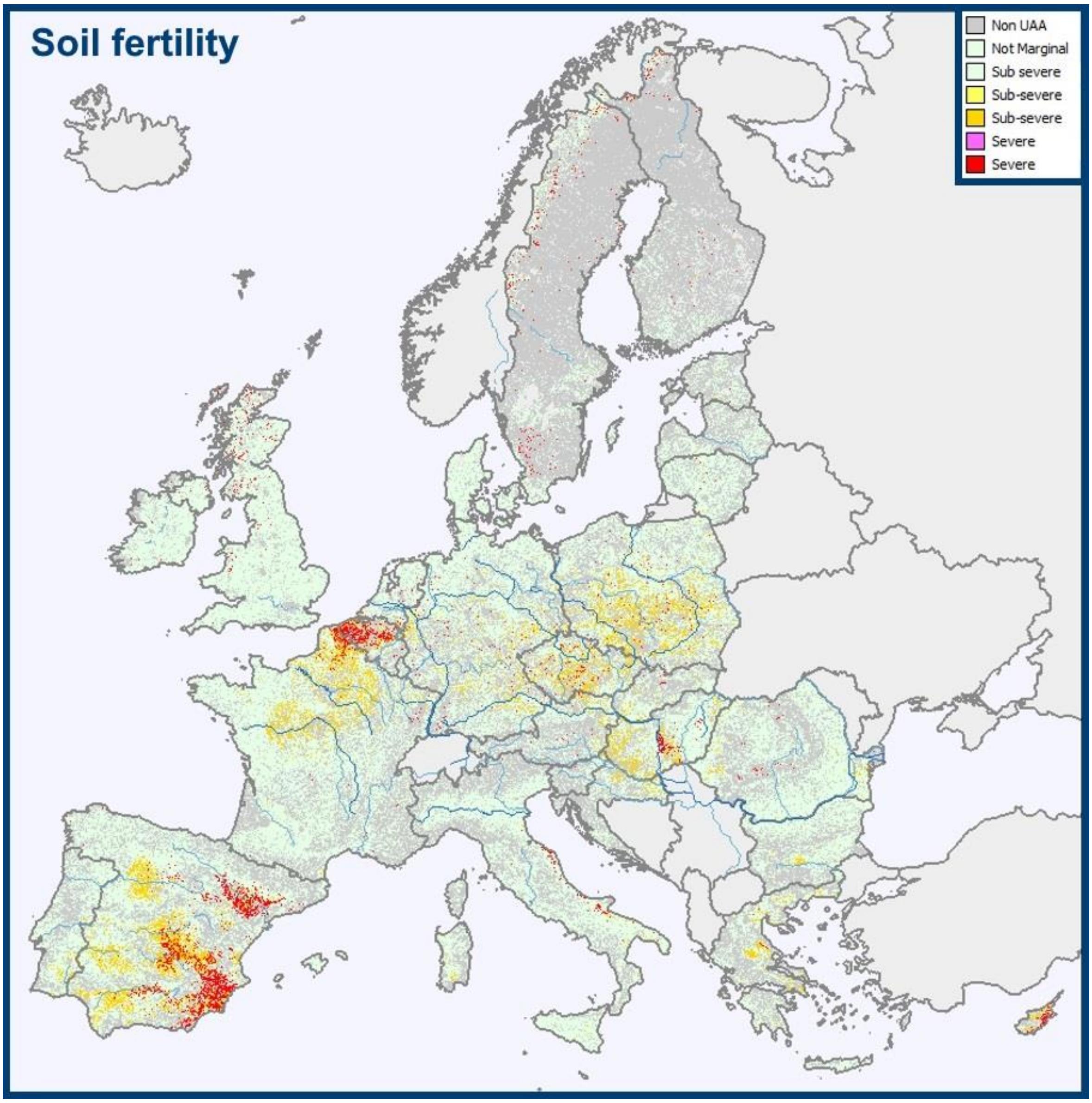
Map 2: Spatial distribution of excess soil wetness (excess soil moisture and/or poor soil drainage) across Europe



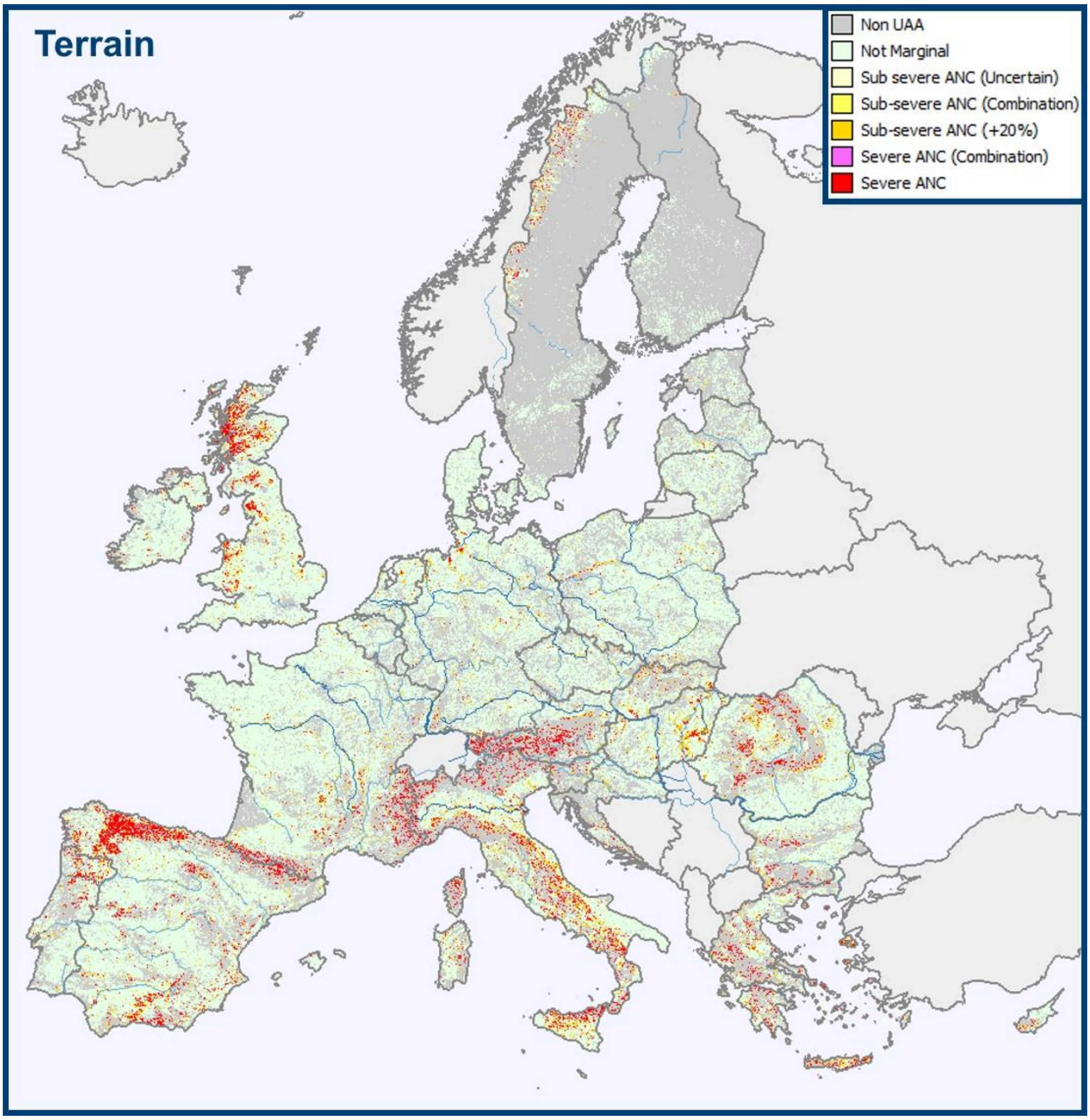
Map 3: Spatial distribution of adverse rooting conditions (unfavourable texture and/or stoniness and/or shallow rooting depth) across Europe



Map 4: Spatial distribution of adverse soil chemical properties across Europe



Map 5 Spatial distribution of adverse soil fertility across Europe



Map 6: Spatial distribution of adverse terrain across Europe

Annex 2 Notes WP 2 QUICKScan working meeting

WP2 Mapping marginal lands
QUICKScan working meeting
Wageningen 28 and 29 September 2017

Participants: Ioannis Eleftheriadis, Andrea Monti, Zhanguo Bai, Yasir Iqbal, Danilo Scordia, Juan Carrasco, Carlos Ciria Ramos, Ian McCallum, Wolter Elbersen, Sander Mucher, Hendrik Boogaard, Tomaso Ceccarelli, Marta Perez, Soba, Simone Verzandvoort
Meeting organisers: Berien Elbersen, Michiel van Eupen & Stephan Mantel

Thursday afternoon:

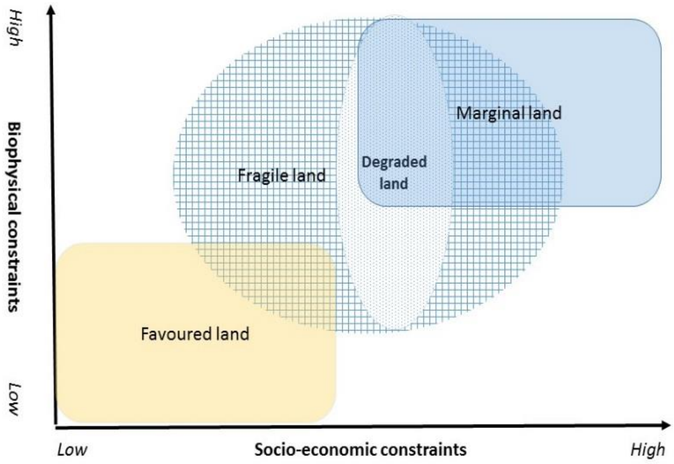
1. **Start of meeting, welcome and short introduction of all participants**
   Berien opens the meeting and explains the purpose of the meeting and the agenda for the 2 days. All participants introduce themselves.

2. **Introduction of the marginal land concept, state of play. Approach to mapping in MAGIC** (based on paper circulated before meeting).

Berien gives a presentation summarizing the background note (see Powerpoint 'Introduction.... '. This is followed by a first discussion.
Discussion:

- It was discussed whether marginal lands are overlapping with degraded lands. Some people think they are not overlapping, others think they are as degradation is seen as a process while marginal lands are a land class.
- It was claimed that the focus should be (only) on abandoned lands and concentrate on the envelope of land in-between what is currently used for cropping and the land that is good for nothing. So this implies that according to the figure underneath (presented in the presentation by Berien) it is proposed to map all fragile, marginal and degraded land. So not only concentrate on marginal land

as other land types may also be suitable for use by industrial crops.



- In MAGIC we promised to at least focus on Areas of Natural constraints defined purely by biophysical limitations as defined by JRC (van Oorschoven et al, 2014 and Terres, et al., 2014)
- It was mentioned that lands can also become more or less marginal because of human management. In the mapping of the marginal lands in MAGIC the human influence factors need to be taken into account.

3. Quickscan introduction followed by interactive session (on Post its) to identify marginality factors and marginal land types.

Michiel gave a short introduction on the QUICKScan tool and approach. See powerpoint presentation 'QUICKScan....'.

Outcomes of Post-It session:
All participants were asked to write up 3 main factors according to which marginal lands should be identified and the 3 main marginal land types.
Outcome of this inventory showed the following groups of marginal land identification factors:

- Climate (temperature & water availability)
- Economic: low/negative return
- Slope mountains
- Soil fertility limitations
- Social: remote, low population density
- Urban expansion

Types of marginal lands mentioned by the participants:

- Hypo-arid, desert zones
- Low (economic) productive compared to its potential
- Degraded

- Abandoned marginal lands
- Marginal lands with low population density
- Mountain areas, terraces abandoned
- Polluted lands
- Abandoned farm land on the urban fringe
- Marginal HNV land

4. Biophysical constraints for identifying marginal lands. Which constraints? What thresholds?

This part was introduced by Stephan with a presentation showing an overview of the indicators for biophysical constraints largely (but not only) based on the JRC studies on identifying 'Areas of Natural Constraints' . See presentation 'Biophysical constraints ...'.
After the presentation the participants were grouped in 3 sub-groups to discuss 4 questions:
1)Do you agree with the factors chosen by JRC and us?
2)Do you propose alternative factors?
3)Do you agree with thresholds proposed? If no, what alternative do you propose?
4)Do you know/recommend alternative data sources?
Outcome of these sub-group discussions was as follows:
<u>Group 1 (Sander):</u>

- Climate factors do not seem to be complete; still to add are high temperature (above 35° C, vapour pressure deficit and killing frost).
- Resolution of MARS data (25 km2) was debated, maybe also use WorldClim datasets as have higher resolution (1km2).
- Management factors (e.g. irrigation, drainage & fertilisation) influencing marginality (human factors) need to be taken into account in separate group of factors
- Terrain conditions also need aspect (north, south facing). Maybe include these additional factors specific per bioclimatic/environmental zone. Furthermore, terrain factors need to be established at very high resolution data. Best to use would be the Eurodem (25 meter level) data, ASTER, TANDEMX (expensive).
- As to soil fertility factors indicating towards nutrient availability and retention capacity should be included.
- Discussion followed on whether thresholds between marginal and non-marginal can be established per biogeographic region or need to be European wide. Maybe there is no need to have different threshold values, but the severity of the marginality can differ per environmental zone depending on the threshold levels and the combination of marginality factors occurring.
- In the final mapping approach there will be a need for a sensitivity analysis for deciding on the final thresholds.
- Alternative data sources: Global surface water explorer (JRC dataset GSWE which is based on satellite data interpretation)
- As to land cover data it's recommended to use 25 m Copernicus layer
- Sometimes there will be a need to combine variables before integrating

Group II (Hendrik):

- It seems that the drought index for Northern Spain is too strict. It excludes areas that are used for grain production (P/PET). There is enough rainfall for farming. Should the threshold be adjusted?. And then for South and North separately or generic?
- Discussion went more fundamental on how to approach marginal lands, in what order, maybe first focus on unused lands or lands with low economic return and check what are the reasons behind it (bio-physical)?
- Then concluded that biophysical constraints are needed too. What would be informative at the start is to understand per biophysical criterion what the number of hectares are covered by the criterion per country.
- Criteria can be correlated (excessive wetness) so apply a statistical analysis to reduce no of criteria => make it more simple and more complex
- Conclusion on biophysical criteria as presented sofar were generally accepted because the science behind is strong and a good starting point
- Missing as a constraint is plastics in soils as this is an emerging problem. Whether data are available on this aspect needs to be checked.
- It was proposed by the group to decide on suitability based on checking the current uses and then determine limits on suitability for the crops standing on the land. So clip for arable land with crops; clip permanent crops (olives, grapes), clip forests
- Forest is in a potential land use conflict with industrial crops
- Keep value (thresholds) as low as possible to avoid identifying areas that could be used for food crops (is sensitive)
- Dryness: Spain could be more strict, clip for irrigated areas
- Shallow rooting depth: map seems inconsistent
- 3D hydraulic property map needs to be checked as alternative data source
- If we have the maps of marginal lands we can overlay with climate change scenarios

Group III (Tomaso)

- Growing period not very indicative as they exclude area that is not interesting anyway because covers the artic for industrial crops. Therefore the low temperature indicator is not the most relevant.
- Dryness: More relevant than temperature.
- Excess of soil moisture: Relevant there can be cases where we need other crops. Threshold seems too broad. Combine with other issues.
- Salinity is very relevant, thresholds were not clear
- Question 1: Do you agree with the factors chosen?
- Poor drainage: Relevant. We would need alternative crops that can stand water logging.
- Limited Soil drainage: same as above
- pH: Seems a relevant factor to find crops for.

- SOC: Lowering of SOC is relevant. Alternative crops may be needed for sandy soils i.e.
- Toxicity: Very relevant especially since we want to find areas for non-food crops. Do map it.
- Poor rooting conditions: Seems very relevant. Going to new (perennial) crops may be relevant…
- Adverse terrain conditions: Slopes: Very relevant.
- Flooding risk: Hard to map, but may deliver quite relevant areas for new biomass crops.
- We miss:
    - Free frost period,
    - "Degrading soils = See Ukraine" . Toxicity is very relevant factor since we are focussing on non-food crops
    - Poor rooting conditions is very relevant because perennials can better cope with it.
    - Slope very relevant, but not sure about the threshold
    - Flooding is more relevant then waterlogging
    - Miss killing frost
    - Degrading soil fertility
    - Biofactors (threats like pests)

5. Integration of biophysical constraints & validation

In sub-group sessions before the biophysical constraints for marginal lands per factor (soil limitations, weather and topographic factors) were evaluated. In this session the discussion focussed on how all the biophysical indicators need to be integrated/combined to come to a map marginal lands on the basis of biophysical constraints. First the discussion was done in the three sub-groups and these then reported back.
Every group discussed 2 questions:
1) Can integration be done by adding up all factors or are certain factors more important than others?
2)How to classify the resulting marginal lands further (e.g. marginal, strongly marginal etc.)?

<u>Group I (Sander):</u>

- We can add up factors, but based on the relevance for every environmental zone.
- To check the relevance for marginality, factors need to be checked against current and actual productivity of the main crops currently growing on the lands (e.g. wheat, grass, olives, vine etc.). It needs to be done for different crops.
- Juan has 30 year productivity data for Spain which we can use for evaluation of the marginal land identification against their historic and current uses.
- Classification should inform on the gains to reach with industrial crops for example repair degradation

- All biophysical information is relevant to provide with the marginal land classification as all biophysical information influences management requirements and selection of varieties.
- Also important information to provide with the classification is prior land use and intensity of management.
- Current land uses that should not be changed for different reasons: to understand the requirements to establish a crop, but also from the ethical perspective. If the chances are high that industrial crop establishment is not accepted, better not do it.
- Methods of identification need to be transparent and traceable.

Sub group II (Hendrik):

- When combining land units are just below the threshold and when you combine factors then it becomes marginal. How about fuzzy methods?
- We liked the map where all the factors are combined for marginality. It shows that when one selects an area then it is clear what and how many constraints are and what that means for establishment of industrial crops.
- With regards to excessive wetness/marginal lands: overlay croplands with marginal land. Then analyse why the land is cropped to understand the marginality factor.
- The correlation between factors should be quantified

Sub group III (Tomaso)

- We had two lines of thinking. First look at where abandoned and cropped land and then look at limitations to conclude for crop selection and management.

- There are framework such as in UNCCD that take various factors in to account, land, organic carbon etc to arrive at a degradation indicator, using weighting factors.
- We looked at 3 countries to see if it is required to discriminate between factors that are more important in one country than in others.
  - Spain drought, frost, rainfall, salinity
  - Greece: salinity, stoniness, drought, rain distribution
  - Italy: slope, salinity, drought

- Bai Zhanguo: we should not be giving weights, rather take the most limiting factor.

Friday

6. **Wrap-up former day**

    - A summary of the main observations discussed the day before is given
    - Hendrik suggests to look again at the 6 year old JRC study on evaluation of constraining factors. Many suggestions made then are still valid.

7. **Marginal land classification? What are we aiming at?**

1. Discussion on definition of marginal lands
    - The FAO-CGIAR was re-discussed:
        i. Our definition should take the option for industrial cropping as a starting point
        ii. This links to what is the pool of land we want to involve in the analysis. From the perspective of industrial cropping it means the pool should consists of all land potentially being unused. However, pragmatically it is difficult to take such a large pool of land.
        iii. Proposed to be pragmatic: in first version of Marginal Map (end November 2017) we take lands where there is prove of agricultural use in last 30 years.
        iv. In next versions of marginal land mapping we will investigate additional land types that may also be suitable to be used for industrial cropping
        v. We also concluded that we need to evaluate whether the four different FAO-CGIAR land type can be used for industrial cropping.

8. **Socio economic constraints for marginal lands. Which constraints? What thresholds? How do they relate to the biophysical constraints?**

Sub-group discussion about the use of socio-economic variables for marginal land identification and/or classification.

<u>Group I (Sander):</u>

- Marginal lands are often abandoned, so requires a combination of biophysical constraints with socio-economic constraints
- Problem with data is that they are all proxies, but not a complete indicator
- Best indicators are management, low economic return (e.g. FAO < 40% of the potential yield). E.g. Wiegman 2008 and Schroers et al, 2006.
- Very interesting proxy indicator may be subsidies. A discussion followed about this and doubts were expressed whether high subsidy levels are indicative for marginal land use status. It was claimed that it is rather the other way around. High productive lands receive highest CAP payments.
- Land tenure system, smaller farms
- Depopulation, night light, age structure

- Landscan: population/km2 at high resolution

<u>Group (Hendrik)</u>

- Discussion on focus in WP2, some proposed to only focus on biophysical constraints to identify marginal lands, as we accept JRC factors on areas of natural constraints (to avoid 5 year long discussions like in OPTIMA). Others disagreed and indicated that marginal lands need to be identified and characterised according to a combination of biophysical and socio-economic indicators.
- Then the importance of economic return was discussed. A low or even negative economic return is a good indicator for marginality. Market prices have a great influence on economic returns (effects of global markets / less competitive due to higher production costs)
  - Sugarcane in Spain
  - Sugar beets in Italy (20 to 3 plants)
  - Reason for importing so much wheat from USA (sustainable?, quality => protein content composition)
- Then group identified most relevant other socio-economic factors:
  - Marginal lands according to break even cost determined by world market prices. Cost including subsidies. But break-even point is still conservative, as farms need to have some return on cost to cover living cost of farmer.
  - Trend in abandoned lands could be good indicator
  - Population density and jobs in agriculture
  - Other market prices, population density and jobs in agriculture
  - Presence of infrastructure as this influences the logistic efficiency of a biomass chain
  - Need to work on 25 km grid cells
- Grid resolution is a problem? Using coarse gridcells 25 km by km will map a large area as marginal. Maybe not focus too much on map creation? Maps should be unreliable but accept them, it is about the interpretation and presentation of the mapped results. This should be carefully considered.

Discussion followed:

- Should one also take into account the low producing lands and the heavily subsidized lands?
- We should be able to say what group of crops we may suggest to farmers on which lands with specific biophysical constraints
- Need to take into account the lands at the edge of marginality that will be abandoned in the near future. It was then explained that the idea is to first identify the current marginal lands and their use status and then evaluate with GLOBIOM (IIASA) how the different land types identified develop in the future in terms of uses.

<u>Group (Tomaso):</u>

- Labour availability is good indicator (goes further than profitability). Also promote a composite indicator for livelihood, lack of opportunities (combination of e.g. ageing, remoteness of areas, low population density, lack of infrastructure)
- Combination of biophysical with socioeconomic limitations increase the level of marginality
- Ageing of the farming community (but some business models do not depend on the farm labour too much, e.g. where companies rent land)
- The market opportunity for industrial crops is not available in many parts of Europe
- Marketing as a tool to create opportunity for industrial crops?
- Other relevant socio-economic constraints are:
    - Remoteness of areas
    - Urban night light density
- Regulations are now not always in favour of creating opportunities for industrial crops (e.g. Greening regulation: present regulation limits the cultivation for industrial crops)
- The biophysical conditions and the socio-economic conditions are interlinked. To understand this an analysis can be made where the two are combined or where they are single constraints.

Plenary discussion followed:

- Main objective according to Andrea: Biophysical constraints need to be mapped first, then evaluate whether they overlap or not with food production. For the quality of the evaluation data on current uses, do need to be reliable.
- However Juan and Carlos indicate that there is food crop production but on the edge of economic marginality, so there are lands still in use now, but will be abandoned in near future. These type of situations also need to be mapped.

9. Polluted lands overview presentation. Are these marginal lands? How to identify them?

Berien presents an overview of EEA (EONET)/JRC (Panagos et al., 2015) work done on identification of contaminated sites in Europe. For presentation see Annex with powerpoint ‘Contaminated sites.... ‘.
A discussion follows on how to address contaminated sites in MAGIC. It is concluded that these need to be incorporated in the Marginal land inventory. It is however also concluded that they are in another land pool then the one we will first concentrate on, which is lands that have been or are in agricultural use in last 30 years. Contaminated sites are often coinciding with land fill sites, industrial and mining sites and are generally not on land that has been agricultural in recent times.
In WP4 there will be some limited trials with industrial crops focusing on remediation of contaminated sites. To underpin the relevance of these trials it would be relevant information to provide an overview of the most common types of contaminated sites and most common types of pollutions (e.g. heavy metals, radioactivity etc.).
The conclusion was also made that given the work already done by EEA and JRC, it does not make sense to follow another definition of polluted sites other than the one from

EEA for ‘contaminated sites’. Following the EEA definition also implies that we can build on the data collection done by EEA and JRC.

10. Integration and evaluation of marginal land identification factors. In search for best methodology

In this last session the focus is making the final choices about main factors according to identify marginal lands, how to best integrate these factors, how to further classify marginal lands on the socio-economic constraints typical for marginal lands. The group was split in 2 sub-groups this time.
Groups were asked to answer 3 questions:

1. What are main (sustainability) factors according to which marginal lands need to be classified to understand options for industrial cropping use?
2. Indicate per factor chosen :
    a. Why chosen
    b. Classes proposed
3. What are best methods to map marginal lands: adding up, clustering, principle component analysis, Bayesian component analysis etc.

Outcome group discussions:

<u>Group I (Hendrik)</u>

- Factors:
    - Industrial crop suitability
        - Conditions to grow (agronomic) & benefits ~ linked to bio-physical constraints
        - Logistics: infrastructure / spatial fragmentation of these lands
        - Legal ownership (private or common lands)
    - Risks (landslide, erosion, natural hazards, fires, flooding) (e.g. fires) that would discourage the investment of an industrial crops
    - Co-benefits Search for co-benefits and this requires understanding the risks and ecosystem services present / eco system services (broader: the benefits) e.g. cardoon: deep roots that prevent erosion
    - Land use: Current cropping situation (use and intensity of land use) can help us in the analysis to understand the options for industrial cropping. Types of (former) land use:
        - Cropped now
        - Cropped in past (former land use and management)
        - Never cropped
        - Grassland
        - Bareland (outside the pool?, second phase)

- Combinations of criteria make some areas more marginal
- Let marginal severity determine the suitability for industrial crops, so the more marginality factors apply, the more suitable
- Need to analyse the correlation between the factors, to identify the most influential

- Need to establish the suitability for industrial crops and this links the biophysical constraints, but not only, also economic marginality and other socio-economic factors.
- Better go for broader mapping of the marginal lands and characterise it well sothat others are well informed about options for use.
- Number of constraints is an interesting way to decide on whether to use or not for industrial crops
- We should be aware that there is a political sensitivity connected to presentation of the marginal lands at high resolution. So present shares of marginal land at the administrative level in the first years of the project is a safe way of communicating intermediate results.
- Classifications according to environmental zones are important

<u>Group II (Tomaso):</u>

- Maybe the combination of the factors is not so important, but rather what is the use now. Best to focus on lands that are currently not used now/unused
- There are indeed factors in one place that are more relevant than others
- E.g. Spain drought, salinity, slope, stoniness
- UNDC land degradation indicators does not apply weighting.

A plenary discussion follows:

- Can we already mask out areas from the beginning? Better to do it at the end, otherwise we do not know what we missed.
- What are we doing: potential marginal lands or current marginal lands?

11. Wrap up and actions

<u>Actions:</u>

Berien explains how the meeting is followed up and how we plan to take up the mapping work and writing of deliverables until meeting in Athens in November.

- Next week work out minutes and share with all.
- Next week meet with Wageningen colleagues to elaborate a detailed methodological approach to mapping first version of marginal lands based on discussions in QUICKScan workshop.
- The methodological approach will be shared with all WP 2 partners for comments.
- Drafts of first 2 deliverables will be circulated by Berien and input and comments needs to be given by all. The deliverables are:
    - D2.1 Definition and classification of marginal land suitable for industrial crops in Europe (DLO-ALTERRA; M2)
    - D2.6 Methodological approaches to identify and map marginal land suitable for industrial crops in Europe (DLO- ALTERRA; M3).
- Deadlines of D2.1 already reached. Basically D2.1 = Background note already circulated

- Deadline for D2.2 postponed to Month 4 (October). Berien will elaborate the draft and circulate for input from all by 2nd week of October.
- Intermediate maps of marginal lands and sub-groups of marginal lands will be elaborated over next weeks. These mapped results and tables will be shared with all WP2 partners for evaluation and comments. Michiel will set-up a shared drive everybody can access in WP2.
- Berien and Yasir will exchanges views and prepare a template for data collection in the trials (in WP4) to match with the marginality characteristics mapped (in WP2). There are already trials for industrial crops for which a lot of information is available and this information can be systematically collected by Yasir in WP4.
- It was also discussed how to present the mapped marginal lands to the rest of MAGIC consortium in Athens. We agreed that all mapped information in great detail can be shared among the WP2 partners as they participated in the QUICKScan meeting and understnad how to interpret it carefully. For Athens we agreed to not circulate the mapped results before hand to all WP3 and WP4 partners as the interpretation of the maps needs to be done carefully. So in Athens it will first be presented (probably using QUICKScan) to carefully explain results and make clear what different layers and combinations of data are behind it.
- For WP3 and 4 it is very important to classify the marginal lands according to environmental zones and present extensive statistics of the long range of biophysical characteristics that apply to every marginal land type distinguished. In this way WP3 and 4 understand best to which in what biophysical indicator ranges and combinations industrial crops need to grow. Furthermore, industrial crops need to be developed for marginality situations that are most common in every environmental zone and with which it is likely to create most co-benefits.

Conclusions whole meeting by individuals:

Danilo: Focus on abandoned marginal lands defined according to ANC+ contaminated soils. Focus should be on abandoned arable lands (not grazing land). Abandoned land is land that is no longer cropped because of biophysical constraints.

Andrea: Socio-economic factors are important, but too far and complicated to understand within the scope of this project.

Yanis: Go with existing definitions of FAO and criteria of JRC. Then later more up-dates to go further. Important to finalise and share deliverables on time. Updates can always be made. Important that all WP2 partners are closely involved in the processing of data within the project.

Wolter: MAGIC should focus on mapping the envelope of land between land that is good for cropping and land that is good for nothing. We need to show this to the politicians and the public. The perspective of the industrial crops helps to get this clear. The perennials are likely to be most promising on marginal lands in terms of performance and sustainability.

Carlos: combine socio-economic and biophysical, identifying abandoned lands is big challenge.

Juan; want to share the identification of marginal lands in Spain they are working on at CIEMAT and compare with European approach in MAGIC

Ian: Decision support system development requirements have become more clear. For example showing initial marginal land results at administrative level (Nuts 3) is logical for first years, given political sensitivity. Also good to not only show one version of the marginal land map, but provide different perspectives to the end-user to view marginal lands. Display of gridded information needs to be handled carefully given variations in data quality which make adding up different data layers at high spatial resolution challenging.
Jasir: Agri-environmental zones are important classification according to which marginal land mapping results need to be presented to WP3 and 4. Marginal land maps need to at least cover Continental, Atlantic and Mediterranean zone as field trials will also be spread evenly over these zones in the MAGIC project.
Zhandou: Transferability of MAGIC approaches to regions outside Europe should be considered.
Sander: We should not be too afraid to make mistakes. There will always be comments. Whatever we decide, we need to be transparent, focus on the gains and aren't we not losing any opportunities?
Tomaso: Struggling between being pragmatic and acknowledging reality (farmer neighbour in marginal land).
Hendrik: It was an eye-opener to see that his brother in North of NL is actually farming in marginal land, but still has very high yields. It illustrates how important the human management factor is in mapping marginal lands.
Stephan: Need to take account of smart ways to overcome the biophysical limitations.
Marta: Quality of data is crucial. Sometimes results are very poor, added value of our work as compared to what was done before should be kept in mind. Be careful with presentation of mapping results as they have high political sensitivity.

Annex 3 Spatial Data Catalogue

Data available in QUICKScan for the MAGIC WP1 Workshop 27-28 September 2017.

Table 1: Biophysical constraints (see also tables at end of this document on European soil database and soil grid)

Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
Meteriological data (Adverse climate)	The daily long-term meteorological data (since 1975) including variables: temperature minimum, average, maximum (°C), rainfall (mm) and reference evapotranspiration - ET0 (mm). The interpolated data are available on grid cell 25*25 km	MARSGrid (long term averages)	Average (since 1975)	PanEurope on grid cells of 25x25 km. The land surface of the study area is covered by 8075 grid cells.	JRC-MARS-MARSOP projects	JRC-MARS database
NC10	Global equilibrium groundwater table depth	The map is derived from global observations of water table depth compiled from government archives and literature, and fill in data gaps and infer patterns and processes using a groundwater model forced by modern climate, terrain, and sea level. Patterns in water table depth explain patterns in wetlands at the global scale and vegetation gradients at regional and local scales. Units are expressed in meters.	m	Climate-based equilibrium conditions based on GWD observations since 1927	Global 1 km	Global Water Table Depth Observations and Model Simulations http://www2.mmm.ucar.edu/wrf/users/download/get_sources_wps_geog.html (dataset name: groundwater)
Soil types	Soil types at European scale can be derived from two datasets: - the European Soil Database v2.0 - SoilGrids See separate extended annex	Provides information for various indicators, e.g. poorly drained conditions, salinity, organic soils, rooting limitations (limited depth, impeding layers, soils with large	ESDB v2.0: soil information up till 2001	ESDB v2.0: Europe and parts of Asia Rasters at 1 km SoilGrids: global 1 km 250 m	ESDB v2.0: European Soil Data Centre (ESDAC), esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre and the European Soil Bureau Network http://esdac.jrc.ec.europa.eu/content/european-soil-database-v20-vector-and-attribute-data For SoilGrids: ISRIC - World Soil Information http://www.isric.org/data/soilgrids	The European Soil Database* distribution version 2.0, European Commission and the European Soil Bureau Network, CD-ROM, EUR 19945 EN, 2004 (Hengl et al. 2014) (Hengl et al. 2017)

Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
		amount of stones, etc)			ftp://ftp.soilgrids.org/	
Soil depth	Depth class of obstacle to roots: Fragipans and lithic contact Depth to bedrock	- cm	-	EU25 1 km 1 km / 250 m	See NC0 ISRIC - World Soil Information http://www.isric.org/data/soilgrids ftp://ftp.soilgrids.org/	http://eusoils.jrc.ec.europa.eu/ESDB_Archive/ESDBv2/fr_about.htm (Hengl et al. 2017)
Soil texture	Soil texture classes (USDA system) of topsoil (at depth 0 m)	- LEGEND=255:NODATA, 1:Cl, 2:SiCl, 3:SaCl, 4:ClLo, 5:SiClLo, 6:SaClLo, 7:Lo, 8:SiLo, 9:SaLo, 10:Si, 11:LoSa, 12:Sa	1930-2015 for the soil profile data underlying the SoilGrids 1 km database 2000-2015 for the covariates	Global 250 m	ISRIC - World Soil Information http://www.isric.org/data/soilgrids ftp://ftp.soilgrids.org/data/recent/TEXMHT_M_sl1_250m_ll.tif	(Hengl et al. 2014) (Hengl et al. 2017)
Topsoil organic carbon	Predicted topsoil soil organic carbon content in the EU-25, based on LUCAS 2009 soil point data. The map was produced by fitting a generalised additive model between organic carbon measurements from the LUCAS survey and a set of environmental covariates: slope, land cover, annual accumulated temperature, net primary productivity, latitude and longitude. The dataset also includes a map with the standard error of the SOC model predictions and a map with the point locations where soil was sampled in the LUCAS sampling campaign.	$g\ C.kg^{-1}$ dry matter	2014	EU25 (excluded Romania, Bulgaria, Croatia) 1 km	European Soil Data Centre (ESDAC) esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/topsoil-soil-organic-carbon-lucas-eu25#tabs-0-description=0	(de Brogniez et al. 2015)
Soil toxicity	Soils with sulfidic materials or with high aluminium concentrations	Soils with Thionic or Sulfidic qualifier in WRB classification	ESDB v2.0: soil information up till 2001	ESDB v2.0: Europe and parts of Asia Rasters at 1 km	ESDB v2.0: European Soil Data Centre (ESDAC), esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre and the European Soil Bureau Network http://esdac.jrc.ec.europa.eu/content/european-soil-database-v20-vector-and-attribute-data	The European Soil Database distribution version 2.0, European Commission and the European Soil Bureau Network, CD-ROM, EUR 19945 EN, 2004
Soil pH	pH (H_2O) in topsoil (at depth 0 m)	Index.10	1930-2015 1960-2010	Global 250 m	ISRIC - World Soil Information http://www.isric.org/data/soilgrids ftp://ftp.soilgrids.org/data/recent/PHIHOX_M_sl1_250m_ll.tif	(Hengl et al. 2014) (Hengl et al. 2017)
Available soil water capacity	Available soil water capacity of topsoil (depth 0 cm) at pF 2.0	$cm^3.cm^{-3}$	1930-2015 1960-2010	Global 250 m	ISRIC - World Soil Information http://www.isric.org/data/soilgrids ftp://ftp.soilgrids.org/data/recent/AWCh1_M_sl1_250m.tif	(Hengl et al. 2014) (Hengl et al. 2017)
3D Soil	3D spatial database of soil hydraulic properties at	Saturated water	time frame of the	Europe and parts	https://eusoilhydrogrids.rissac.hu/	(Tóth et al. 2017)

Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
Hydraulic Database of Europe	7 soil depths up to 2 m (EU-SoilHydroGrids ver 1.0). The database includes information on the soil water content at the most frequently used matric potential values, saturated hydraulic conductivity, Mualem-van Genuchten parameters of the moisture retention and hydraulic conductivity curves. Properties were calculated with the European pedotransfer functions (EU-PTF) (Tóth et al., 2015) based on the SoilGrids 250m and 1km dataset (Hengl et al., 2017).	content (THS) [$cm^3.cm^{-3}$] × 100 Water content at field capacity (FC) [$cm^3.cm^{-3}$] × 100 Water content at wilting point (WP) [$cm^3.cm^{-3}$] × 100 Saturated hydraulic conductivity (KS) [$cm.day^{-1}$] × 100 Parameters of the moisture retention (MRC) and hydraulic conductivity curve (HCC) × 10000 as specified in the metadata	soil (hydraulic) data used to develop (not to apply) the EU-PTF 1930-2015 1960-2010 for the soil profile data underlying resp. the SoilGrids 1 km and 250 m databases 2000-2015 for the covariates in the SoilGrids databases	of Western Asia	Metadata: http://mta-taki.hu/sites/all/files/linked/eu_soilhydrogrids_further_information_30052017.pdf	(Batjes et al. 2017)
Soil chemical quality	Baseline concentrations of heavy metals (arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc) in topsoils, predicted using 1588 georeferenced samples from the Forum of European Geological Surveys Geochemical database. The concentrations were interpolated using block regression-kriging (support size 5 m).	$mg.kg^{-1}$	2008	EU26	European Soil Data Centre (ESDAC) esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/heavy-metals-topsoils#tabs-0-description=1	(Lado et al. 2008)
Saline and sodic soils	Spatial distribution of saline, sodic and potentially salt affected areas within the European Union. The accuracy of input input data only allows the designation of salt affected areas with a limited level of reliability (e.g. < 50 or > 50% of the area); therefore the results represented in the map should only be used for orientating purposes.	-	2008	EU27 1 km	European Soil Data Centre (ESDAC) esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/saline-and-sodic-soils-european-union	(Tóth et al. 2008)
Heavy metals in agricultural soils	Maps of the concentration of heavy metals in agricultural topsoils in the European Union, including As, Cd, Cr, Cu, Hg, Pb, Zn, Sb, Co and Ni. Based on the FOREGS database New data is available based on the LUCAS Topsoil Survey (2012). The dataset also includes maps of the share of soil samples with heavy metal concentrations above the threshold value.	$mg.kg^{-1}$	2009-2012	EU27 NUTS2	https://esdac.jrc.ec.europa.eu/content/heavy-metals-topsoils	(Toth et al. 2016)
Soil Biomass	Three maps indicating the soil biomass	-	?	EU27	European Soil Data Centre (ESDAC)	(Tóth et al. 2013)

Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
Productivity maps of grasslands and pasture, of croplands and of forest areas in the European Union (EU27)	productivity of grasslands and pasture, of croplands and of forest areas in the European Union (EU27). The soil biomass productivity is expressed as a productivity score based on soil properties, the climatic zone, response to fertilizers (for cropland) and the slope.			1 km	esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/soil-biomass-productivity-maps-grasslands-and-pasture-coplands-and-forest-areas-european	
Slope/topography	European Digital Elevation model EU-DEM with 30 m.(EEA)			Pan European-30 m	JRC	

*For European soil database and soil grids info see tables at end of this document

Table 2 Socioeconomic constraints

Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
Population density	Population-grid dataset representing population density in Europe	Persons.km^{-2}	2011	EU28 1 km	EUROSTAT http://ec.europa.eu/eurostat/statistics-explained/index.php/Population_grids	(Eurostat 2016)
Population change			2006-2011			
Urban night lights	Urban night light calculated from the Version 4 DMSP-OLS Nighttime Lights Time Series. The files are cloud-free composites made using all the available archived DMSP-OLS smooth resolution data for calendar years. In cases where two satellites were collecting data - two composites were produced. The products are 30 arc second grids, spanning. In the spatial data catalogue the file F182013_v4c_stable_lights.avg_vis.tif is included. The cleaned up avg_vis contains the lights from cities, towns, and other sites with persistent lighting, including gas flares. Ephemeral events, such as fires have been discarded. Then the background noise was identified and replaced with values of zero.	Data values range from 1-63. Areas with zero cloud-free observations are represented by the value 255.	2013	-180 to 180 degrees longitude and -65 to 75 degrees latitude. 30 arc seconds	National Centers for Environmental Information (NCEI, part of NOAA) https://ngdc.noaa.gov/eog/data/web_data/v4composites/F182013.v4.tar	Image and data processing by NOAA's National Geophysical Data Center. DMSP data collected by US Air Force Weather Agency.
Urban night light	city lights: Visible Infrared Imaging Suite (VIIRS)	Grid 5*5 km		EU-28	VIRIS	https://kumu.io/ivitseva/integrated-data-platform-land-degradation#all/urban-night-light
Access to infrastructures, markets, urban centres	Travelling time to roads, main market and urban centres, rurality level	Grid 5*5 km			FARO database of rural areas in Europe:	FARO Project: Van Eupen, : M., Metzgera, M.J. Perez-Sobaa, M, . Verburgc P.H., van Doorn A., Bunce R.G.H. (2011). A rural typology for strategic European policies. Land

Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
						Use Policy 29 (2012) 473– 482
% Jobs in Agriculture		%	2008	EU	ESPON GEOSPECS	ESPON GEOSPECS
Access to Services	Average traveltime to cities of different size as proxy for access to services of general interest	Time min	2012	EU	FARO-FP7	Van eupen et al 2012.
Internet connectivity	Percentage of households who have internet access at home (per unit). All forms of internet use are included. The population considered is aged 16 to 74. Data represents the percentage of households with access to the internet at home, mostly NUTS2 level data distribution, but for some of the countries data is given in NUTS0 (country level, eg. Iceland) or NUTS1 (eg.Germany). Time series data starts from 2012 to 2016. Most of the data is from the latest year (2016). However, for some of the regions has break in time series or exist for only 1 year in the period. For those regions, only available or oldest data is used.	% (of households)	2003-present	EU-Member States, Candidate countries, Iceland and Norway.	EUROSTAT http://ec.europa.eu/eurostat/cache/RCI/#?vis=nuts2.infosoc&lang=en	http://ec.europa.eu/eurostat/cache/RCI/Eurostat_Regions_and_Cities_Illustrated_Help.pdf (interactive tool) http://bit.ly/2swX9Tg (tables)
Land use intensity on croplands	The map shows cropping frequency expressed as the number of years a cropland pixel was cropped over the observation period 2000-2012.	- (frequency)	2000-2012	The European continent and Turkey 231.6 m	-	(Estel et al. 2016) http://iopscience.iop.org/article/10.1088/1748-9326/11/2/024015
Irrigation (agri-environmental indicator)	Share of the irrigable and irrigated areas and their share in the total utilised agricultural area (UAA). The irrigable area is the area which is equipped for irrigation. This area does not show so much variation from year to year as it is costly for the farmer to invest in irrigation equipment. The irrigated area measures the actual amount of land irrigated and can vary significantly from year to year due to for instance meteorological conditions or the choice of crop.	% of UAA	2013	EU28 and Norway	EUROSTAT http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_irrigation	(Eurostat 2016)
Wood production	Wood production statistics for 29 European countries from 2000 to 2010 and comprehensive sets of biophysical and socioeconomic location factors were collected. Regression analyses were used to produce maps indicating the harvest likelihood on a 1 × 1 km^2 grid.	$m^3.ha^{-1}.y^{-1}$	2000-2010	Europe (29 countries) 1 km^2	http://datadryad.org/resource/doi:10.5061/dryad.mk067	(Verkerk et al. 2015) http://www.sciencedirect.com/science/article/pii/S0378112715004302
Land use change trajectories	Archetypical changes of patterns of land-use extent and intensity between 1990 and 2006, based on 14 explanatory factors of land use change and underlying drivers.	-	1990-2006	EU27 1 km^2	-	(Levers et al. 2015) http://link.springer.com/article/10.1007/s10113-015-0907-x
Grazing cattle	-	Grid 1*1 km	-	EU28	EUROSTAT EU-PEGASUS Project	Data not publicly available yet

Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
				1 km?		
Farm typology	Typology of cropland and grassland areas	Grid 1*1 km	-	EU28 1 km?	EUROSTAT EU-PEGASUS Project	Data not publicly available yet
Abandonment/ use status of land	Land Use and Coverage Area frame Survey (LUCAS) data as it provides a systematic European-wide sample of some 200000 in-situ photos with detailed land cover and land-use characteristics over time (2009, 2012, 2015)	Sample plots	(2009, 2012, 2015)	EU27	EUROSTAT LUCAS data	
De-population in hilly-mountain areas	Demographic trends : census data from Eurostat (FSS, REGIO) and national statistical offices, LandScan Global Population Database	Nuts 2		EU28	http://web.ornl.gov/sci/landscan/landscan_documentation.shtml	-
Land productivity dynamics	Land productivity dynamics are a measure for general productivity levels of the land or human-environment system. The map shows long-term linear trends in the remote sensing observed Spot Vegetation FAPAR productivity combined with current levels of productivity performance. Productivity was defined as the yearly FAPAR integral value within the vegetation growing season.	- (steadiness classes for standing biomass)	1982-2010	Europe, of Asia and North-Africa	JRC	(Cherlet et al. 2013) http://publications.jrc.ec.europa.eu/repository/bitstream/JRC80541/lb-na-26052-en-n%20.pdf
Soil Biomass Productivity maps of grasslands and pasture, of croplands and of forest areas in the European Union (EU27)	Three maps indicating the soil biomass productivity of grasslands and pasture, of croplands and of forest areas in the European Union (EU27). The soil biomass productivity is expressed as a productivity score based on soil properties, the climatic zone, response to fertilizers (for cropland) and the slope.	-	??	EU27 1 km	European Soil Data Centre (ESDAC) esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/soil-biomass-productivity-maps-grasslands-and-pasture-coplands-and-forest-areas-european	(Tóth et al. 2013)

Table 3 Biodiversity and ecosystem services

Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
High Nature Value farmland	Farming is often seen as a threat to biodiversity in Europe, but in fact certain types of farming are major benefactors of biodiversity. Traditional or extensive farmed landscapes can even be real biodiversity hotspots. Such areas or pockets are called "high nature value farmland". By definition, in HNV farmland agriculture supports, or is associated with, either a high	1*1 Km2	Static	EU-28+ Turkey	JRC & EEA	Paracchini M.L., J.-E.Petersen, Y.Hoogeveen, C.Bamps, I.Burfield, C.van Swaay (2008): High Nature Value Farmland in Europe - An estimate of the distribution patterns on the basis of land cover and biodiversity data, Report EUR 23480 EN. 87 p.

Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
	species and habitat diversity or the presence of species of European conservation concern, or both.					
Number of agricultural related article 17 habitats	The map shows the total number of agriculture-related Article 17 habitats. For the list of habitats see Table 1 (page 11) under the publication link.	number	2007-2012	EU27 10 km	-	(Masante et al. 2015) https://ec.europa.eu/jrc/en/publication/indicators-biodiversity-agroecosystems-insights-article-17-habitat-directive-and-iucn-red-list
Land productivity dynamics	Land productivity dynamics are a measure for general productivity levels of the land or human-environment system. The map shows long-term linear trends in the remote sensing observed Spot Vegetation FAPAR productivity combined with current levels of productivity performance. Productivity was defined as the yearly FAPAR integral value within the vegetation growing season.	- (steadiness classes for standing biomass)	1982-2010	Europe, of Asia and North-Africa	-	(Cherlet et al. 2013) http://publications.jrc.ec.europa.eu/repository/bitstream/JRC80541/lb-na-26052-en-n%20.pdf
Soil biodiversity potential	Overall potentials for soil biodiversity in Europe, assessed and mapped by means of several indicators which might affect the conditions of soils for biodiversity (pH, soil texture, soil organic matter, potential evapotranspiration, average temperature, soil biomass productivity, land use).	-	Datasets used have time stamps between 2006 and 2015	EU27 1 km	-	(Aksoy et al. 2017) http://www.sciencedirect.com/science/article/pii/S0048969717304229
Map of ecosystem types V2.1	Map of ecosystem types according to the EUNIS classification. The data set aims to combine spatially explicit land cover information with non-spatially referenced habitat information to improve our knowledge about ecosystems and their distribution across Europe.		2006 2013	36 countries 100 m 1 km	European Environment Agency http://www.eea.europa.eu/data-and-maps/data/ecosystem-types-of-europe Metadata: https://www.eea.europa.eu/downloads/d851e1b7f678468b8f0b1b98930ba3e1/1457619858/ecosystem-types-of-europe.pdf	(EEA 2016) (EEA 2015)
Soil Biomass Productivity maps of grasslands and pasture, of croplands and of forest areas in the European Union (EU27)	Three maps indicating the soil biomass productivity of grasslands and pasture, of croplands and of forest areas in the European Union (EU27). The soil biomass productivity is expressed as a productivity score based on soil properties, the climatic zone, response to fertilizers (for cropland) and the slope.	-	?	EU27 1 km	European Soil Data Centre (ESDAC) esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/soil-biomass-productivity-maps-grasslands-and-pasture-coplands-and-forest-areas-european	(Tóth et al. 2013)
Soil biodiversity potential	Overall potentials for soil biodiversity in Europe, assessed and mapped by means of several indicators which might affect the conditions of soils for biodiversity (pH, soil texture, soil organic matter,	-	Datasets used have time stamps between 06 and 2015	EU27 1 km	-	(Aksoy et al. 2017) http://www.sciencedirect.com/science/article/pii/S0048969717304229

Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
	potential evapotranspiration, average temperature, soil biomass productivity, land use).					
Vegetation cover	Greenness of the land surface expressed as yearly mean NDVI, calculated from time series of MODIS satellite images. The greenness change map shows the difference between the yearly mean NDVI values for the years 2011 and 2000.	NDVI-index normalised to values from 0-100	2000-2011	EU28 plus Iceland, Norway, Switzerland and part of Turkey 1 km	European Environment Agency	(Malak et al. 2013)
Soil Biomass Productivity maps of grasslands and pasture, of croplands and of forest areas in the European Union (EU27)	Three maps indicating the soil biomass productivity of grasslands and pasture, of croplands and of forest areas in the European Union (EU27). The soil biomass productivity is expressed as a productivity score based on soil properties, the climatic zone, response to fertilizers (for cropland) and the slope.	-	??	EU27 1 km	European Soil Data Centre (ESDAC) esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/soil-biomass-productivity-maps-grasslands-and-pasture-coplands-and-forest-areas-european	(Tóth et al. 2013)
Land productivity dynamics	Land productivity dynamics are a measure for general productivity levels of the land or human-environment system. The map shows long-term linear trends in the remote sensing observed Spot Vegetation FAPAR productivity combined with current levels of productivity performance. Productivity was defined as the yearly FAPAR integral value within the vegetation growing season.	- (steadiness classes for standing biomass)	1982-2010	Europe, of Asia and North-Africa	-	(Cherlet et al. 2013) http://publications.jrc.ec.europa.eu/repository/bitstream/JRC80541/lb-na-26052-en-n%20.pdf

Table 4 Drivers of land degradation (D)

Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
Wood production	Wood production statistics for 29 European countries from 2000 to 2010 and comprehensive sets of biophysical and socioeconomic location factors were collected. Regression analyses were used to produce maps indicating the harvest likelihood on a 1 × 1 km^2 grid.	$m^3.ha^{-1}.y^{-1}$	2000-2010	Europe (29 countries) 1 km^2	http://datadryad.org/resource/doi:10.5061/dryad.mk067	(Verkerk et al. 2015) http://www.sciencedirect.com/science/article/pii/S0378112715004302
Land use change trajectories	Archetypical changes of patterns of land-use extent and intensity between 1990 and 2006, based on 14 explanatory factors of land use change and underlying drivers.	-	1990-2006	EU27 1 km^2	-	(Levers et al. 2015) http://link.springer.com/article/10.1007/s10113-015-0907-x
Regionalised Water Exploitation Index (WEI+)	The regionalised Water Exploitation Index (WEI+) is calculated as the ratio of water use (by source and sector) over renewable water resources at sub-basin or river basin scale. Quarterly average per river basin district as defined in the European catchments and rivers network system (ECRINS).	%	2002-2014	EEA39 Sub-basin or river basin	EEA https://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources-2/assessment-2	-
Drought frequency, intensity	Linear trends in drought frequency and intensity fitted over the Standardized Precipitation and Evapotranspiration Index within the vegetation growing season. Drought frequency was calculated as the number of negative SPEI values within the vegetation growing season for each year between 1999-2013. Drought intensity was defined as the negative values within the vegetation growing season for each year between 1999-2013.	-	1999-2013	Eurasia 8 km^2	-	(Ivits et al. 2016) http://onlinelibrary.wiley.com/doi/10.1111/geb.12472/pdf
Risk of farmland abandonment	Indicator framework for accessing the risk for farmland abandonment	Nuts 2	-	EU-27	JRC	TERRES JM , NISINI, L., ANGUIANO, E. (2013). Assessing the risk of farmland abandonment in the EU. JRC78131
De-population in hilly-mountain areas	Demographic trends : census data from Eurostat (FSS, REGIO) and national statistical offices, LandScan Global Population Database	Nuts 2		EU28	http://web.ornl.gov/sci/landscan/landscan_documentation.shtml	-

Table 5 Soil threats and other land degradation types (LD)

Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
Soil erosion by water	Modelled risk for soil erosion by water based on the RUSLE model (RUSLE 2015). The input factors (rainfall erosivity, soil erodibility, cover/ management, slope length and steepness, and support practices) have been peer-reviewed and published at the ESDAC.	$t.ha^{-1}year^{-1}$	2010	EU28 100 m	European Soil Data Centre (ESDAC) esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/soil-erosion-water-rusle2015	(Panagos et al. 2015)
Wind erosion susceptibility	The Index of Land Susceptibility to Wind Erosion (ILSWE) is based on the combination of the most influential parameters for wind erosion, i.e. climate (wind, rainfall and evaporation), soil characteristics (sand, silt, clay, CaCO3, organic matter, water-retention capacity and soil moisture) and land use (land use, percent of vegetation cover and landscape roughness).	-	1981-2010	EU28 and Montenegro, Serbia, the Former Yugoslav Republic of Macedonia, Albania, Bosnia and Herzegovina, Kosovo, Norway and Switzerland	European Soil Data Centre (ESDAC) esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre http://eusoils.jrc.ec.europa.eu/Library/Themes/Erosion/WindErosion/LandSusceptibility.html	(Borrelli et al. 2016)
Classified European Landslide Susceptibility Map (ELSUS1000) v1'.	Landslide susceptibility levels at European scale, derived from heuristic-statistical modelling of main landslide conditioning factors based on 3 parameters: slope gradient, lithology and land cover.	5 classes: Very low (<0.2) Low (0.2-0.4) Moderate (0.4-0.6) High (0.6-0.8) Very High (>0.8)	GTOPO 1996; ESDB 2012; land cover: PELCOM 1999	EU27 (excl. Cyprus) and Albania, Bosnia and Herzegovina, Croatia, Kosovo, FYR Macedonia, Montenegro, Norway, Serbia and Switzerland 1 km	European Landslide Expert Group http://esdac.jrc.ec.europa.eu/themes/european-landslide-expert-group	(Günther et al. 2014)
Heavy metals in agricultural soils	Maps of the concentration of heavy metals in agricultural topsoils in the European Union, including As, Cd, Cr, Cu, Hg, Pb, Zn, Sb, Co and Ni. Based on the FOREGS database New data is available based on the LUCAS Topsoil Survey (2012). The dataset also includes maps of the share of soil samples with heavy metal concentrations above the threshold value.	$mg.kg^{-1}$	2009-2012	EU27 NUTS2	https://esdac.jrc.ec.europa.eu/content/heavy-metals-topsoils	(Toth et al. 2016)
Eroded soil organic carbon	Distribution of average eroded SOC (Mg C ha-1 yr-1) for the decade 2000–2010, in agricultural soils of the EU. The map is a result of a recently developed high resolution pan-European simulation platform to assess the potential impact of six management practices on SOC stock levels of arable soil under two IPCC climate change scenarios to 2100: 1) arable to grassland conversion (and vice versa), 2) straw incorporation, 3) reduced tillage, 4) straw incorporation with reduced tillage, 5) ley cropping and 6) cover crops.	$Mg.C^{-1}.ha^{-1}.year^{-1}$	2000-2010	EU28	European Soil Data Centre (ESDAC) esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/pan-european-soc-stock-agricultural-soils	(Lugato et al. 2016)

Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
Saline and sodic soils	Spatial distribution of saline, sodic and potentially salt affected areas within the European Union. The accuracy of input data only allows the designation of salt affected areas with a limited level of reliability (e.g. < 50 or > 50% of the area); therefore the results represented in the map should only be used for orientating purposes.	-	2008	EU27 1 km	European Soil Data Centre (ESDAC) esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/saline-and-sodic-soils-european-union	(Tóth et al. 2008)
Natural susceptibility to soil compaction	Natural susceptibility of agricultural soils to compaction, based on pedotransfer rules using attributes of the European soil database: soil type, texture and water regime, depth to textural change and the limitation of the soil for agricultural use. Auxiliary soil properties used include impermeable layer, depth of an obstacle to roots, water management system, dominant and secondary land use.	-	2000 (land cover) 2006 (soil properties)	EU27 1 km	European Soil Data Centre (ESDAC) esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/natural-susceptibility-soil-compaction-europe	(Houkova & Van Liederkerke 2008)
Drought vulnerability	Ecosystems vulnerable to drought in the period 1999-2013. Ecosystem vulnerability was calculated as significant correlations between the anomalies of the remote sensing derived vegetation index FAPAR and of the negative values of the SPEI03 dataset. The regression was run within the vegetation growing season. FAPAR= Fraction of Absorbed Photosynthetically Active Radiation. SPEI03 =Standardized Precipitation and Evaporation Index. Anomalies show deviations from the long term mean.	-	1999-2013	Eurasia 8 km^2	-	(Ivits et al. 2016)
Land productivity dynamics	Land productivity dynamics are a measure for general productivity levels of the land or human-environment system. The map shows long-term linear trends in the remote sensing observed Spot Vegetation FAPAR productivity combined with current levels of productivity performance. Productivity was defined as the yearly FAPAR integral value within the vegetation growing season.	- (steadiness classes for standing biomass)	1982-2010	Europe, of Asia and North-Africa	-	(Cherlet et al. 2013) http://publications.jrc.ec.europa.eu/repository/bitstream/JRC80541/lb-na-26052-en-n%20.pdf
Potential threats to soil biodiversity in Europe	Dataset of 3 maps showing potential threats to soil biodiversity in Europe. A list of 13 potential threats to soil biodiversity was proposed to experts to assess the potential for three major components of soil biodiversity: soil microorganisms, fauna, and biological functions.	-	2015	EU27 500 m	European Soil Data Centre (ESDAC) esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/potential-threats-soil-biodiversity-europe	(Orgiazzi et al. 2016) (Orgiazzi et al. 2015)
Soil biodiversity potential	Overall potentials for soil biodiversity in Europe, assessed and mapped by means of several indicators which might affect the conditions of soils for biodiversity (pH, soil texture, soil organic matter, potential evapotranspiration, average temperature, soil biomass productivity, land use).	-	Datasets used have time stamps between 2006 and 2015	EU27 1 km	-	(Aksoy et al. 2017) http://www.sciencedirect.com/science/article/pii/S0048969717304229

Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
Contaminated sites	European Soil Data Centre ESD C) 11) CSI- 15 "Progress in the management of contaminated sites".	Static	?	EU27 (but not all countries reported data)	EEA & JRC; http://eusoils.jrc.ec.europa.eu/library/data/eionet/ 11_Contaminated_Sites.htm EEA- EIONET Data Survey 2011: Progress in the Management of Contaminated Sites based on JRC data (see Panagos et al., 2013): http://www.eea.europa.eu/data-and-maps/indicators/progress-in-management-of-contaminated-sites-3/assessment .	Panagos, P., Van Liedekerke, M., Yigini, Y., Montanarella, L. 2013. Contaminated Sites in Europe: Review of the Current Situation Based on Data Collected through a European Network. *Journal of Environmental and Public Health, vol. 2013, Article ID 158764, pp 1-11. doi:10.1155/2013/158764.*

Table 6 Reporting units

Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
The Environmental Stratification of Europe (EnS)	The Environmental Stratification of Europe (EnS) is based on climatic variables, altitude, slope, latitude and oceanicity. The stratification has 84 strata, which have been aggregated into 13 Environmental Zones.	-	1971-2000 (climate variables) 1996 (altitude, oceanicity) 1993-1996 (geomorphology)	'Greater European Window' with the following boundaries: 11° W, 32° E, 34° N, 72° N. 1 km^2	?	(Metzger et al. 2005)
Biogeographical regions (v2, 2016)	European wide map of the biogeographical regions independent of political boundaries. Official delineations used in the Habitats Directive (92/43/EEC) and for the EMERALD Network set up under the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention).	-	2016	45 countries Varying resolution depending on scale: 1:1 000 000 (EU-countries), 1:1 000 000 or 1:10 000 000 for other regions.	European Environment Agency https://www.eea.europa.eu/data-and-maps/data/biogeographical-regions-europe-3	-
Land System Archetypes	This map shows land-system archetypes for the year 2006, defined as characteristic patterns of land-use extent and intensity. The analysis identified 15 land-system archetypes, with low-intensity archetypes dominating (ca. 55 % coverage) followed by high-intensity archetypes (ca. 26 %).	-	1990-2006	EU27	Christian Levers, University of Berlin	(Levers et al. 2015)
Dominant land cover flows	Land accounting is based on organising land cover changes as reported by the Corine Land Cover (CLC) survey into different land cover flows (LCFs). These LCFs are spatial datasets based on grouping land cover changes according to the underlying processes or drivers.	-	2000-2012	CLC2000: 35 countries CLC2006: 38 countries CLC2012: 39 countries 100 m	EEA and Eionet network National Reference Centres Land Cover Hosted through the Copernicus Land Monitoring Service http://land.copernicus.eu/pan-european/corine-land-cover/view	(EEA & JRC 2017)
Administrative units: Nomenclature of territorial units for statistics (NUTS)	The NUTS classification (Nomenclature of territorial units for statistics) is a hierarchical system for dividing up the economic territory of the EU. The current NUTS 2013 classification is valid from 1 January 2015 and lists 98 regions at NUTS 1, 276 regions at NUTS 2 and 1342 regions at NUTS 3 level.	-	2013-present	NUTS 1: major socio-economic regions NUTS 2: basic regions for the application of regional policies NUTS 3: small regions for specific diagnoses	EUROSTAT http://bit.ly/2blJNVH	http://ec.europa.eu/eurostat/web/nuts/overview
European river catchments	Dataset of European catchments at scale 1:1 million				European Environment Agency http://www.eea.europa.eu/data-	-

Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
					and-maps/data/european-river-catchments-1	

References for data sources

Aksoy, E. et al., 2017. Assessing soil biodiversity potentials in Europe. *Science of The Total Environment*, 589, pp.236–249. Available at: http://www.sciencedirect.com/science/article/pii/S0048969717304229 [Accessed June 9, 2017].

Batjes, N.H. et al., 2017. WoSIS: providing standardised soil profile data for the world. *Earth System Science Data*, 9(1), pp.1–14. Available at: http://www.earth-syst-sci-data.net/9/1/2017/ [Accessed June 23, 2017].

Borrelli, P. et al., 2016. Towards a Pan-European Assessment of Land Susceptibility to Wind Erosion. *Land Degradation & Development*, 27(4), pp.1093–1105. Available at: http://doi.wiley.com/10.1002/ldr.2318 [Accessed June 13, 2017].

de Brogniez, D. et al., 2015. A map of the topsoil organic carbon content of Europe generated by a generalized additive model. *European Journal of Soil Science*, 66(1), pp.121–134. Available at: http://doi.wiley.com/10.1111/ejss.12193 [Accessed June 20, 2017].

Cherlet, M. et al., 2013. *Land Productivity Dynamics in Europe Towards Valuation of Land Degradation in the EU*,

EEA, 2015. *European ecosystem assessment — concept, data, and implementation Contribution to Target 2 Action 5 Mapping and Assessment of Ecosystems and their Services (MAES) of the EU Biodiversity Strategy to 2020*, Available at: http://catalogue.biodiversity.europa.eu/uploads/document/file/1228/Tech_06_2015_THAK15006ENN-1.pdf.

EEA, 2016. *Mapping and assessing the condition of Europe's ecosystems: progress and challenges*,

EEA & JRC, 2017. *Land resource efficiency: Integrated accounting of land cover change and soil functions - DRAFT REPORT FOR EIONET CONSULTATION*, Copenhagen.

Elbersen, B. et al., 2006. *System for Environmental and Agricultural Modelling ; Linking European Science and Society Protocols for spatial allocation of farm types*,

Estel, S. et al., 2016. Mapping cropland-use intensity across Europe using MODIS NDVI time series. *Environmental Research Letters*, 11(2), p.24015. Available at: http://stacks.iop.org/1748-9326/11/i=2/a=024015?key=crossref.fa3dc3f8957422bc9946e69ed7036a1e [Accessed June 13, 2017].

Eurostat, 2016. Agri-environmental indicator - irrigation. Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_irrigation [Accessed April 1, 2017].

Fan, Y., Li, H. & Miguez-Macho, G., 2013. Global patterns of groundwater table depth. *Science*, 339(6122), pp.940–943. Available at: http://science.sciencemag.org/content/sci/339/6122/940.full.pdf?sid=a886992b-3322-4a48-9090-cc5bc3acd7f0 [Accessed June 20, 2017].

Günther, A. et al., 2014. Synoptic Pan-European Landslide Susceptibility Assessment: The ELSUS 1000 v1 Map. In K. Sassa, P. Canuti, & Y. Yin, eds. *Landslide Science for a Safer Geoenvironment: Vol.1: The International Programme on Landslides (IPL)*. Cham: Springer International Publishing, pp. 117–122. Available at: http://dx.doi.org/10.1007/978-3-319-04999-1_12.

Hengl, T. et al., 2014. SoilGrids1km ? Global Soil Information Based on Automated Mapping B. Bond-Lamberty, ed. *PLoS ONE*, 9(8), p.e105992. Available at: http://dx.plos.org/10.1371/journal.pone.0105992 [Accessed June 20, 2017].

Hengl, T. et al., 2017. SoilGrids250m: Global gridded soil information based on machine learning B. Bond-Lamberty, ed. *PLOS ONE*, 12(2), p.e0169748. Available at: http://dx.plos.org/10.1371/journal.pone.0169748 [Accessed June 22, 2017].

Houkova, B. & Van Liederkerke, M., 2008. Map for Europe of Natural Susceptibility of Soils to Compaction.

Ivits, E. et al., 2016. Assessing European ecosystem stability to drought in the vegetation growing season. *Global Ecology and Biogeography*, pp.1–13. Available at: http://doi.wiley.com/10.1111/geb.12472.

Jaeger, J.A.G., 2000. Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation. *Landscape Ecology*, 15(2), pp.115–130. Available at: http://dx.doi.org/10.1023/A:1008129329289.

Kempen, M. et al., 2011. Spatial allocation of farming systems and farming indicators in Europe. *Agriculture, Ecosystems and Environment*, 142(1–2), pp.51–62. Available at: http://dx.doi.org/10.1016/j.agee.2010.08.001.

Lado, L.R., Hengl, T. & Reuter, H.I., 2008. Heavy metals in European soils: A geostatistical analysis of the FOREGS Geochemical database. *Geoderma*, 148, pp.189–199. Available at: http://download.xuebalib.com/xuebalib.com.8567.pdf [Accessed June 20, 2017].

Levers, C. et al., 2015. Archetypical patterns and trajectories of land systems in Europe. *Regional Environmental Change*, pp.1–18.

Lugato, E. et al., 2016. Quantifying the erosion effect on current carbon budget of European agricultural soils at high spatial resolution. *Global Change Biology*, 22(5), pp.1976–1984. Available at: http:https://dx.doi.org/10.1111/gcb.13198.

Malak, D.A. et al., 2013. *Available data for mapping and assessing ecosystems in Europe*, Available at: https://circabc.europa.eu/sd/a/7b5eb5f5-8b52-4256-bc72-9f69a38dcf78/Ecosystem assessment - Final Report v.1 (03.06.2013) [Accessed August 16, 2017].

Masante, D. et al., 2015. *Indicators of biodiversity in agroecosystems: insights from Article 17 of the Habitats Directive and IUCN Red List of Threatened Species* JRC techni., Publications Office of the European Union.

Metzger, M.J. et al., 2005. A climatic stratification of the environment of Europe. *Global Ecology and Biogeography*, 14(6), pp.549–563. Available at: http://doi.wiley.com/10.1111/j.1466-822X.2005.00190.x [Accessed September 23, 2016].

Orgiazzi, A. et al., 2016. A knowledge-based approach to estimating the magnitude and spatial patterns of potential threats to soil biodiversity. *Science of the Total Environment*, 545–546, pp.11–20. Available at: http://dx.doi.org/10.1016/j.scitotenv.2015.12.092.

Orgiazzi, A. et al., 2015. Soil biodiversity and DNA barcodes: opportunities and challenges. *Soil Biology and Biochemistry*, 80, pp.244–250. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0038071714003617 [Accessed June 19, 2017].

Panagos, P. et al., 2015. The new assessment of soil loss by water erosion in Europe. *Environmental Science & Policy*, 54, pp.438–447. Available at: http://www.sciencedirect.com/science/article/pii/S1462901115300654 [Accessed September 1, 2015].

Paracchini, M. L.; Petersen, J.-E.; Hoogeveen, Y.; Bamps, C.; Burfield, I. and van Swaay, C., 2008. High Nature Value Farmland in Europe. An estimate of the distribution patterns on the basis of land cover and biodiversity data. JRC Scientific and Technical Reports. European Communities, Luxembourg http://agrienv.jrc.ec.europa.eu/activities_HNV.htm

Tóth, B. et al., 2017. 3D Soil Hydraulic Database of Europe at 250 m resolution. *Hydrological Processes*. Available at: http://doi.wiley.com/10.1002/hyp.11203 [Accessed May 18, 2017].

Toth, G. et al., 2016. Heavy metals in agricultural soils of the European Union with implications for food safety. *Environment International*, 88, pp.299–309. Available at: http://dx.doi.org/10.1016/j.envint.2015.12.017.

Tóth, G. et al., 2013. Continental-scale assessment of provisioning soil functions in Europe. *Ecological Processes*, 2(1), pp.1–18. Available at: http://dx.doi.org/10.1186/2192-1709-2-32.

Tóth, G. et al., 2008. Updated Map of Salt Affected Soils in the European Union. In G. Toth, L. Montanarella, & E. Rusco, eds. *Threats to Soil Quality in Europe.* European Commission, pp. 65–77.

Van Eupen, : M., Metzgera, M.J. Perez-Sobaa, M, . Verburgc P.H., van Doorn A., Bunce R.G.H. (2011). A rural typology for strategic European policies. Land Use Policy *29 (2012) 473– 482*

Verkerk, P.J. et al., 2015. Mapping wood production in European forests. *Forest Ecology and Management*, 357, pp.228–238. Available at: http://dx.doi.org/10.1016/j.foreco.2015.08.007.

SOILGRIDS, all available data 30 cm depth:							
SOILGRID KEYWORD1	**KEYWORD2**	**ATTRIBUTE_LABEL**	**VARIABLE_NAME**	**0.025 m**	**0.30 m**	**None**	**Nr of datasets**
bedrock	**depth**	BDRICM_M	Depth to bedrock (R horizon) up to 200 cm			1	1
		BDRLOG_M	Predicted probability of occurrence (0-100%) of R horizon			1	1
		BDTICM_M	Absolute depth to bedrock (in cm)			1	1
bulk	**density**	BLDFIE_M_sl4	Bulk density (fine earth) in kg / cubic-meter		1		1
cation	**capacity**	CECSOL_M_sl4	Cation exchange capacity of soil in cmolc/kg		1		1
clay	**texture**	CLYPPT_M_sl4	Clay content (0-2 micro meter) mass fraction in %		1		1
coarse	**texture**	CRFVOL_M_sl4	Coarse fragments volumetric in %		1		1
hand	**texture**	TEXMHT_M_sl4	Texture class (USDA system)		1		1
organic	**carbon**	ORCDRC_M_sl4	Soil organic carbon content (fine earth fraction) in g per kg		1		1
pH	**acidity**	PHIHOX_M_sl4	Soil pH x 10 in H2O		1		1
	KCl	PHIKCL_M_sl4	Soil pH x 10 in KCl		1		1
sand	**texture**	SNDPPT_M_sl4	Sand content (50-2000 micro meter) mass fraction in %		1		1
silt	**texture**	SLTPPT_M_sl4	Silt content (2-50 micro meter) mass fraction in %		1		1
stock	**carbon**	OCSTHA_M_sd1	Soil organic carbon stock in tonnes per ha	1			1
water	**available**	AWCh1_M_sl4	Available soil water capacity (volumetric fraction) for h1		1		1
		AWCh2_M_sl4	Available soil water capacity (volumetric fraction) for h2		1		1
		AWCh3_M_sl4	Available soil water capacity (volumetric fraction) for h3		1		1
		AWCtS_M_sl4	Saturated water content (volumetric fraction) for tS		1		1
		WWP_M_sl4	Available soil water capacity (volumetric fraction) until wilting point		1		1

SOILGRIDS all available data 30 cm depth:							
SOILGRID KEYWORD1	**KEYWORD2**	**ATTRIBUTE_LABEL**	**VARIABLE_NAME**	**0.025 m**	**0.30 m**	**None**	**Nr of datasets**
WRB	**Acrisols**	TAXNWRB	WRB 2006 class			6	6
	Albeluvisols	TAXNWRB	WRB 2006 class			3	3
	Alisols	TAXNWRB	WRB 2006 class			2	2
	Andosols	TAXNWRB	WRB 2006 class			3	3
	Arenosols	TAXNWRB	WRB 2006 class			6	6
	Calcisols	TAXNWRB	WRB 2006 class			4	4
	Cambisols	TAXNWRB	WRB 2006 class			11	11
	Chernozems	TAXNWRB	WRB 2006 class			3	3
	Cryosols	TAXNWRB	WRB 2006 class			3	3
	Durisols	TAXNWRB	WRB 2006 class			1	1
	Ferralsols	TAXNWRB	WRB 2006 class			5	5
	Fluvisols	TAXNWRB	WRB 2006 class			5	5
	Gleysols	TAXNWRB	WRB 2006 class			6	6
	Gypsisols	TAXNWRB	WRB 2006 class			2	2
	Histosols	TAXNWRB	WRB 2006 class			5	5
	Kastanozems	TAXNWRB	WRB 2006 class			2	2
	Leptosols	TAXNWRB	WRB 2006 class			5	5
	Lixisols	TAXNWRB	WRB 2006 class			3	3
	Luvisols	TAXNWRB	WRB 2006 class			9	9
	Nitisols	TAXNWRB	WRB 2006 class			2	2
	Phaeozems	TAXNWRB	WRB 2006 class			3	3
	Planosols	TAXNWRB	WRB 2006 class			5	5
	Plinthosols	TAXNWRB	WRB 2006 class			2	2
	Podzols	TAXNWRB	WRB 2006 class			2	2
	Regosols	TAXNWRB	WRB 2006 class			6	6
	Solonchaks	TAXNWRB	WRB 2006 class			3	3
	Solonetz	TAXNWRB	WRB 2006 class			4	4
	Stagnosols	TAXNWRB	WRB 2006 class			1	1
	type	TAXNWRB	WRB 2006 class			1	1
	Umbrisols	TAXNWRB	WRB 2006 class			2	2
	Vertisols	TAXNWRB	WRB 2006 class			4	4
Grand Total				**1**	**15**	**122**	**138**

The European Soil Database
Attributes of the SGDBE version 2/3/4 inside QUICKSCan:
Complete overview of the ESDB:
https://esdac.jrc.ec.europa.eu/ESDB_Archive/ESDBv3/Legend/sg_attr.htm

AGLIM1: Code of the most important limitation to agricultural use

0 No information
1 No limitation to agricultural use
2 Gravelly (over 35% gravel diameter < 7.5 cm)
3 Stony (presence of stones diameter > 7.5 cm, impracticable mechanisation)
4 Lithic (coherent and hard rock within 50 cm)
5 Concretionary (over 35% concretions diameter < 7.5 cm near the surface)
6 Petrocalcic (cemented or indurated calcic horizon within 100 cm)
7 Saline (electric conductivity > 4 mS.cm-1 within 100 cm)
8 Sodic (Na/T > 6% within 100 cm)
9 Glaciers and snow-caps
10 Soils disturbed by man (i.e. landfills, paved surfaces, mine spoils)
11 Fragipans
12 Excessively drained
13 Almost always flooded
14 Eroded phase, erosion
15 Phreatic phase (shallow water table)
16 Duripan (silica and iron cemented subsoil horizon)
17 Petroferric horizon
18 Permafrost

ROO: Depth class of an obstacle to roots

0 No information
1 No obstacle to roots between 0 and 80 cm
2 Obstacle to roots between 60 and 80 cm depth
3 Obstacle to roots between 40 and 60 cm depth
4 Obstacle to roots between 20 and 40 cm depth
5 Obstacle to roots between 0 and 80 cm depth
6 Obstacle to roots between 0 and 20 cm depth

TEXT-SRF-DOM: Dominant surface textural class

0 No information
9 No mineral texture (Peat soils)
1 Coarse (18% < clay and > 65% sand)
2 Medium (18% < clay < 35% and >= 15% sand, or 18% < clay and 15% < sand < 65%)
3 Medium fine (< 35% clay and < 15% sand)
4 Fine (35% < clay < 60%)
5 Very fine (clay > 60 %)

WR: Dominant annual average soil water regime class of the soil profile

0 No information
1 Not wet within 80 cm for over 3 months, nor wet within 40 cm for over 1 month
2 Wet within 80 cm for 3 to 6 months, but not wet within 40 cm for over 1 month
3 Wet within 80 cm for over 6 months, but not wet within 40 cm for over 11 months
4 Wet within 40 cm depth for over 11 months

WRB-LEV1 :Soil reference group code from the World Reference Base (WRB) for Soil Resources

AB Albeluvisol
AC Acrisol
AL Alisol
AN Andosol
AR Arenosol
AT Anthrosol
CH Chernozem
CL Calcisol
CM Cambisol
CR Cryosol
DU Durisol
FL Fluvisol
FR Ferralsol

GL Gleysol
GY Gypsisol
HS Histosol
KS Kastanozem
LP Leptosol

LV Luvisol
LX Lixisol
NT Nitisol
PH Phaeozem
PL Planosol
PT Plinthosol
PZ Podzol

RG Regosol
SC Solonchak
SN Solonetz
UM Umbrisol
VR Vertisol
1 Town
2 Soil disturbed by man
3 Water body
4 Marsh
5 Glacier
6 Rock outcro

DGH = Depth to a gleyed horizon.

S = Shallow (< 40 cm)
M = Moderate (40 - 80 cm)
D = Deep (80 - 120 cm)
V = Very deep (> 120 cm)

DR = Depth to rock.

S = Shallow (< 40 cm)
M = Moderate (40 - 80 cm)
D = Deep (80 - 120 cm)
V = Very deep (> 120 cm)

TEXT = Dominant surface textural class (infered).

1 = Coarse (clay < 18 % and sand > 65 %)
2 = Medium (18% < clay < 35% and sand > 15%,\or clay < 18% and 15% < sand < 65%)
3 = Medium fine (clay < 35 % and sand < 15 %)
4 = Fine (35 % < clay < 60 %)
5 = Very fine (clay > 60 %)
7 = No texture (because of rock outcrop)
8 = No texture (because of organic layer)
6 = No texture (other cases)
0 = No information
# = No information

VS = Volume of stones

00 = 0 % stones
10 = 10 % stones
15 = 15 % stones
20 = 20 % stones

WRB-ADJ1: First soil adjective code from the World Reference Base (WRB) for Soil Resources

ll	Lamellic
lv	Luvic
lx	Lixic
ab	Albic
ac	Acric
ad	Aridic
ae	Aceric
ah	Anthropic
ai	Aric
al	Alic
am	Anthric
an	Andic
ao	Acroxic
ap	Abruptic
aq	Anthraquic
ar	Arenic
au	Alumic
ax	Alcalic
az	Arzic
ca	Calcaric
cb	Carbic
cc	Calcic
ch	Chernic
cl	Chloridic
cn	Carbonatic
cr	Chromic
ct	Cutanic
cy	Cryic
dn	Densic
du	Duric
dy	Dystric
es	Eutrisilic
et	Entic
eu	Eutric
fg	Fragic
fi	Fibric
fl	Ferralic
fo	Folic
fr	Ferric
fu	Fulvic
fv	Fluvic
ga	Garbic
gc	Glacic
ge	Gelic
gi	Gibbsic
gl	Gleyic
gm	Grumic
gp	Gypsiric
gr	Geric
gs	Glossic
gt	Gelistagnic
gy	Gypsic
gz	Greyic
ha	Haplic
hg	Hydragric
hi	Histic
hk	Hyperskeletic
ht	Hortic
hu	Humic
hy	Hydric
ir	Irragric
le	Leptic
li	Lithic
me	Melanic
mg	Magnesic
mo	Mollic
ms	Mesotrophic
mz	Mazic
na	Natric
ni	Nitic
oa	Oxyaquic
oh	Ochric
om	Ombric
or	Orthic
pa	Plaggic
pc	Petrocalcic
pd	Petroduric
pe	Pellic
pf	Profondic
pg	Petrogypsic
ph	Pachic
pi	Placic
pl	Plinthic
pn	Planic
po	Posic
pp	Petroplinthic
pr	Protic
ps	Petrosalic
pt	Petric
rd	Reductic
rg	Regic
rh	Rheic
ro	Rhodic
rp	Ruptic
rs	Rustic
ru	Rubic
rz	Rendzic
sa	Sapric
sd	Spodic
si	Silic
sk	Skeletic
sl	Siltic
so	Sodic
sp	Spolic
st	Stagnic
su	Sulphatic
sz	Salic
tf	Tephric
ti	Thionic
tr	Terric
tu	Turbic
tx	Toxic
ty	Takyric
ub	Urbic
um	Umbric
vi	Vitric
vm	Vermic
vr	Vertic
vt	Vetic
xa	Xanthic
ye	Yermic
1	Town
2	Soil disturbed by man
3	Water body
4	Marsh
5	Glacier
6	Rock outcrops

WRB-FULL: Full soil code from the World Reference Base (WRB) for Soil Resources

AB	Albeluvisol
ABal	Alic Albeluvisol
ABap	Abruptic Albeluvisol
ABar	Arenic Albeluvisol
ABau	Alumic Albeluvisol
ABeun	Endoeutric Albeluvisol
ABfg	Fragic Albeluvisol
ABfr	Ferric Albeluvisol
ABge	Gelic Albeluvisol
ABgl	Gleyic Albeluvisol
ABha	Haplic Albeluvisol
ABhi	Histic Albeluvisol
ABsl	Siltic Albeluvisol
ABst	Stagnic Albeluvisol
ABum	Umbric Albeluvisol
AC	Acrisol
ACab	Albic Acrisol
ACan	Andic Acrisol
ACap	Abruptic Acrisol
ACar	Arenic Acrisol
ACau	Alumic Acrisol
ACcr	Chromic Acrisol
ACdyh	Hyperdystric Acrisol
ACfr	Ferric Acrisol
ACgl	Gleyic Acrisol
ACgr	Geric Acrisol
ACha	Haplic Acrisol
AChu	Humic Acrisol
ACle	Leptic Acrisol
ACll	Lamellic Acrisol
ACohh	Hyperochric Acrisol
ACpf	Profondic Acrisol
ACpl	Plinthic Acrisol
ACro	Rhodic Acrisol
ACsk	Skeletic Acrisol
ACst	Stagnic Acrisol
ACum	Umbric Acrisol
ACvi	Vitric Acrisol
ACvt	Vetic Acrisol
AL	Alisol
ALab	Albic Alisol
ALan	Andic Alisol
ALap	Abruptic Alisol
ALar	Arenic Alisol
ALcr	Chromic Alisol
ALdyh	Hyperdystric Alisol
ALfr	Ferric Alisol
ALgl	Gleyic Alisol
ALha	Haplic Alisol
ALhu	Humic Alisol
ALll	Lamellic Alisol
ALni	Nitic Alisol
ALpf	Profondic Alisol
ALpl	Plinthic Alisol
ALro	Rhodic Alisol
ALsk	Skeletic Alisol
ALst	Stagnic Alisol
ALum	Umbric Alisol
ALvr	Vertic Alisol
AN	Andosol
ANao	Acroxic Andosol
ANar	Arenic Andosol
ANca	Calcaric Andosol
ANdu	Duric Andosol
ANdy	Dystric Andosol
ANes	Eutrisilic Andosol
ANeu	Eutric Andosol
ANfu	Fulvic Andosol
ANgl	Gleyic Andosol
ANha	Haplic Andosol
ANhi	Histic Andosol
ANhy	Hydric Andosol
ANle	Leptic Andosol
ANlv	Luvic Andosol
ANme	Melanic Andosol
ANmo	Mollic Andosol
ANph	Pachic Andosol
ANpi	Placic Andosol
ANsi	Silic Andosol
ANsk	Skeletic Andosol
ANso	Sodic Andosol
ANth	Thaptic Andosol
ANum	Umbric Andosol
ANvi	Vitric Andosol
ANvt	Vetic Andosol
AR	Arenosol
ARab	Albic Arenosol
ARad	Aridic Arenosol
ARca	Calcaric Arenosol
ARduw	Hypoduric Arenosol
ARdy	Dystric Arenosol
AReu	Eutric Arenosol
ARfg	Fragic Arenosol
ARfl	Ferralic Arenosol
ARge	Gelic Arenosol
ARgl	Gleyic Arenosol
ARgp	Gypsiric Arenosol
ARha	Haplic Arenosol
ARll	Lamellic Arenosol
ARlvw	Hypoluvic Arenosol
ARpl	Plinthic Arenosol
ARpr	Protic Arenosol
ARru	Rubic Arenosol
ARszw	Hyposalic Arenosol
ARtf	Tephric Arenosol
ARye	Yermic Arenosol
AT	Anthrosol
ATar	Arenic Anthrosol
ATfl	Ferralic Anthrosol
ATgl	Gleyic Anthrosol
AThg	Hydragric Anthrosol
ATht	Hortic Anthrosol
ATir	Irragric Anthrosol
ATlv	Luvic Anthrosol
ATpa	Plaggic Anthrosol
ATrg	Regic Anthrosol
ATsd	Spodic Anthrosol
ATst	Stagnic Anthrosol
ATtr	Terric Anthrosol
CH	Chernozem
CHcc	Calcic Chernozem
CHch	Chernic Chernozem
CHgl	Gleyic Chernozem
CHgs	Glossic Chernozem
CHha	Haplic Chernozem
CHlv	Luvic Chernozem
CHsl	Siltic Chernozem
CHvm	Vermic Chernozem
CHvr	Vertic Chernozem
CL	Calcisol
CLad	Aridic Calcisol
CLcch	Hypercalcic Calcisol
CLccw	Hypocalcic Calcisol
CLgl	Gleyic Calcisol
CLha	Haplic Calcisol
CLle	Leptic Calcisol
CLlv	Luvic Calcisol
CLohh	Hyperochric Calcisol
CLpt	Petric Calcisol

CLsk Skeletic Calcisol
CLso Sodic Calcisol
CLszn Endosalic Calcisol
CLty Takyric Calcisol
CLvr Vertic Calcisol
CLye Yermic Calcisol
CM Cambisol
CMad Aridic Cambisol
CMan Andic Cambisol
CMca Calcaric Cambisol
CMcr Chromic Cambisol
CMdy Dystric Cambisol
CMeu Eutric Cambisol
CMfl Ferralic Cambisol
CMfv Fluvic Cambisol
CMge Gelic Cambisol
CMgl Gleyic Cambisol
CMgp Gypsiric Cambisol
CMgt Gelistagnic Cambisol
CMha Haplic Cambisol
CMle Leptic Cambisol
CMmo Mollic Cambisol
CMohh Hyperochric Cambisol
CMpl Plinthic Cambisol
CMro Rhodic Cambisol
CMsk Skeletic Cambisol
CMso Sodic Cambisol
CMst Stagnic Cambisol
CMszn Endosalic Cambisol
CMty Takyric Cambisol
CMvi Vitric Cambisol
CMvr Vertic Cambisol
CMye Yermic Cambisol
CR Cryosol
CRad Aridic Cryosol
CRan Andic Cryosol
CRcc Calcic Cryosol
CRgc Glacic Cryosol
CRgl Gleyic Cryosol
CRgy Gypsic Cryosol
CRha Haplic Cryosol
CRhi Histic Cryosol
CRle Leptic Cryosol
CRli Lithic Cryosol
CRmo Mollic Cryosol
CRna Natric Cryosol
CRoa Oxyaquic Cryosol
CRst Stagnic Cryosol
CRsz Salic Cryosol
CRti Thionic Cryosol
CRtu Turbic Cryosol
CRum Umbric Cryosol
CRye Yermic Cryosol
DU Durisol
DUad Aridic Durisol
DUar Arenic Durisol
DUcc Calcic Durisol
DUcr Chromic Durisol
DUgy Gypsic Durisol
DUha Haplic Durisol
DUle Leptic Durisol
DUlv Luvic Durisol
DUohh Hyperochric Durisol
DUpt Petric Durisol
DUty Takyric Durisol
DUvr Vertic Durisol
DUye Yermic Durisol
FL Fluvisol
FLad Aridic Fluvisol
FLar Arenic Fluvisol
FLca Calcaric Fluvisol
FLdy Dystric Fluvisol
FLeu Eutric Fluvisol
FLge Gelic Fluvisol
FLgl Gleyic Fluvisol
FLgp Gypsiric Fluvisol
FLha Haplic Fluvisol
FLhi Histic Fluvisol
FLhu Humic Fluvisol
FLmo Mollic Fluvisol
FLsk Skeletic Fluvisol
FLso Sodic Fluvisol
FLst Stagnic Fluvisol
FLsz Salic Fluvisol
FLtf Tephric Fluvisol
FLti Thionic Fluvisol
FLty Takyric Fluvisol
FLum Umbric Fluvisol
FLye Yermic Fluvisol
FR Ferralsol
FRac Acric Ferralsol
FRan Andic Ferralsol
FRar Arenic Ferralsol
FRau Alumic Ferralsol
FRdyh Hyperdystric Ferralsol
FReuh Hypereutric Ferralsol
FRfr Ferric Ferralsol
FRgi Gibbsic Ferralsol
FRgl Gleyic Ferralsol
FRgr Geric Ferralsol
FRha Haplic Ferralsol
FRhi Histic Ferralsol
FRhu Humic Ferralsol
FRlx Lixic Ferralsol
FRmo Mollic Ferralsol
FRpl Plinthic Ferralsol
FRpo Posic Ferralsol
FRro Rhodic Ferralsol
FRstn Endostagnic Ferralsol
FRum Umbric Ferralsol
FRvt Vetic Ferralsol
FRxa Xanthic Ferralsol
GL Gleysol
GLan Andic Gleysol
GLap Abruptic Gleysol
GLaq Anthraquic Gleysol
GLar Arenic Gleysol
GLau Alumic Gleysol
GLax Alcalic Gleysol
GLca Calcaric Gleysol
GLcc Calcic Gleysol
GLdy Dystric Gleysol
GLeu Eutric Gleysol
GLge Gelic Gleysol
GLgy Gypsic Gleysol
GLha Haplic Gleysol
GLhi Histic Gleysol
GLhu Humic Gleysol
GLmo Mollic Gleysol
GLpl Plinthic Gleysol
GLso Sodic Gleysol
GLszn Endosalic Gleysol
GLtf Tephric Gleysol
GLti Thionic Gleysol
GLtx Toxic Gleysol
GLty Takyric Gleysol
GLum Umbric Gleysol
GLvi Vitric Gleysol
GY Gypsisol
GYad Aridic Gypsisol
GYaz Arzic Gypsisol
GYcc Calcic Gypsisol
GYdu Duric Gypsisol
GYgyh Hypergypsic Gypsisol
GYgyw Hypogypsic Gypsisol
GYha Haplic Gypsisol
GYle Leptic Gypsisol
GYlv Luvic Gypsisol
GYohh Hyperochric Gypsisol
GYpt Petric Gypsisol
GYsk Skeletic Gypsisol
GYso Sodic Gypsisol
GYszn Endosalic Gypsisol
GYty Takyric Gypsisol
GYvr Vertic Gypsisol
GYye Yermic Gypsisol
HS Histosol
HSax Alcalic Histosol
HScy Cryic Histosol
HSdy Dystric Histosol
HSeu Eutric Histosol
HSfi Fibric Histosol
HSfo Folic Histosol
HSgc Glacic Histosol
HSge Gelic Histosol
HSom Ombric Histosol
HSrh Rheic Histosol
HSsa Sapric Histosol
HSsz Salic Histosol
HSti Thionic Histosol
HStx Toxic Histosol
KS Kastanozem
KSam Anthric Kastanozem
KScc Calcic Kastanozem
KScr Chromic Kastanozem
KSgy Gypsic Kastanozem
KSha Haplic Kastanozem
KSlv Luvic Kastanozem
KSsl Siltic Kastanozem
KSsow Hyposodic Kastanozem
KSvr Vertic Kastanozem
LP Leptosol
LPad Aridic Leptosol
LPca Calcaric Leptosol
LPdy Dystric Leptosol
LPeu Eutric Leptosol
LPge Gelic Leptosol
LPgl Gleyic Leptosol
LPgp Gypsiric Leptosol
LPha Haplic Leptosol
LPhk Hyperskeletic Leptosol
LPhu Humic Leptosol
LPli Lithic Leptosol
LPmo Mollic Leptosol
LPrz Rendzic Leptosol
LPum Umbric Leptosol
LPvr Vertic Leptosol
LPye Yermic Leptosol
LV Luvisol
LVab Albic Luvisol
LVan Andic Luvisol
LVar Arenic Luvisol
LVcc Calcic Luvisol
LVcr Chromic Luvisol
LVct Cutanic Luvisol
LVdy Dystric Luvisol
LVfr Ferric Luvisol
LVgl Gleyic Luvisol
LVha Haplic Luvisol
LVle Leptic Luvisol
LVll Lamellic Luvisol
LVohh Hyperochric Luvisol
LVpf Profondic Luvisol
LVro Rhodic Luvisol
LVsow Hyposodic Luvisol
LVst Stagnic Luvisol
LVvi Vitric Luvisol
LVvr Vertic Luvisol
LX Lixisol
LXab Albic Lixisol
LXan Andic Lixisol
LXap Abruptic Lixisol
LXar Arenic Lixisol
LXcc Calcic Lixisol
LXcr Chromic Lixisol
LXfr Ferric Lixisol
LXgl Gleyic Lixisol
LXgr Geric Lixisol
LXha Haplic Lixisol
LXhu Humic Lixisol
LXle Leptic Lixisol
LXll Lamellic Lixisol
LXohh Hyperochric Lixisol
LXpf Profondic Lixisol
LXpl Plinthic Lixisol
LXro Rhodic Lixisol
LXst Stagnic Lixisol
LXvi Vitric Lixisol
LXvt Vetic Lixisol
NT Nitisol
NTal Alic Nitisol
NTan Andic Nitisol
NTau Alumic Nitisol
NTdy Dystric Nitisol
NTeu Eutric Nitisol
NTfl Ferralic Nitisol
NTha Haplic Nitisol
NThu Humic Nitisol
NTmo Mollic Nitisol
NTro Rhodic Nitisol
NTum Umbric Nitisol
NTvt Vetic Nitisol
PH Phaeozem
PHab Albic Phaeozem
PHan Andic Phaeozem
PHap Abruptic Phaeozem
PHca Calcaric Phaeozem
PHcr Chromic Phaeozem
PHgl Gleyic Phaeozem
PHgs Glossic Phaeozem
PHgz Greyic Phaeozem
PHha Haplic Phaeozem
PHle Leptic Phaeozem
PHlv Luvic Phaeozem
PHph Pachic Phaeozem
PHsk Skeletic Phaeozem
PHsl Siltic Phaeozem
PHso Sodic Phaeozem
PHst Stagnic Phaeozem
PHtf Tephric Phaeozem
PHvi Vitric Phaeozem
PHvm Vermic Phaeozem
PHvr Vertic Phaeozem
PL Planosol
PLab Albic Planosol
PLal Alic Planosol

PLar Arenic Planosol
PLau Alumic Planosol
PLax Alcalic Planosol
PLca Calcaric Planosol
PLcc Calcic Planosol
PLcr Chromic Planosol
PLdy Dystric Planosol
PLeu Eutric Planosol
PLfr Ferric Planosol
PLge Gelic Planosol
PLgl Gleyic Planosol
PLgr Geric Planosol
PLgy Gypsic Planosol
PLha Haplic Planosol
PLhi Histic Planosol
PLlv Luvic Planosol
PLmo Mollic Planosol
PLpf? Petroferric Planosol
PLpl Plinthic Planosol
PLro Rhodic Planosol
PLso Sodic Planosol
PLszn Endosalic Planosol
PLti Thionic Planosol
PLum Umbric Planosol
PLvr Vertic Planosol
PT Plinthosol
PTab Albic Plinthosol
PTac Acric Plinthosol
PTal Alic Plinthosol
PTap Abruptic Plinthosol
PTau Alumic Plinthosol
PTdun Endoduric Plinthosol
PTeun Endoeutric Plinthosol
PTfr Ferric Plinthosol
PTgr Geric Plinthosol
PTgs Glossic Plinthosol
PTha Haplic Plinthosol
PThu Humic Plinthosol
PTph Pachic Plinthosol
PTpt Petric Plinthosol
PTst Stagnic Plinthosol
PTum Umbric Plinthosol
PTvt Vetic Plinthosol
PZ Podzol
PZam Anthric Podzol
PZcb Carbic Podzol
PZdn Densic Podzol
PZet Entic Podzol
PZfg Fragic Podzol
PZge Gelic Podzol
PZgl Gleyic Podzol
PZha Haplic Podzol
PZhi Histic Podzol
PZll Lamellic Podzol
PZpi Placic Podzol
PZrs Rustic Podzol
PZsk Skeletic Podzol
PZst Stagnic Podzol
PZum Umbric Podzol
RG Regosol
RGad Aridic Regosol
RGah Anthropic Regosol
RGai Aric Regosol
RGanb Thaptoandic Regosol
RGar Arenic Regosol
RGca Calcaric Regosol
RGdy Dystric Regosol
RGeu Eutric Regosol
RGga Garbic Regosol
RGge Gelic Regosol
RGgl Gleyic Regosol
RGgp Gypsiric Regosol
RGgt Gelistagnic Regosol
RGha Haplic Regosol
RGhu Humic Regosol
RGle Leptic Regosol
RGohh Hyperochric Regosol
RGrd Reductic Regosol
RGsk Skeletic Regosol
RGsow Hyposodic Regosol
RGsp Spolic Regosol
RGst Stagnic Regosol
RGszw Hyposalic Regosol
RGtf Tephric Regosol
RGty Takyric Regosol
RGub Urbic Regosol
RGvib Thaptovitric Regosol
RGvm Vermic Regosol
RGye Yermic Regosol
SC Solonchak
SCad Aridic Solonchak
SCae Aceric Solonchak
SCcc Calcic Solonchak
SCcl Chloridic Solonchak
SCcn Carbonatic Solonchak
SCdu Duric Solonchak
SCge Gelic Solonchak
SCgl Gleyic Solonchak
SCgy Gypsic Solonchak
SCha Haplic Solonchak
SChi Histic Solonchak
SCmo Mollic Solonchak
SCoh Ochric Solonchak
SCps Petrosalic Solonchak
SCso Sodic Solonchak
SCst Stagnic Solonchak
SCsu Sulphatic Solonchak
SCszh Hypersalic Solonchak
SCty Takyric Solonchak
SCvr Vertic Solonchak
SCye Yermic Solonchak
SN Solonetz
SNab Albic Solonetz
SNad Aridic Solonetz
SNcc Calcic Solonetz
SNdu Duric Solonetz
SNgl Gleyic Solonetz
SNgy Gypsic Solonetz
SNha Haplic Solonetz
SNhu Humic Solonetz
SNmg Magnesic Solonetz
SNmo Mollic Solonetz
SNst Stagnic Solonetz
SNsz Salic Solonetz
SNty Takyric Solonetz
SNvr Vertic Solonetz
SNye Yermic Solonetz
UM Umbrisol
UMab Albic Umbrisol
UMam Anthric Umbrisol
UMar Arenic Umbrisol
UMfl Ferralic Umbrisol
UMge Gelic Umbrisol
UMgl Gleyic Umbrisol
UMha Haplic Umbrisol
UMhu Humic Umbrisol
UMle Leptic Umbrisol
UMsk Skeletic Umbrisol
UMst Stagnic Umbrisol
VR Vertisol
VRal Alic Vertisol
VRcc Calcic Vertisol
VRcr Chromic Vertisol
VRdu Duric Vertisol
VReu Eutric Vertisol
VRgm Grumic Vertisol
VRgp Gypsiric Vertisol
VRgy Gypsic Vertisol
VRha Haplic Vertisol
VRms Mesotrophic Vertisol
VRmz Mazic Vertisol
VRna Natric Vertisol
VRpe Pellic Vertisol
VRsow Hyposodic Vertisol
VRsz Salic Vertisol
VRti Thionic Vertisol
1 1 11 1 Town
2 2 22 2 Soil disturbed by man
3 3 33 3 Water body
4 4 44 4 Marsh
5 5 55 5 Glacier
6 6 66 6 Rock outcrops