Marginal lands for Growing Industrial Crops

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Type

R	Document, report	☐
DEM	Demonstrator, pilot, prototype	☐
DEC	Websites, patent fillings, videos, etc.	☐
OTHER		☒

Dissemination Level

PU	Public	☒
CO	Confidential, only for members of the consortium (including the Commission Services)	☐

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1 Publishable executive summary

This application is designed to let users visualize the MAGIC Marginal Land (MAEZ) maps:

- Marginal Land
- Marginal Land, combined with all individual factors

Maps for each factor separately:

- chemical
- climate
- fertility
- rooting
- terrain
- wetness
- intensity (current land use combined with intensity and indicators

The portal provides cross-platform access to the Marginal Land spatial datasets (MAEZ). Mouse-over the various icons to see what each does. Currently the application requires internet access. In the upper left of the application, you can search for a location. You can also zoom in/out, select the home key to return to the full extent, turn on your GPS, change the background base map, add the legend and select visible layers. The attribute tables can be accessed from the bottom of the screen when maps are visible.

To access the ESRI viewing tool for MAEZ open underneath link:
https://iiasa-spatial.maps.arcgis.com/apps/webappviewer/index.html?id=c0105c0d94c34048a1c32fba1d65a6b1

2 Introduction

This document explains access and contents of the second version of the database of the Marginal land map (MAP-DB, version 1) which was made available to project partners on the 21ste of December 2017 as is illustrated in the Figure 1 underneath.

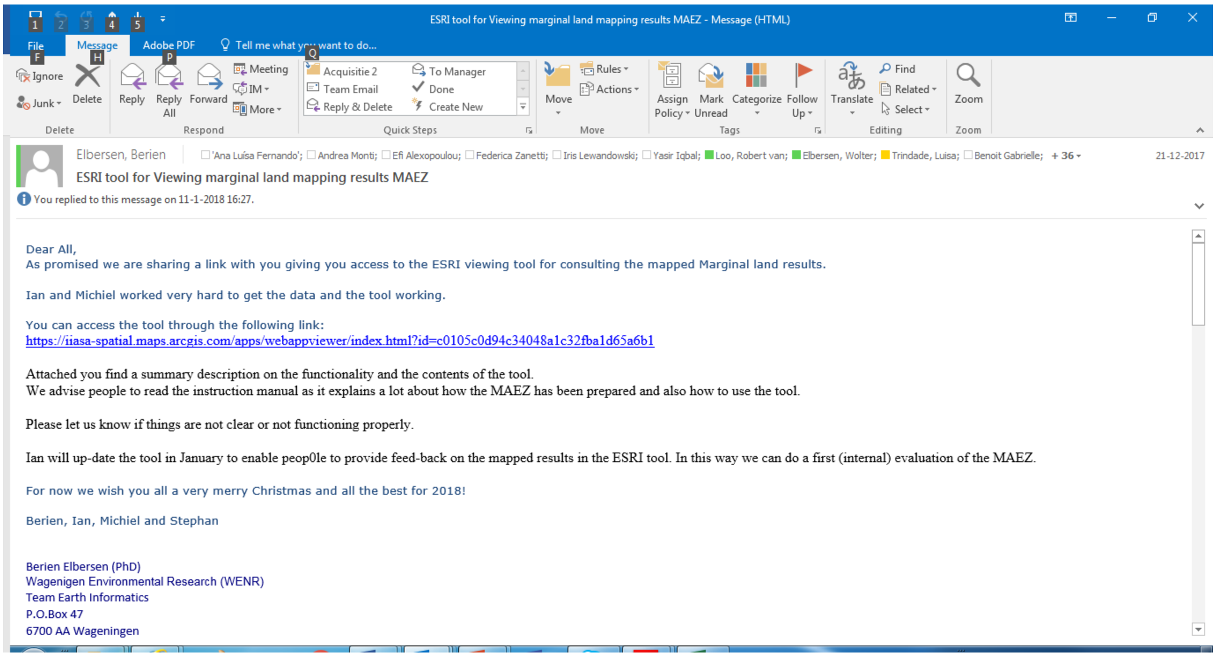


Figure 1 Launch of MAP-DB version 1 to the partners

To access the ESRI viewing tool for MAEZ open underneath link: https://iiasa-spatial.maps.arcgis.com/apps/webappviewer/index.html?id=c0105c0d94c34048a1c32fba1d65a6b1

If the link does not work copy it and paste it in the webrowser address bar.

When you open the ESRI tool you will see Figure 1:

Figure 2: View after opening the link and explanation of icons (In the clouds the functions of the icons are explained)

3 Marginal agri-environmental zonation (MAEZ)

The MAEZ layers are displayed in the ESRI tool. The MAEZ layers contained in the tool are displayed when one clicks on the icon:

In Figure 2 an overview is given of the MAEZ layers and in the following it is explained what these MAEZ layers mean and how they have been mapped.

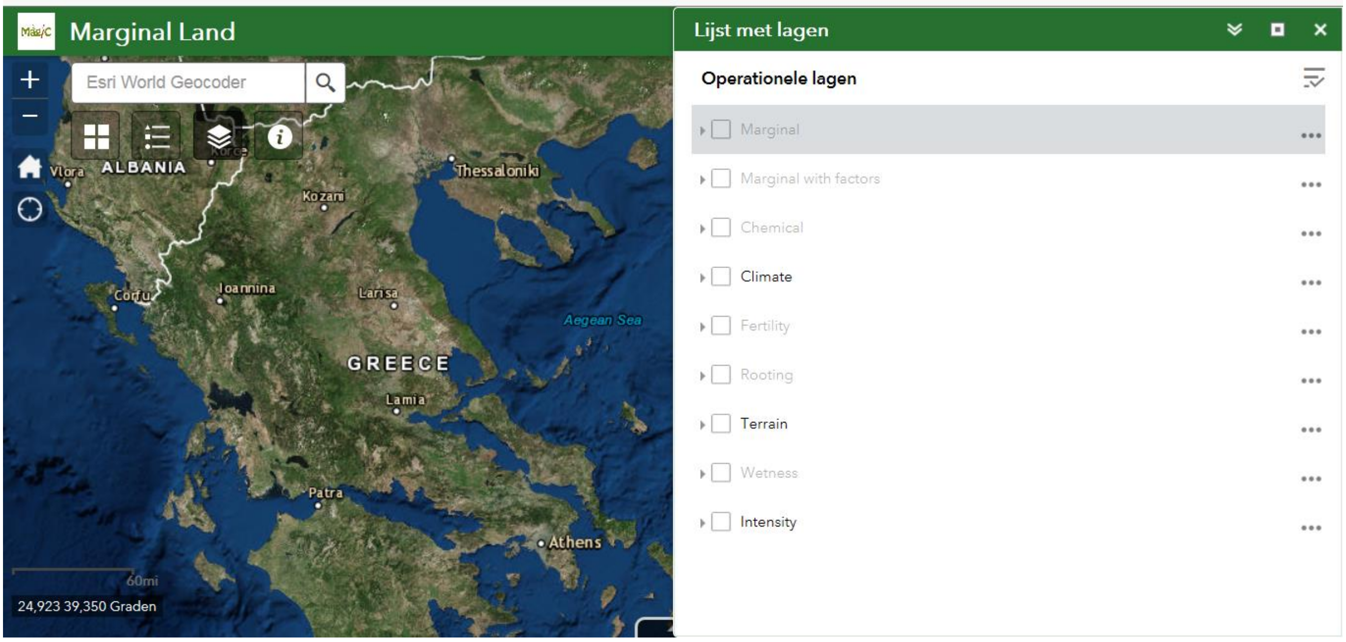


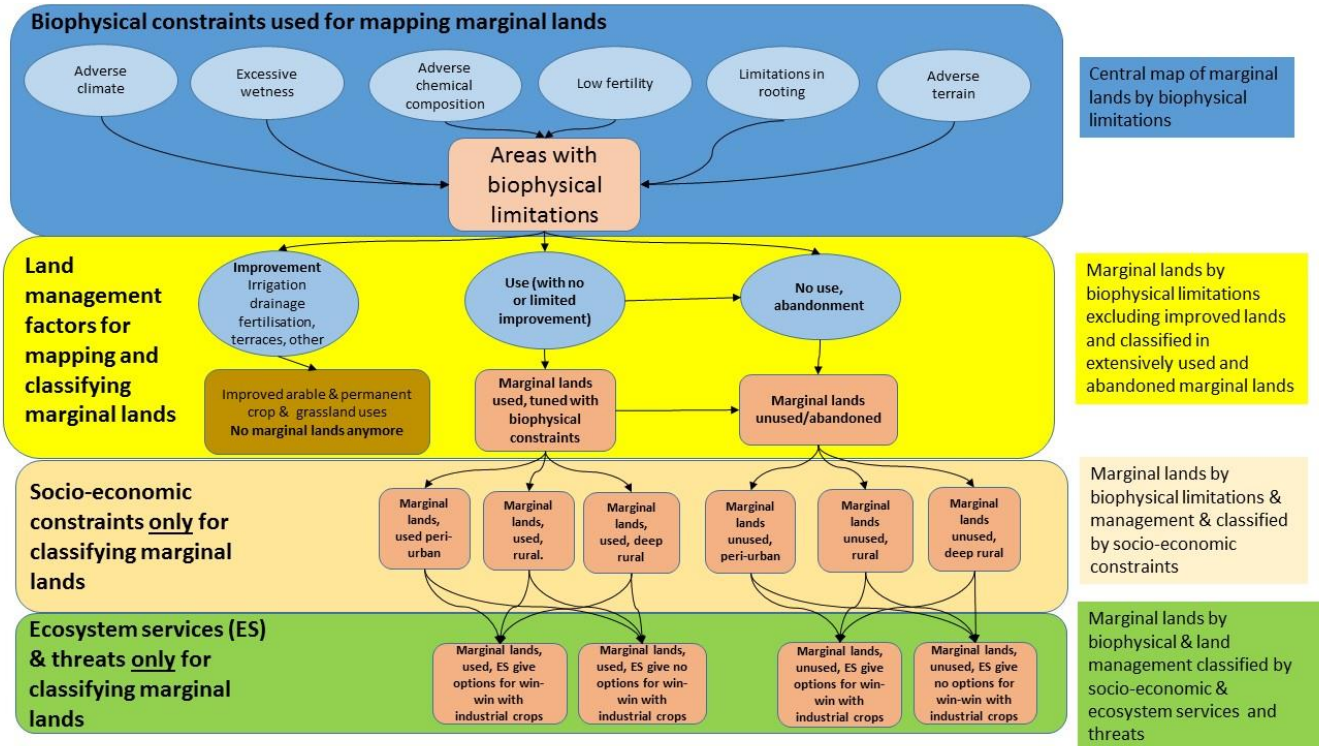
Figure 2 MAEZ layers displayed in ESRI tool

To select one MAEZ map layer to be displayed select one of the operational layers (see Figure 2, right panel).
Depending on the internet connection the loading of the map can take some time. We recommend to zoom in a smaller part of Europe (e.g. one country) to reduce the time for loading the selected MAEZ layer.
When the MAEZ layer is loaded you can click on every grid and then the ESRI tool display the MAEZ information for the grid selected (See also next part of this note).

- *Background marginal land mapping and elaboration of MAEZ in MAGIC*

The Marginal lands identification in MAGIC is based purely on the biophysical constraints identified and described by the JRC (Van Oorschoven et al., 2014 and Terres et al., 2014) to identify Areas of Natural Constraints (ANCs) in Europe. The biophysical constraints are clustered in 6 groups (see Figure 3) and after mapping they have been corrected for land management factors where current intensive land use gives proof of neutralisation of the natural constraints through measures like irrigation, drainage, soil fertility management, mulching and slope management measures like terraces.

Figure 3: Stepwise approach followed to mapping and classifying marginal lands for the M-AEZ



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 MAGIC D2.1 have been grouped into 6 clusters (compound land characteristics) of constraints:

1. **Adverse climate**
    a. Low temperature
    b. Dryness
2. **Excessive wetness**
    a. Excess soil moisture
    b. 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

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). See for further information on the pair-wise combinations Annex 2.

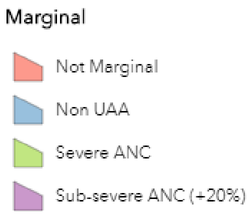
In the ESRI viewing tool the final map of Marginal lands is displayed, based on an integration of the 6 clusters of marginal constraints. In addition separate maps of the 6 clusters of biophysical constraints are also viewable in the ESRI tool.

In the following a description is given of all map layers included in the ESRI tool.

4 Description of operational layers of MAEZ included in ESRI tool

<u>Marginal with factors</u>

This map shows the final marginal land map that is based on an integration of the 6 sub-clusters on biophysical constraints (see Figure 6) but not showing the 6 background layers. The legend for this map is as follows:

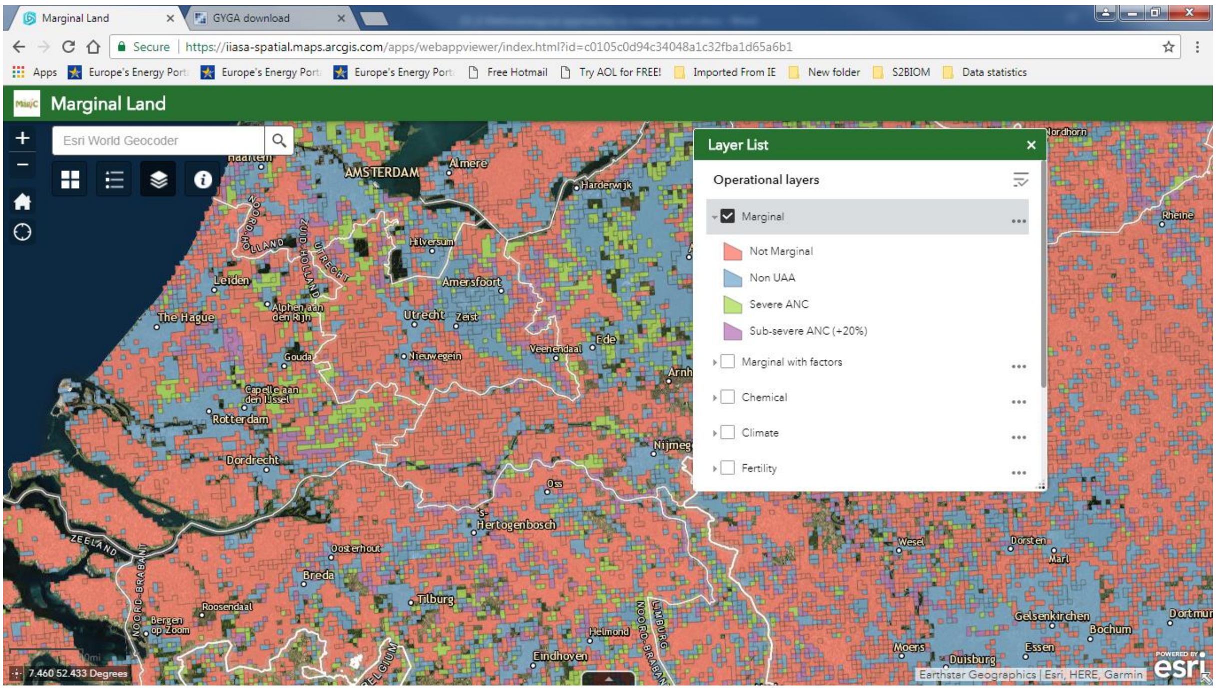


This map shows the final marginal land map that is based on an integration of the 6 sub-clusters on biophysical constraints (see Figure 4).

The explanation of the legend for this map is as follows:

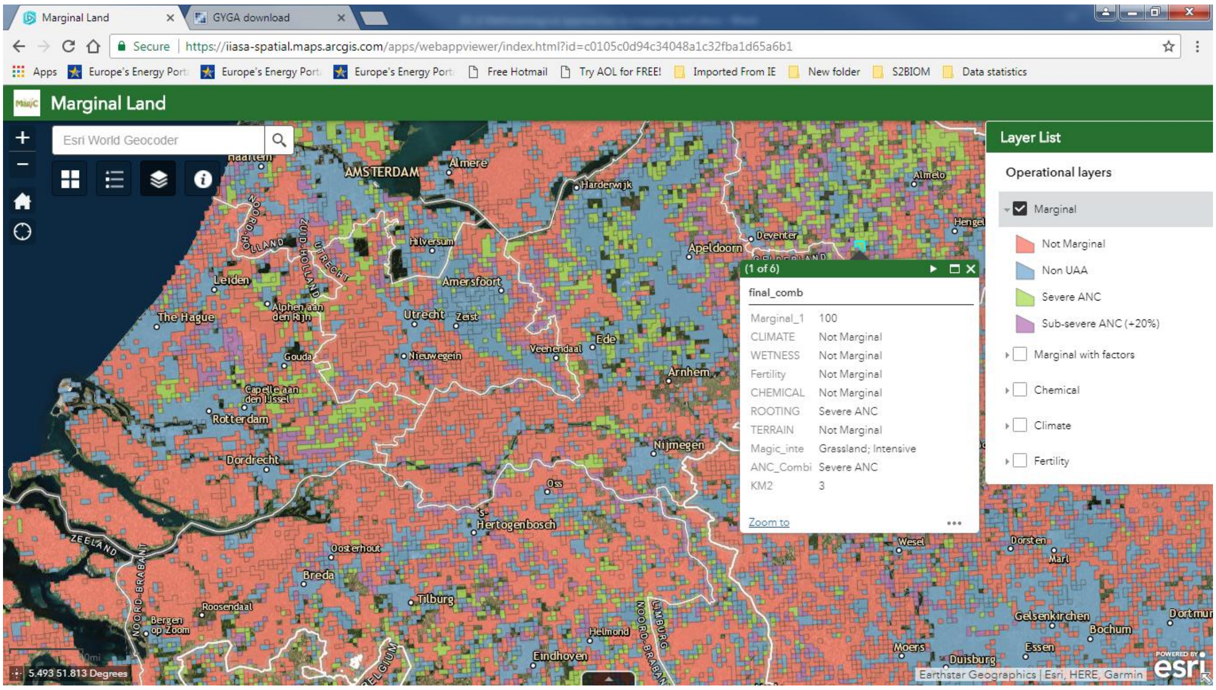
- <u>Not marginal</u>: This is agricultural land with no biophysical limitations
- <u>Non-UAA</u>: This is land that has not been classified as utilised Agricultural Area (UAA) (see Annex 1).
- <u>Severe ANC</u>: This land is classified as Marginal for at least one or more of the 6 clustered biophysical limitations
- <u>Sub-severe ANC (+20%)</u>: This land is sub-marginal as one or more of the 6 clustered biophysical limitations are scored within a 20% range of the threshold value for the marginal range. In the logic of the MAEZ they are NOT marginal, but they are near to marginal.

Figure 4 View of ESRI tool with a selection of the 'Marginal' operational layer



To understand why a grid is classified as marginal click on one grid and the score for that grid (or cluster of grid) is displayed (see Figure 5). In the example displayed in Figure 5 we can see that the grid selected is marginal because of limitations in rooting. The current land use is 'grassland, intensive' (see Annex 3 for explanation).

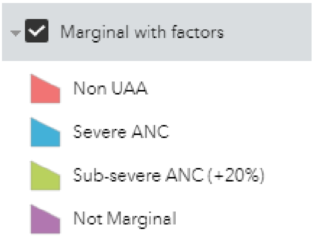
Figure 5 Example of display of information for one selected grid



Marginal

This map shows the final marginal land map that is based on an integration of the 6 sub-clusters on biophysical constraints (see Figure 6). The map is more simple in that it does not provide background information on what the determining marginal factors are in relation to the 6 sub-clusters of biophysical constraints.

The legend for this map is as follows:



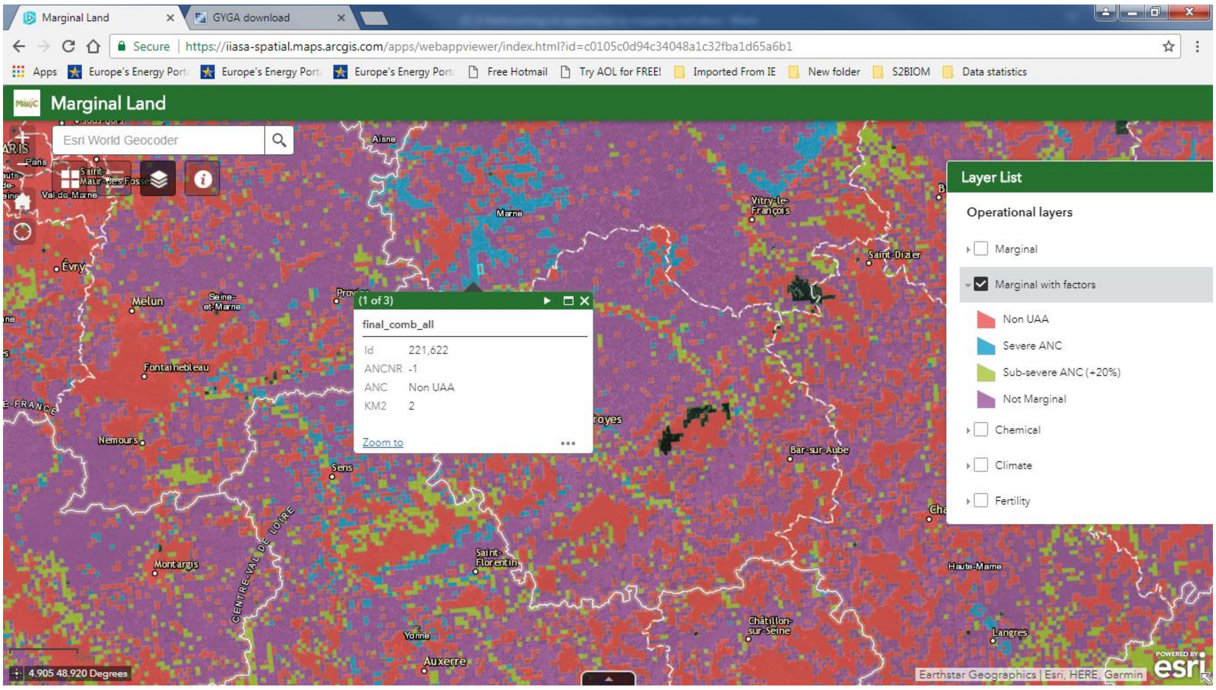
The explanation of the legend is as follows:

- Non-UAA: This is land that has not been classified as utilised Agricultural Area (UAA) (see Annex 1).
- Severe ANC: This land is classified as Marginal for at least one or more of the 6 clustered biophysical limitations
- Sub-severe ANC (+20%): This land is sub-marginal as one or more of the 6 clustered biophysical limitations are scored within a 20% range of the threshold value for the

marginal range. In the logic of the MAEZ they are NOT marginal, but they are near to marginal.

- Not marginal: This is agricultural land with no biophysical limitations

Figure 6 Example of display of information for one selected grid



Chemical

This clustered bio-physical limitation refers to ‘adverse chemical conditions’ .

The factors and threshold value for marginal land for the subfactors are presented underneath (Table 1).

Table 1: Subfactors and thresholds for marginal ranges for ‘adverse chemical conditions’

Cluster	Sub-factor	Description	Selection based on (JRC, Meuncheberg, other...)	Threshold for marginal lands
Adverse chemical conditions	Salinity (Ec)	Soils with high salinity content	Toth et al. (2008) and Van Oorschoven et al (2014)	Solonchaks, soils with a salic qualifier. high: ECse > 15 dS/m and more than 50% of the mapping unit area
	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
	Natural	Soils with high	JRC (Van Oorschoven et al,	Soils with Thionic

Cluster	Sub-factor	Description	Selection based on (JRC, Meuncheberg, other...)	Threshold for marginal lands
	toxicity (e.g. Al, S)	content of sulfur that have acidification potential upon drainage	2014) but with adapted thresholds/selections from the Reference Soil Groups (RSGs) of the World	qualifier
	Toxicity by pollutants	Soils that have been polluted by man mostly through waste disposal or industrial processes	Data not included yet (Toth et al, 2016)	NOT INCLUDED YET

This factor 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.

Toxicity in soils caused by human induced soil pollution is not taken into account in this. Although there is a report (with maps) published on soil pollution in Europe, these data were not available to the authors. Therefore this factor is ignored for current effort of mapping marginal lands.

Climate

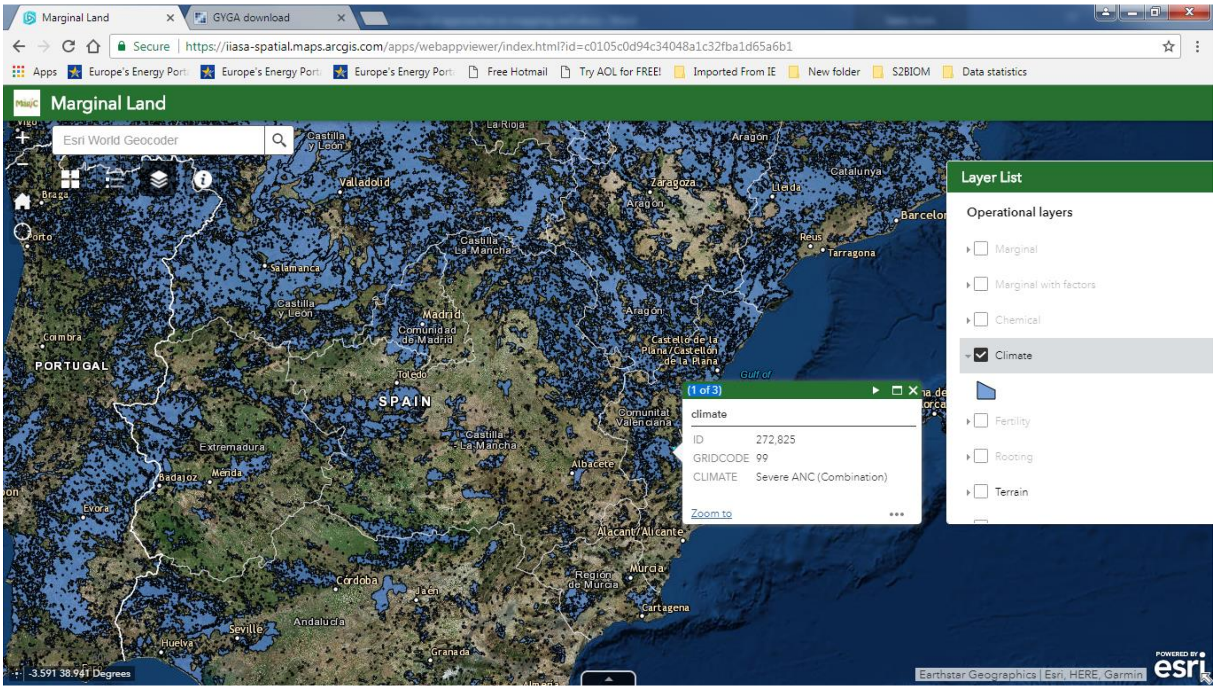
This clustered bio-physical limitation refers to ‘adverse climate’ .

The factors and threshold value for marginal land for the sub-factors are presented underneath (Table 2).

Table 2: Subfactors and thresholds for marginal ranges for ‘adverse climate’

Cluster	Sub-factor	Description	Selection based on (JRC, Meuncheberg, other...)	Threshold for marginal lands
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
	Dryness	Ratio of the annual precipitation (P) to the annual potential evapotranspiration (PET). Thresholdlimit: (P/PET ≤ 0.5)	JRC (Van Oorschoven et al, 2014)	P/PET ≤ 0.5

Figure 7 View with climate layer and grid selection information in ESRI viewing tool



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 rainfall 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 taking 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.

Of the overall marginal land classification, 12% (natural) to 11% (improved) is severely limited by adverse climate. Areas with severely low temperatures and short growing seasons are clearly concentrated in northern Europe (Sweden, Finland, Estonia and Latvia) and Schotland. 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 marginal in Estonia, Finland and Sweden (Table 5). 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 (6% decrease of the area to 23% through irrigation in areas with dryness).

Fertility

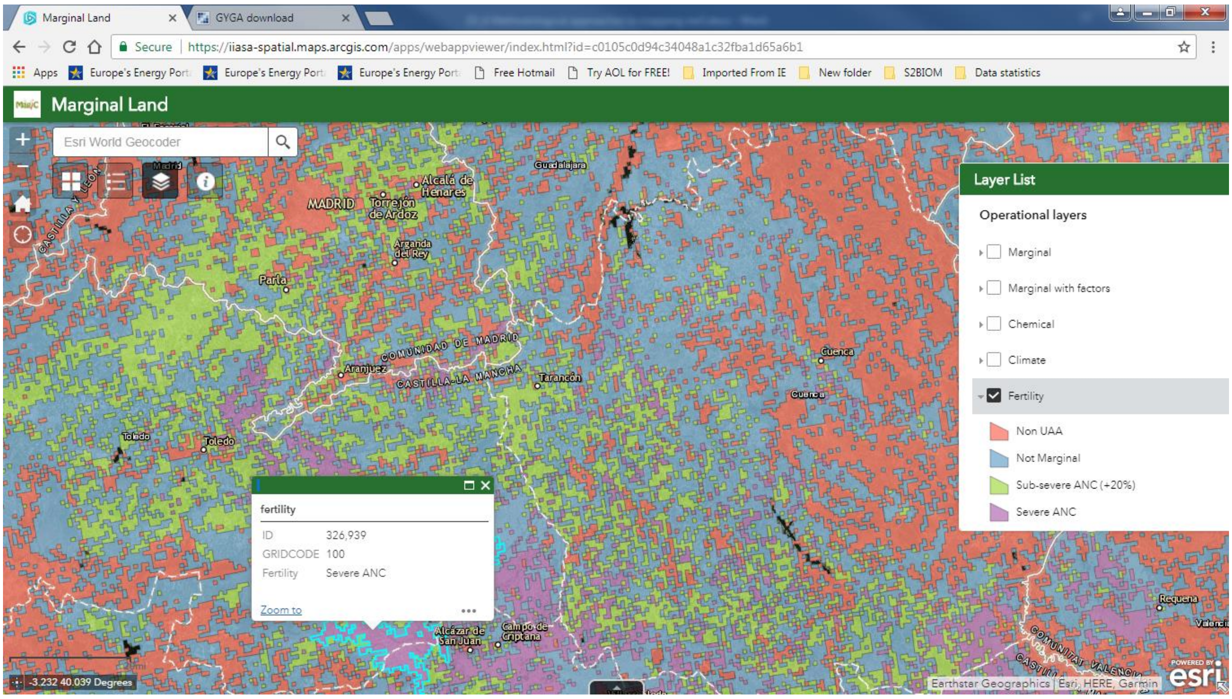
This clustered bio-physical limitation refers to 'low soil fertility' .

The factors and threshold value for marginal land for the sub-factors are presented underneath (Table 3).

Table 3: Subfactors and thresholds for marginal ranges for 'low soil fertility'

Cluster	Sub-factor	Description	Selection based on (JRC, Meuncheberg, other...)	Threshold for marginal lands
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)
	Soil organic carbon (%)	Low organic carbon containing soils as an indicator for soils with low fertility and low biomass turnover (0-30 cm)	JRC, but based on Mantel et al (2010)	SOC <0.5% average of depth range 0-30 cm

Figure 8 View with fertility limitations layer and grid selection information in ESRI viewing tool



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 therefore 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).

Rooting

This clustered bio-physical limitation refers to 'limitations in rooting' .
The factors and threshold value for marginal land for the sub-factors are presented underneath (Table 4).

Table 4: Subfactors and thresholds for marginal ranges for 'limitations in rooting'

Cluster	Sub-factor	Description	Selection based on (JRC, Meuncheberg, other...)	Threshold for marginal lands
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	Texture class in half or more (cumulatively) of the 100 cm soil surface is sand, loamy sand defined as: silt% + (2 x clay%) ≤ 30%
	Coarse fragments	> 35 cm (0-30 cm)	JRC (Van Oorschoven et al, 2014) but with adapted thresholds/selections	> 35 cm (0-30 cm)
	Organic soils	Organic matter ≥ 20%)	JRC (Van Oorschoven et al, 2014) but with adapted thresholds/selections	Histosols
	Surface stones and rocks	> 15% surface cover	JRC (Van Oorschoven et al, 2014) but with adapted thresholds/selections	> 15% surface cover
	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	Leptosols (<30 cm depth), Albeluvisols, Lithic, Petrocalcic, Fragipans, Duripans, Petroferric

Figure 9 View with rooting limitations layer and grid selection information in ESRI viewing tool

Root growth is directly related to possibility for uptake of nutrients and water and provides foothod 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 perannial crops. Peatlands are both ecological valuable and fragile. Cultivation of organic soils required drainage. This causes oxidation of the peat and CO_2 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.

Terrain

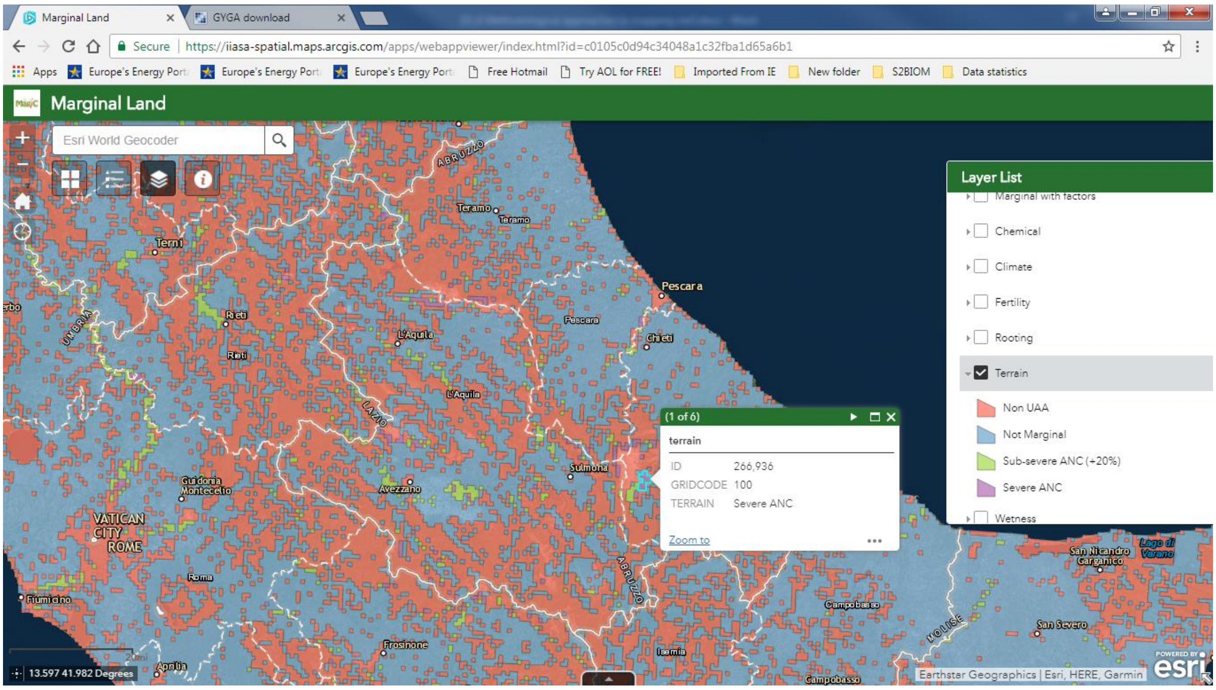
This clustered bio-physical limitation refers to 'adverse terrain' .

The factors and threshold value for marginal land for the sub-factors are presented underneath (Table 5).

Table 5: Subfactors and thresholds for marginal ranges for 'adverse terrain'

Cluster	Sub-factor	Description	Selection based on (JRC, Meuncheberg, other...)	Threshold for marginal lands
Adverse terrain conditions	Steep slope	Change of elevation with respect to planimetric distance (%).	JRC (Van Oorschoven et al, 2014) but with adapted thresholds/selections	> 20% (severe), > 15%(subsevere)
	Flood risk	Risk of flooding in relation to risk of damage to the field and to crops during the growing season	> 2 meter severe limitation 1 – 2 meter limitation < 1 m no limitation	

Figure 10 View with adverse terrain limitations layer and grid selection information in ESRI viewing tool



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 (prolongued) water ponding may damage crops.

Wetness

This clustered bio-physical limitation refers to 'Excessive wetness' .

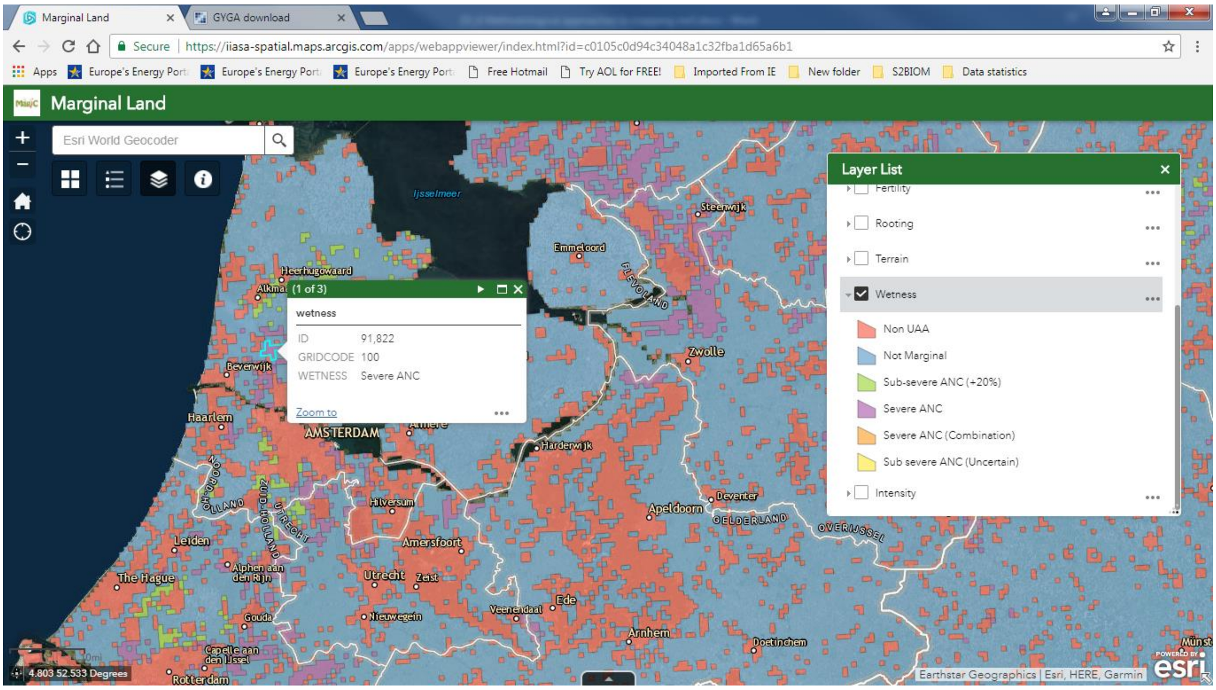
The factors and threshold value for marginal land for the sub-factors are presented underneath (Table 6).

Table 6: Subfactors and thresholds for marginal ranges for 'Excessive wetness'

Cluster	Sub-factor	Description	Selection based on (JRC, Meuncheberg, other…)	Threshold for marginal lands
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)	210 days severe and 170 days (subsevere)
	Limited soil drainage	Soils with high water tables throughout the year that have a lack of oxygen in the rooting zone, effectively limiting	JRC (Van Oorschoven et al, 2014) but with adapted thresholds/selections from the Reference Soil Groups (RSGs) of the	Gleysols, Histosols, Stagnosols, Planosol, Soils with primary qualifiers

Cluster	Sub-factor	Description	Selection based on (JRC, Meuncheberg, other...)	Threshold for marginal lands
		growth of crops	World Reference Base for Soil Resources	Histic, Gleyic and Stagnic and marshlands

Figure 11 View with wetness limitations layer and grid selection information in ESRI viewing tool



Excess of soil moisture (water content above field capacity) over prolonged 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 reflects the combined effects of climate, 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.

Intensity

This layer has been overlayed with the MAEZ to understand what the current land use and intensity of land use is in the areas that are classified as marginal. This land use intensity combination map is a combination of different data sources as specified in the Table 7.

Legend class	Corine Land Cover	Land intensity	Estel

	2012 (CLC)	classification	
Description	See Annex 1 for all CLC classes.	Land use intensity maps gridded in PEGASUS based on Perez-Soba et al., (2015), high, medium and low intensity farmland based on input-output	Active/managed cropland & grassland (Estel et al. (2015) based on NDVI index from MODIS analysed for 2001-2012)
Combi: medium or low intensive	Mixed CLC classes (see Annex 1, Table 1)	Classes medium and low intensive	No data specified
Combi: medium or low intensive > 25% years fallow	Mixed CLC classes (see Annex 1, Table 1)	Classes medium and low intensive	No management according to NDVI index in at least 3 of the 12 years
Cropland: medium or low intensive	Cropland classes (see Annex 1, Table 1)	Classes medium and low intensive	No management according to NDVI index in at least 3 of the 12 years
Grassland: Medium or low intensive > 25% years fallow	Grassland classes (see Annex 1, Table 1)	Classes medium and low intensive	No management according to NDVI index in at least 3 of the 12 years
Combi intensive	Mixed CLC classes (see Annex 1, Table 1)	Class intensive	Management according to NDVI index in at least 10 of the 12 years
No UAA	Non-agricultural CLC classes	-	-

Annex 1 Overview of agricultural-non agricultural land cover classes

The mapping of the first version of M-AEZ (excluding the contaminated lands) will be limitted 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**
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

CLC-NR	CLC Description_Level3	Agricultural mask MAGIC	Grazing	Cropping
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

Annex 2 Marginal by pair-wise combination

Biophysical factors have been identified for the classification of severe limitations 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.

<u>Pairwise combinations of sub-severe single factors</u>
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.