Soil Use and Management

Soil Use and Management, December 2014, **30**, 560–568 doi: 10.1111/sum.12145

Potential for using the World Reference Base for Soil Resources to identify less favoured areas†

H. E. Erdogan[1] & T. Tóth[2]

[1]*Turkish Republic Ministry of Food, Agriculture and Livestock, General Directorate of Agrarian Reform, Eskişehir Yolu, Lodumlu, Ankara, Turkey, and* [2]*Institute for Soil Sciences and Agricultural Chemistry, Centre for Agricultural Research, Hungarian Academy of Sciences, MTA ATK TAKI 1022 Budapest Herman Ottó út 15, Budapest, Hungary*

Abstract

The European Commission (EC) has adopted a resolution seeking to test a proposed set of eight soil and climate criteria that objectively assesses and delimits agricultural areas suffering from natural handicaps. In areas designated as 'Less Favoured Areas' (LFA) agricultural production is hampered by natural handicaps, for example difficult climatic conditions, steep slopes in mountain areas or poor soil productivity. To delineate LFAs, a set of factsheets were provided by the EC Joint Research Center for mapping the proposed common soil, climate and terrain criteria. The present study was performed to determine the suitability of the World Reference Base for Soil Resources, 2006 (WRB) soil classification system in terms of estimating LFA thresholds. It was concluded that the WRB soil categories are directly applicable for delineating areas affected by the LFA criteria for soil constraints Organic Soil and Vertic Properties. The WRB categories correctly defined areas constrained by Salinity and Sodicity, but since they are stricter, than the LFA criteria, further analysis is needed to delineate the larger areas corresponding to LFA criteria. The climate and terrain criteria of LFA are only broadly indicated by WRB categories.

Keywords: Less Favoured Areas, World Reference Base for Soil Resources

Introduction

In recent years, there has been extensive discussion on how rural development measures could be better integrated into the Common Agricultural Policy. For the period 2007–2013, the concept of Less Favoured Areas (LFAs) was part of Axis II of the Rural Development Policy (EC, 2005), which aimed 'to protect and enhance natural resources, as well as preserving high nature value farming and forestry systems and cultural landscapes in Europe's rural areas' by promoting sustainable land management. The aid scheme to farmers in Less Favoured Areas (LFA) needs to be renewed to improve its transparency and objectivity. Additionally, the delimitation of intermediate LFAs with respect to sustainable agricultural land management, passed by the Council in 2005, was designed for areas where the hazard of land abandonment is greatest. Therefore, the European Commission adopted a resolution in April 2009 calling for a new definition of LFA. Setting out a common framework to delineate 'intermediate' LFAs, that is those which are neither mountainous in character nor have specific handicaps, on the basis of common, objective criteria would enhance the transparency, robustness and coherence of the delineating system throughout the EU. With the help of scientific experts, the Commission has identified eight soil and climate criteria as a basis for delineating such areas objectively and clearly.

The LFA criteria are based on existing definitions, many of which are recognized in other national and continental land evaluation frameworks (Klingebiel & Montgomery, 1961; FAO, 1976, 1996, 2007; Le Bas *et al*., 2001, 2002; Fischer *et al*., 2002). The criteria were combined according to Liebig's law of the minimum and several were also applied in the Problem Land Approach (FAO, 1990).

To provide a solid basis for conforming to the required legislative proposal, a set of new factsheets was provided by

Correspondence: H. E. Erdogan, E-mail: mailto:hakki.erdogan@tarim.gov.tr; hakki.emrah.erdogan@gmail.com

†Though the Council Regulation (EC) No 1698/2005 refers to 'natural handicaps', the terminology 'Less Favoured Areas' will be utilized in this study since it is more wide spread.

Received April 2013; accepted after revision August 2014

the Joint Research Center (Van Orshoven *et al.*, 2008 and later updated as Van Orshoven *et al.*, 2012) for mapping the proposed common soil, climate and terrain criteria for LFA. Table 1 lists the criteria, their definitions and their respective threshold values.

The soil data available to the Commission at the pan-European level are not sufficiently detailed to simulate the application of the proposed common criteria on a community scale. For an overview of the spatial distribution of the constraints (Boettcher *et al.*, 2008) used three open databases. Soil data were extracted from the European Soil Data Base (http://eusoils.jrc.ec.europa.eu/esdb_archive/ESDB/Index.htm), climate data were obtained from the JRC MARS Database (http://www.marsop.info) and Terrain data from SRTM 100 DEM (http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1#methodology). These databases are not detailed enough for the settlement-wise delineation of less favoured areas inside member states. The guidelines (Eliasson *et al.*, 2010) recommend that Member States make use of the most suitable soil and land data available. However, national data are not homogeneous, and a common framework could only be achieved through harmonization. So it is necessary for each national dataset to be searched to find areas that correspond to the respective soil criterion. When the required soil characteristics are not present in the national soil dataset, one option could be to deduce their values on the basis of soil classes, which implicitly provide a great deal of information on soil properties.

The World Reference Base for Soil Resources (WRB) aims to provide a simple way of identifying, characterizing and naming major types of soils, acting as a common denominator for the comparison of national systems (Nachtergaele *et al.*, 2000). The diagnostic features applied by

Table 1 Soil, climate and terrain criteria for classifying land according to its suitability for generic agricultural activity. Threshold values indicate agricultural areas with severe natural handicap to agriculture

Criterion	Definition	Threshold
Climate		
Low temperature	Length of Growing Period (number of days) defined by number of days with daily average temperature >5 °C (LGPt5) OR	≤180 days
	Thermal-time sum (degree-days) for Growing Period defined by accumulated daily average temperature >5 °C	≤1500 degree-days
Dryness	Ratio of the annual precipitation (P) to the annual potential evapotranspiration (PET)	P/PET ≤ 0.5
Climate and soil		
Excess soil moisture	Number of days at or above field capacity	≥230 days
Soil		
Limited soil drainage	Areas which are water logged for a significant part of the year	Wet within 80 cm from the surface for over 6 months, or wet within 40 cm for over 11 months ORPoorly or very poorly drained soil ORGleyic colour pattern within 40 cm from the surface
Unfavourable texture and stoniness	Relative abundance of clay, silt, sand, organic matter (weight %) and coarse material (volumetric %) fractions	≥15% of topsoil volume is coarse material, including rock outcrop, boulder OR Topsoil texture class of sand, loamy sand defined as: silt% + (2 * clay%) ≤30% OR Topsoil texture class is heavy clay (≥60% clay) OR Organic soil (organic matter ≥30%) of at least 40 cm OR Topsoil texture class of clay, silty clay, sandy clay and vertic properties within 100 cm of the soil surface
Shallow rooting depth	Depth (cm) from soil surface to coherent hard rock or hard pan	≤30 cm
Poor chemical properties	Presence in topsoil of salts, exchangeable sodium, excessive acidity	Salinity: ≥4 deci-Siemens per meter (dS/m) OR Sodicity: ≥6 Exchangeable Sodium Percentage (ESP) OR Soil Acidity: pH ≤ 5 (in water)
Terrain		
Steep slope	Change of elevation with respect to planimetric distance (%)	≥15%

the WRB to distinguish soil categories are also used by several national classification systems, but the definitions and thresholds of the diagnostic features are often different. The first official version of the WRB was released at the 16th World Congress of Soil Science at Montpellier, France (FAO/ISRIC/ISSS, 1998). It was endorsed and adopted as the International Union of Soil Sciences (IUSS) standard for soil correlation and international communication. After 8 yrs of intensive worldwide testing and data collection, the second version of WRB was published in 2006 (IUSS Working Group WRB, 2006). The system has contributed to the understanding of soil science in the public debate and in the scientific community and has been used extensively. The WRB classification scheme was shown to be at least moderately correlated with soil-forming factors (climate, parent material and topography) and maintains an appropriate balance between soil management and soil genesis factors in its underlying principles (Gray *et al.*, 2011).

No studies have yet been performed to investigate the relationship between the delineation criteria for LFAs and the threshold values of the WRB soil class definitions. WRB is the most widespread correlation scheme in the EU, and its use is supported by the European Soil Bureau and the European Confederation of Soil Science Societies. There is thus an obvious need to check how useful the WRB categories are for the delineation of LFA areas. The aim of this study was to correlate the suggested LFA criteria with WRB thresholds and more specifically, to investigate the suitability of WRB soil definitions for estimating LFA thresholds.

As the definition of LFA criteria was an ongoing process until very recently, the most recently published versions (Van Orshoven *et al.*, 2008, 2012)[1] were considered in the present work.

Method

All LFA criteria were considered and their threshold values were compared with WRB elements, diagnostic criteria for horizons and the description of the reference soil (Figure 1).

First, each LFA criterion was interpreted from the point of view of agricultural production and soil formation. The WRB handbook was searched to determine whether the concept of that particular LFA constraint was part of the classification or not. When soil formation was used as a mental guide, a reply was sought to the question: what conditions lead to the appearance of a specific criterion? Criteria with a clearly defined geographical extension were conceptually redefined by the logic of soil formation. Maps of each criterion (Boettcher *et al.*, 2008) were then visually compared with the Soil Atlas of Europe, European Soil Bureau Network European Commission (2005) to find alternative proxies.

Secondly, the WRB (2006) handbook was searched for the occurrence of the criterion, possible proxies or other closely related properties.

Thirdly, when the criterion or its proxy was identified in the WRB handbook, in the diagnostic criteria of the horizons, the keys and the descriptions to the reference soil groups threshold values were searched.

According to goodness of match between the LFA and WRB threshold values, four classes were distinguished: (i) WRB thresholds and LFA criteria indicate the same process, (ii) WRB thresholds are less strict than LFA thresholds, (iii) WRB has a stricter thresholds than LFA and (iv) WRB and LFA thresholds match perfectly.

As an example, in estimating the LFA Limited Soil Drainage criterion, ‘gleying process’ was considered as the ‘occurrence of the concept’ and ‘*gleyic colour pattern*’ as ‘related properties’. The thresholds in the diagnostic criteria of the horizons, the keys and the descriptions for the reference soil groups were then analysed and finally *Gleysols* was found to be associated with the drainage criteria of LFA. The correlation between the WRB and LFA thresholds was classified in the category ‘indicates same process’. Both Limited Soil Drainage criterion and *Gleysols* are associated with the lack of gaseous phase in soils. But their threshold values are different.

The categories ‘WRB has a stricter thresholds than LFA’ and ‘WRB and LFA thresholds match perfectly’ were considered to be directly applicable for the delineation of LFA areas.

Results and discussion

Correlations between the thresholds used to delineate LFA and WRB soil categories are listed in Table 2. The WRB thresholds are the limits of taxonomical units; they focus on identifying distinct categories of soils based on properties which are measurable and/or observable in the field. On the other hand, LFA identifies areas where cultivation is barely profitable based on measurable environmental conditions and on numerical thresholds established from the results of long-term cultivation. The results revealed links between these different standpoints of LFA and WRB.

Low temperature

Low temperature limits crop growth and development due to its impact on photosynthesis and the time of leaf appearance (Table 1). This criterion was defined in the LFA system as the condition in which crop performance is limited by temperature during the growing period, which is not long

[1]A political agreement was reached on these criteria on 26th June 2013.

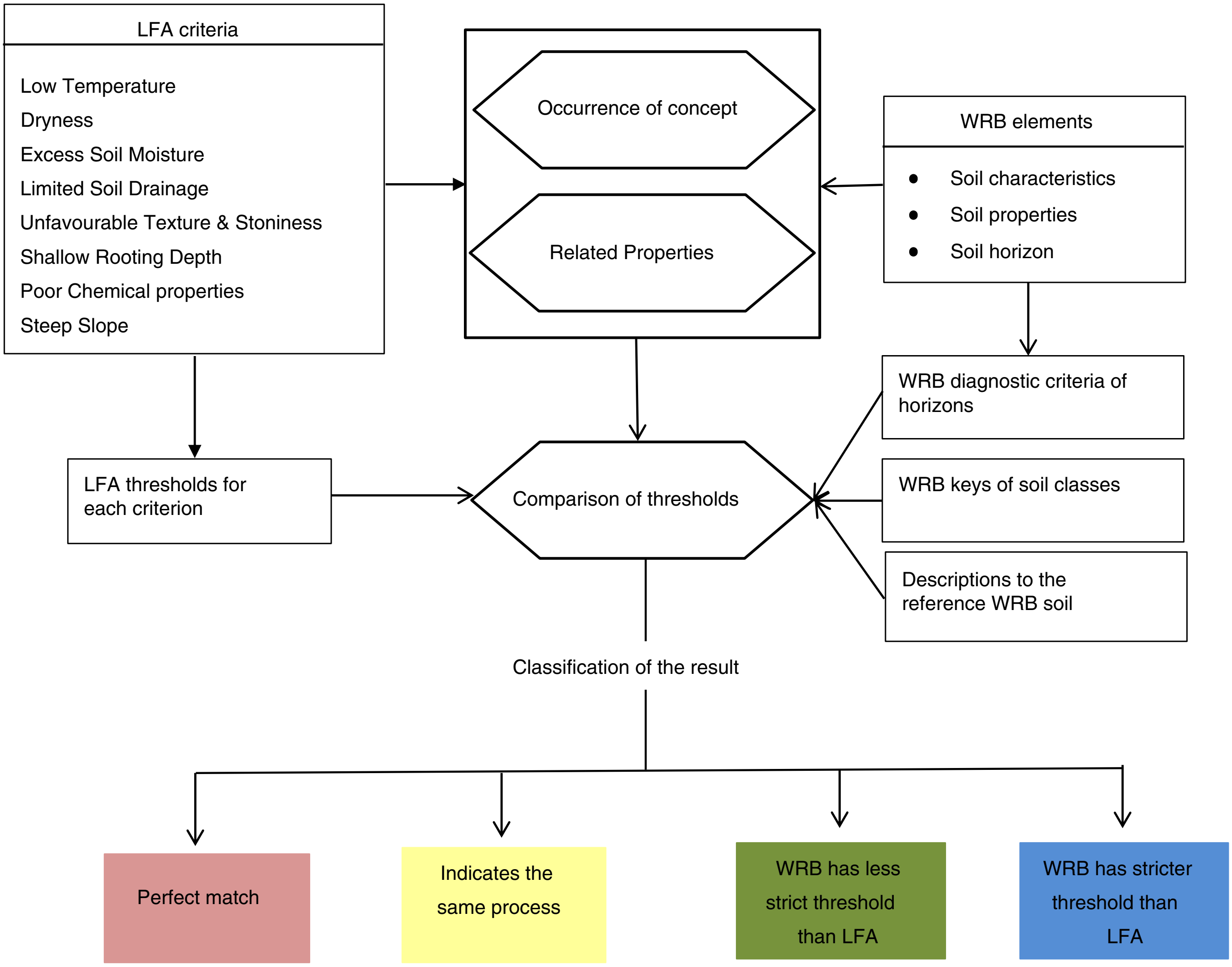

Figure 1 Flow chart of the methodological approach.

enough for normal plant growth and development. The concepts of thermal-time sums (TSb, degree C days) or length of growing period (LGPt, days) were suggested to assess Low Temperature criteria. The length of the growing period (LGPt5), that is the number of days with a daily average temperature (Tavg) above 5 °C, is calculated for each year. LGPt5 characterizes the days on which temperatures are conducive to crop growth. Thermal-time sums above a base temperature (Tb) of 5 °C (TS5) are calculated for each year by accumulating the difference between the daily Tavg and Tb values. The calculated values of LGPt5 and TS5 are then compared with the reference thresholds for severely limiting conditions shown in Table 1.

Since the WRB soil classification system does not consider climatic temperature values as a key to reference soil groups, the LFA thresholds for Low Temperature could not be assessed directly from the WRB classification except for *Cryosols* and *Cryic Horizon* (Table 2). However, the distribution and environmental description of these soil groups help to pinpoint areas affected by Low Temperature. *Albeluvisols* were found to be one such soil group due to the fact that they occur in a climate which is boreal with cold winters. Some *Albeluvisols* are located in continental regions of north-east Europe where permafrost was experienced in the Pleistocene. *Histosols* were also relevant soils, as they have organic material starting at the soil surface, immediately overlying ice in arctic and subarctic regions. Although they may also be found in the temperate and tropical climate zones, most *Histosols* are formed in cold regions and in cool mountainous areas. In the case of the Low Temperature criterion, the WRB classification therefore indicates the same process (Table 2).

Dryness

Dryness indices, such as the Aridity Index of the LFA system, express numerically the -severity of regular water stress at a location. The main use of this index is to

Table 2 Correlation between thresholds for delineating LFA and WRB, 2006 Soil Classes

LFA criterion	LFA threshold	Relevant WRB elements & classes	Relevant WRB diagnostic criteria
Climate			
Low temperature	LGPt5 < 180 days	Histosols, Albeluvisols	• Located in continental regions that had permafrost in the Pleistocene of northeast Europe
Dryness	P/PET ≤ 0.5	Aridic properties, Durisols, Calcisols, , Gypsisols Solonchaks	• A number of properties in surface horizons of soils occurring under arid conditions. • Soils in arid and semi-arid environments. • Soils with substantial accumulation of secondary lime in hilly land in arid and semi-arid regions. • Soils with gypsum, located in the driest parts of the arid climate zone
Climate and soil			
Excess soil moisture	≥ 230 days at or above field capacity	Gleyic colour pattern, Umbrisols, Gleysols, Histosols, Albeluvisols	• No soil moisture deficit • High soil moisture conditions during the year
Soil			
Limited soil drainage	Wet within 80 cm from the surface for over 6 months, or wet within 40 cm for over 11 months OR Poorly or very poorly drained soil OR Gleyic colour pattern within 40 cm from the surface	Gleyic colour pattern, Stagnic colour pattern, Solonetz, Gleysols, Stagnosols, Solonchaks, Histosols	• Based on soil colour variations, at least temporarily saturated with surface water, unless drained, • Soils in flat lands with impeded vertical and lateral drainage. • Wetland soils that, unless drained, are saturated with groundwater • Soils with a perched water table showing redoximorphic features caused by surface water. • In low lying areas with a shallow water table
Unfavourable texture and stoniness	≥15% of topsoil volume is coarse material, including rock outcrop, boulder OR	Episkeletic	• In the case of >40% gravel or other coarse fragments in top soil
	Topsoil texture class of sand, loamy sand defined as: silt% + (2 * clay%) ≤ 30% OR	Tephric material, Arenosols	• Tephric blown sand OR a weighted average texture of loamy sand or coarser
	Topsoil texture class is heavy clay (≥60% clay) OR	Vertisols, Acrisols, Luvisols	• Heavy clay soils OR Low/high base status, low/high-activity clay
	Organic soil (organic matter ≥30%) of at least 40 cm OR	Histic horizon, Histosols	• In the case of topsoil with >20% Organic Carbon content
	Topsoil texture class of clay, silty clay, sandy clay and vertic properties within 100 cm of the soil surface	Vertic properties, Vertisols	• In the case of topsoil with > 30% clay and slickensides or wedge-shaped aggregates
Shallow rooting depth	<30 cm	Leptosols	• >40% gravel or other coarse fragments averaged over a depth of 50 cm from the soil surface. • Limitation of depth by continuous rock within 25 cm of the soil surface
Poor chemical properties	Salinity: >4 (dS/m) in topsoil	Salic horizon, Solonchaks	>15 dS/m (if it is in the topsoil)
	Sodicity: >6 ESP in topsoil	Natric horizon, Solonetz	>15 ESP (if it is in the topsoil)
	Soil Acidity: pH ≤ 5 (in water)	Thionic horizon, umbric horizon, Acrisols, Albeluvisols, Anthrosols with plaggic horizons, Fluvisols	• Acid reaction (pH < 5.5), • Shallow, horizontal rooting pattern in the absence of a physical barrier
Terrain			
Steep slope	> 15%	Leptosols	• Mostly land occurring at high or medium altitude and with strongly dissected topography

(□), Indicates the same process; (□), Perfect match; (□), Less strict threshold than LFA; (□), Stricter threshold than LFA.

delineate areas affected by water stress at various levels of severity. In the assessment procedure, a full time-series of meteorological data is used to calculate the probability of occurrence at each location. Severe conditions correspond to UNEP Aridity Index values of ≤0.5, which hamper crop and pasture growth and reduce production opportunities. If the probability of exceeding the severe limit (UNEP Aridity Index ≤0.5) in an area occurs more than 20% of the time (i.e. this constraint occurs in at least 7 yrs out of 30), then the area is considered to be severely affected by excessively dry climatic conditions. Only with supplementary water supplies, such as irrigation, can normal crop and pasture growth be ensured in such areas.

In the WRB, on the other hand, the *aridic properties* were considered as characteristic features of dry conditions. The presence of *Solonchaks*, *Gypsisols*, *Durisols* and *Calcisols* may suggest the occurrence of dry conditions, since these Reference Soil Groups are characterized by accumulations of less soluble or soluble substances under conditions of high evaporation, like those encountered in closed basins in warm to hot climates with a well-defined dry season, as in arid zones. In the case of the Dryness criterion, the WRB classification indicates the same process (Table 2).

Excess soil moisture condition

Soil moisture is an important interface between agriculture and the environment. The 'Excess Soil Moisture Condition' of LFA system was defined as the duration of the period (measured in days) when soil moisture contents are at or larger than field capacity 'wet season'. For the assessment of the Excess Soil Moisture condition in soils, it was suggested that a classical water mass-balance model with a daily time step, calculating soil moisture status from the cumulative balance of precipitation and soil water removal through evapo-transpiration and percolation, and taking into account the antecedent soil moisture conditions, should be used to assess the duration of the saturated soil period.

The climatic water balance is one of the key elements of the Excess Soil Moisture Condition. Although it is hard to delineate this information from WRB, some clues can be found from the gleyic and stagnic colour patterns, which indicate that the soils may be over the field capacity or at zero water deficit during a long period of the year. *Umbrisols*, *Gleysols* and *Histosols* may indicate excess soil moisture, as these soils occur in humid climates with no moisture deficit. Furthermore, *Albeluvisols* may be selected because of their drainage problems and because of the climate, with frost during long winters. In the case of the Excess Soil Moisture Condition, the criterion WRB classification indicates the same process (Table 2).

Limited soil drainage

Poor drainage reduces the space available for the gaseous phase, in particular gaseous oxygen, in the rooting zone (Table 1). It increases the incidence and severity of soilborne pathogens and makes tillage impossible. Soil drainage class refers to the maintenance of the gaseous phase in the soil pores by the removal of water. The Limited Soil Drainage threshold of the LFA system was designed to identify soils on which farming operations for adapted crops are possible, but with severe yield reductions due to late planting or poor tillage, crop damage by transient anoxic conditions or plant pathogens resulting from poor drainage. Soil drainage is limiting if the soil is classified as poorly or very poorly drained, as defined by the Soil Survey Division Staff (1993, pp. 98–99).

The WRB defines several soil properties which are directly related to poor drainage, namely *gleyic* and *stagnic* features (Table 2), which are characteristic of the Reference Soil Groups *Gleysols* and *Stagnosols*. Other soil groups are also associated with poor internal drainage, for example (i) *Solonchaks* in low-lying areas with a shallow saline water table, (ii) *Solonetz* soils in flat lands with impeded vertical and lateral drainage, (iii) *Histosols* with a shallow water table. In the case of the Limited Soil Drainage criterion, the WRB classification indicates the same process (Table 2).

Unfavourable soil texture and stoniness

These features affect workability (ease of tillage), water infiltration, runoff and water movement within the soil (both down and up). Soil texture as a criterion refers to the particle size distribution of the soil. The LFA thresholds for severely limiting conditions were identified as (i) more than 15% volume made up by coarse fragments (>2 mm) of any kind in the topsoil or (ii) the dominant texture class (fine earth e.g. <2 mm) in the rooting zone is (ii_a) sand or loamy sand [silt% + (2 * clay%) ≤30%] or (ii_b) heavy clay (>60% clay) or (iii) organic soil defined as having an organic matter (>30%) layer of more than 40 cm either extending down from the surface or taken cumulatively within the upper 80 cm of the soil, (iv) texture classes of clay, silty clay or sandy clay with *vertic* properties as defined by the WRB (FAO-IUSS-ISRIC, 2006).

The LFA threshold for Coarse Materials was estimated using the definition of formative elements for second-level units of the WRB. *Episkeletic property* is identified as more than 40% gravel or other coarse fragments, may be representative of some of the lands in the LFA category facing severe constraints (more than 15% of topsoil volume is coarse material). The identification of *Episkeletic property* is an indication of the LFA threshold for coarse material, but is not sufficient for a full estimation. In the case of the Coarse Material criterion, the WRB classification indicates the same process (Table 2).

Tephric material, that is tephric blown sand, is generally associated with *Arenosols*, which have the weighted average texture of loamy sand or coarser, and indicates that the soil may reach the possible LFA threshold for sand or loamy sand. In the case of the Coarse Texture criterion, the WRB has a less strict threshold than LFA.

Heavy Clay (more than 60% clay content) is an LFA criterion. In WRB, the *argic horizon* has been defined as a subsurface horizon with distinctly higher clay content than the overlying horizon. Soil groups such as *Acrilsols* and *Luvisols*, which contain an *argic horizon,* may be representative of heavy clay. In certain cases, the high clay content may be due to illuviation. In the case of the Heavy Clay criterion, the WRB classification indicates the same process (Table 2).

According to the definition used for delimiting the Organic Soil criterion of LFA, *Histosols* with an organic carbon content of 20% or more qualify, but this WRB classification of *Histosols* only requires a 40-cm thick layer of organic material within 1 m, whereas in the definition given in LFA point iii) it is required within 80 cm. Therefore, a few soils with buried organic matter might not qualify according to the LFA definition above, but would still be defined as *Histosols* in WRB. In the case of the Organic Soil criterion, there is a perfect match between WRB and LFA.

The LFA threshold for the texture class of clay, silty clay, or sandy clay with vertic properties defined by the WRB (FAO-IUSS-ISRIC, 2006) must have either: (i) ≥30% clay throughout a thickness of at least 15 cm and one or both of the following characteristics: (a) slickensides or wedge-shaped aggregates or (b) cracks ≥1 cm wide that open and close periodically or (ii) a coefficient of linear expansion (COLE) of 0.06 or more averaged over a depth of 100 cm from the soil surface. In the case of the Vertic Properties criterion, there is a perfect match between WRB and LFA.

Shallow rooting depth

Roots are important for plants as they act as physical anchors and also extract soil-bound water and nutrients. For annual grain crops and grasses, the anchoring function does not require great depth. However, water is rapidly exhausted from shallow depths by the growing plant. Physical limitations to rooting depth are also impediments to normal tillage, so if plant roots cannot grow easily, it is unlikely that the plough can cut easily into the soil. The LFA threshold designated the severely limiting physical rooting depth as <30 cm.

Any proportion of rock outcrops or boulders within 15 cm of the surface and the physical rooting depth (<30 cm) has been defined in the LFA classification as a severe limitation for agriculture. The presence of WRB Reference Soil Group *Leptosols*, which have continuous rock within 25 cm of the soil surface, indicates severe constraints in terms of rooting depth and rock outcrops. In most cases, *Episkeletic property* may also be an indicator of rock outcrops. In the case of the Shallow Rooting Depth criterion, the WRB classification indicates the same process (Table 2).

Salinity (Poor chemical properties)

Soil salinity is the cause of significant losses of productivity, with some land taken entirely out of production. It generates several problems with regard to agriculture (i) making it difficult for plants to extract water from the altered soils, (ii) damaging the soil structure and increasing the content of toxic substances that may be limiting to plant growth (iii) and lead to more serious soil erosion, both by wind and by water, due to worsening soil structure and reduced vegetation cover. Salinity was defined as the presence of soluble salts in the land surface, in soil or rocks, or dissolved in water and it refers to the total amount of soluble salts in the soil. Although the crop response to soil salinity is crop specific, overall there are good arguments to accept the identified threshold as >4 dS/m (Huber *et al*., 2008) in LFA system.

The soil categories in the WRB that can be used for indicating severe salinity constraints on natural saline soils are *Solonchaks* and *salic* and *petrosalic* soils, which are completely in line with the LFA soil Salinity criteria, which require only 4 dS/m compared with 15 dS/m required by the WRB, if these values occur in the top soils. In the case of the Salinity criterion, the WRB has a stricter threshold than LFA.

Sodicity (Poor chemical properties)

Soil sodicity has two main effects on soils that indirectly influence agricultural production: (i) water may not be able to drain off, leading to waterlogging at the surface on flatter land; (ii) topsoil erodibility may increase, in which case sodic top soils are subject to dust storms in dry regions, while on sloping land, they are also subject to water erosion, which means that important fertile topsoil is lost from agricultural land. Sodicity has been defined as a characteristic of land in which the proportion of adsorbed sodium in the soil clay fraction is too high for plants to develop or survive. The threshold has been set to exchangeable sodium percentage (ESP) >6 because of the effect of high sodicity on the yield, chemical composition, protein and oil content, and because the uptake of nutrients is severely limited above this level (Huber *et al*., 2008).

According to the WRB classification, soils having a high content of exchangeable Na are classified as *Solonetz*, *natric* soils or *sodic* soils, so these categories can be used to indicate severe sodicity constraints if the soil salinity occurs in the topsoil. However, the WRB definition requires an ESP value higher than 15, so in the case of the Sodicity criterion, the WRB has a stricter threshold than LFA.

Soil acidity (Poor chemical properties)

The threshold for the Soil Acidity criterion of LFA was defined as topsoil with pH values of <5.0, severely impeding crop growth and having a negative impact on nutrient availability.

In the WRB, the definition of the *thionic horizon* definitely satisfies the LFA Soil Acidity criterion, being an extremely acid subsurface horizon with a pH of <4 (1:1 in water). Most *umbric horizons*, having an acid reaction pH [H_2O, 1:2.5] of less than about 5.5, may also be clear indicators of the LFA Soil Acidity criterion. *Acrisols,* with strongly weathered acid soils, *Albeluvisols,* with high clay illuviation, and *Fluvisols,* with a *Thionic* horizon, can also be used for assessing the correspondence with the LFA Soil Acidity criterion. In the case of the Soil Acidity criterion, the WRB has a less strict threshold than LFA.

Steep slope

Slope as such has little or no direct influence on the yield of crops. However, the steeper the slope the more difficult it becomes to manage the land and to grow crops. It is also associated with shallower soils in general and with a higher risk of soil erosion and landslides. Slopes above 15% have been accepted as the threshold which poses severe limitations for mechanized cultivation and necessitates the use of specific equipment.

In general, slope can be determined from neighbouring altitude data using numerical algorithms. The presence of the WRB Reference Soil Groups *Regosols* and *Leptosols* can be used to assess the LFA slope criteria in the case of soils located in mountainous terrain or for land at high or medium altitude with strongly dissected topography. In the case of the Steep Slope criterion, the WRB classification indicates the same process (Table 2).

Conclusions

The thresholds for the Climate and Terrain criteria of LFA have been defined using numerical limits. However, the definitions in the WRB classification involve diagnostic horizons, and the characteristics of soil groups according to our understanding of soil-forming processes under different climate and terrain conditions. It was concluded that the WRB classification could be used, but that there are limits to how well these estimate the LFA criteria for climate and terrain constraints.

There is no single answer to how to assess soil criteria appropriately in a common framework on a European scale. Various classification systems exist, focussing on different properties of the soils, which are represented in various ways, according to the national and regional characteristics, needs and purposes of the respective countries (Jones *et al.*, 2005). The LFA criteria for soil constraints such as Salinity, Sodicity, Organic Soil and Vertic Properties were clearly indicated by the WRB soil categories as these constraints are closely related to particular soil categories. Other criteria, such as Coarse Material, Heavy Clay, etc., could not be estimated easily by WRB, as they are not so closely related to particular soils.

The results of this research provide a scientifically sound basis for the correlation between the WRB soil classification and the biophysical criteria for delineating less favoured areas, with poor soil productivity or climatic conditions. One reason for the creation of the WRB was to provide a communication tool for different applications in related fields such as agriculture and the international use of pedological data not only by soil scientists but also by other users of soil and land information. However, WRB has limitations in the estimation of LFA criteria, as its overall aim was to classify soil groups, rather than focussing on limitations to agricultural production. It is best suited for delineating areas affected by agricultural handicaps related to Salinity, Sodicity, Organic Soil and Vertic Properties.

The category ‘WRB and LFA thresholds match perfectly’ in Table 2 shows that the WRB can be directly applied for the delineation of LFA areas constrained by Organic Soil and Vertic Properties. The category ‘WRB has a stricter threshold than LFA’, established for the Salinity and Sodicity criteria, means that the WRB is also applicable directly, but larger areas are delineated on the basis of the LFA criteria. The category ‘WRB has less strict thresholds than LFA’ in Table 2 is useful for locating regions where further analysis could delineate LFAs. The category ‘WRB thresholds and LFA criteria indicate the same process’ gives only a broad indication for the delineation of the LFA areas.

Acknowledgements

This study was carried out when the authors were working employed by the European Commission, Joint Research Center, Ispra, Italy. The second author acknowledges funding from the Hungarian National Science Foundation (OTKA), Grant No. NN79835. The authors are grateful for the useful comments of the anonymous reviewers of the manuscript.

References

Boettcher, K., Terres, J.-M., Ramos, F. & Aloe, A. 2008. Assessment of criteria for the identification of natural (soil and climate) handicaps to agriculture in Europe – Spatial assessment, Pan-European maps. Office for Official Publications of the European Communities, Luxembourg. p. 54.

EC, 2005. Council Regulation No. 1698/2005 of 20.09.2005. Official Journal L 277/1, 21.10.2005.

Eliasson, Å., Jones, R.J.A., Nachtergaele, F., Rossiter, D.G., Terres, J.-M., Van Orshoven, J., van Velthuizen, H., Böttcher, K., Haastrup, P. & Le Bas, C. 2010. Common criteria for the redefinition of Intermediate Less Favoured Areas in the European Union. *Environmental Science & Policy*, **13**, 766–777.

FAO, 1976. *A Framework for land evaluation*. Soils Bulletin 32, p. 72. FAO, Rome, Italy.

FAO, 1990. Problem Soils of Asia and the Pacific. RAPA Report 1990/6. FAO/RAPA, Bangkok, p. 283.

FAO, 1996. *Agro-Ecological Zoning, Guidelines*. Soils Bulletin 73, p. 78. FAO, Rome, Italy.

FAO, 2007. *Land evaluation: towards a revised framework*. FAO Land and Water Discussion Paper 6, p. 107. FAO, Rome, Italy.

FAO/ISRIC/ISSS, 1998. World Reference Base for Soil Resources. World Soil Resources Report, a84. FAO, Rome.

FAO-IUSS-ISRIC, 2006. World Reference Base for Soil Resources 2006, 2nd edn. World Soil Resources Report 103, p. 128. FAO, Rome.

Fischer, G., vanVelthuizen, H., Shah, M. & Nachtergaele, F., 2002. Global Agro-ecological Assessment for Agriculture in the 21st Century: Methodology and Results. Research Report RR-02-02. International Institute for Applied Systems Analysis, Laxenburg, Austria, p. 119.

Gray, J.M., Humphreys, G.S. & Deckers, J.A. 2011. Distribution patterns of World Reference Base soil groups relative to soil forming factors. *Geoderma*, **160**, 373–383.

Huber, S., Prokop, G., Arrouays, D., Banko, G., Bispo, A., Jones, R.J.A., Kibblewhite, M.G., Lexer, W., Möller, A., Rickson, R.J., Shishkov, T., Stephens, M., Toth, G., Van den Akker, J.J.H., Varallyay, G., Verheijen, F.G.A. & Jones, A.R. (eds) 2008. Environmental Assessment of Soil for Monitoring: Volume I. Indicators & Criteria. EUR 23490 EN/1, Office for the Official Publications of the European Communities, Luxembourg, p. 339.

Jones, R.J.A., Houskova, B., Bullock, P. & Montanarella, L. (eds) 2005. Soil Resources of Europe, 2nd edn. European Soil Bureau Research Report No. 9, EUR 20559 EN, Office for the Official Publications of the European Communities, p. 420.

Klingebiel, A.A. & Montgomery, P.H. 1961. *Land-capability classification. Agricultural handbook 210, Soil conservation service*, p. 21. US Govt. Printing Office, Washington, DC.

Le Bas, C., Boulonne, L. & King, D. 2001. Expert System for Constraints to Agricultural Production in Europe, Final Report. INRA and European Soil Bureau, p. 31 (in French).

Le Bas, C., Boulonne, L., King, D. & Montanarella, L. 2002. A tool for assessing land suitability for Europe. INRA and European Soil Bureau. In: 17th World Congress of Soil Science, 14–21 August 2002, p. 11, Bangkok, Thailand, Symposium 48, 256-1-11.

Nachtergaele, F.O., Spaargaren, O., Deckers, J.A. & Ahrens, B. 2000. New developments in soil classification World Reference Base for Soil Resources. *Geoderma*, **96**, 345–357.

Soil Atlas of Europe, European Soil Bureau Network European Commission, 2005, 128 pp, EUR 21676 EN, Office for the Official Publications of the European Communities, L-2995 Luxembourg.

Soil Survey Division Staff, 1993. *Soil survey manual. United States department of agriculture handbook no. 18*, p. 437. US Department of Agriculture, Washington, DC.

Van Orshoven, J., Terres, J. & Eliasson, Å. (eds) 2008. Common bio-physical criteria to define natural constraints for agriculture in Europe. EUR. 23412 EN, Office for the Official Publications of the European Communities, p. 61.

Van Orshoven, J., Terres, J. & Tóth, T. (eds) 2012. Updated common bio-physical criteria to define natural constraints for agriculture in Europe – Definition and scientific justification for the common biophysical criteria. EUR 25203 EN, Office for the Official Publications of the European Communities, p. 75.