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Editors: Jos Van Orshoven, Jean-Michel Terres, Ase Eliasson

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First interim deliverable: Definition and scientific justification for the common criteria; Technical Fiches

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Foreword

This work is part of the Administrative Arrangement (n°AGRI-2008-0181) (JRC ref. n°30969-2008-05 NFP ISP) between DG Agriculture and Rural Development and the Joint Research Centre, Institute for Environment and Sustainability. The purpose of this Administrative Arrangement is to provide support for the ***"Assessment of criteria for the identification of Less Favoured Areas"*** through 6 inter-linked task packages.

This report is the first interim deliverable corresponding to Task 1: Provide a clear definition and scientific justification for the common criteria"; it presents potential common bio-physical soil and climate criteria that were identified by a group of experts to define natural constraints for agriculture in Europe.

The report is based on several pieces of scientific information:

- The review by a panel of soil, climate and land evaluation experts of land evaluation methods in order to elaborate a proposal supporting the definition and delineation of the "intermediate less Favoured Areas" for agriculture in EU27.
- The working expert meeting held on 7th Dec 2007 by the Joint Research Centre in Ispra, Italy including the panel of experts contributing to this report, 4 representatives of DG Agriculture and Rural Development and 5 experts from the Joint Research Centre.
- Findings of the expert meeting that was organised by the Joint Research Centre and occurred on the 19th and 20th of April 2007 in Ispra, Italy. The meeting included 33 participants, including 14 experts from various scientific institutes, four participants from DG Agriculture and Rural Development and 15 experts from the DG Joint Research Centre.
- Findings of the expert meeting held in May 2006 on land quality assessment, which was organised to anticipate the technical work from the Joint Research Centre for DG Agriculture and Rural Development in the new definition of the Intermediate Less Favoured Areas.

This report includes: background information to the Less Favoured Areas (objectives of the project and context); an abstract / executive summary; an introduction; a problem statement; materials and methods; results; conclusions; references.
For each criterion proposed by the panel of experts, the agronomic rationale, the definition, the scientific background, the assessment, the values for severe / very severe thresholds, the conclusions and some references are provided as fact sheets in the annexes.

This scientific information is aimed to be a base for DG Agriculture and Rural Development in their consultation with Member States and future proposal for identifying the Intermediate Less Favoured Areas from biophysical criteria, seen as natural handicaps to agriculture.

Acknowledgements

This work results from the compilation made by J Van Orshoven from contributions provided by a panel of experts (Robert Jones, Christine Le-Bas, Freddy Nachtergaele, David Rossiter and Harrij van Velthuizen). Thank you to all of them to have dedicated some of their limited available time to this review, in particular to R Jones and F Nachtergaele for whom it was particularly difficult for different reasons.
The panel of experts have themselves relied on studies carried-out by colleagues as well as previous literature and references which shall be acknowledged.

Many thanks to Ase Eliasson who initiated the scientific network and whose scientific reports have been used in this work.

Contents

1 Abstract / Executive summary

A panel of soil, climate and land evaluation experts reviewed a set of land evaluation methods in order to elaborate an approach which can support the definition and delineation of the so called "Intermediate Less Favoured Areas for agriculture (iLFA)" in EU27. The driver for this exercise is Article 50.3 of EC-Regulation 1698/2005 calling for the revision of the existing system based on criteria related to low soil productivity and poor climate conditions for agriculture.

FAO's agricultural problem land approach was selected and adjusted to come forward with the requested approach. The FAO approach was deemed appropriate because it is not crop-specific and for its simple assumptions regarding the mutual interaction of land characteristics on the overall suitability of the land, making it applicable for a territory as large and diverse as EU27. Two climatic and four soil criteria were retained and complemented by one integrated soil-climate criterion (soil water balance), with slope as the sole topographic criterion. For each criterion two critical limits were defined dividing the criterion range into three sub-ranges: *not limiting*, *severely limiting* and *very severely limiting* for agriculture.

The criteria and the associated critical limits or threshold values can be used anywhere to discriminate land with biophysical constraints to agricultural production on the basis that soil and climate data of sufficient spatial and semantic detail are available. Whereas such datasets are held at regional and national levels, Pan-European soil and climate data sets also exist to which the criteria and threshold values can be applied. However, their spatial and to a lesser extent semantic resolution is too restricted to classify land fully in line with terrain reality. The pan-European assessments are however useful as a reference backdrop for assessment of consistency of exercises which use national or regional data sets.

2 Background information

2.1 Objective of the project

The aim of this project is to assess and define possible criteria and indicators to be used for designating areas affected by significant natural handicaps, notably low soil productivity or poor climate conditions, and where maintaining extensive farming activity is important for the management of the land, hereafter referred to as "intermediate LFAs".
To this end, JRC-IES shall provide scientific support and advice as concerns the definition of criteria and methodologies that could possibly be used to designate intermediate LFAs, as well as by assessing their expected impacts.
This project is the follow-up of a joint work programme carried out by DG AGRI and JRC-IES in 2006-2007, and it is aimed at enhancing the understanding of criteria and methods currently used by the Member States for designating LFAs and at identifying possible common biophysical criteria for defining areas. It aims at developing the definition of the criteria previously identified and testing them at a more accurate level.

2.2 Context

The Rural Development Policy for 2007-2013 includes a significant evolution of the support scheme for farmers in Less Favoured Areas. The LFA scheme in place since 1975 had met with strong concerns from the European Court of Auditors in 2003. The Court recommended a complete and in-depth review of the existing classification of LFAs.

In 2005, when designing the new strategic approach for the Rural Development Policy and taking into account the Court of Auditors' concerns, the Council set out a new direction for the LFA scheme: the aid to farmers in areas with handicaps is now part of Axis 2, which aims at improving the environment and the countryside by supporting sustainable land management. Article 50 of Regulation 1698/2005 characterises the eligible areas as areas affected by natural handicaps, and no reference is made to the socio-economic criteria widely used in the past for designating LFAs. At the same time, the Council called on the Commission to present in 2008 a report and proposals concerning the future payment system and designation of LFAs for a Council decision.

The current project aims at supporting DG AGRI in preparing the Commission report and proposals above, and to assess the impact of possible options for reviewing the designation of intermediate LFAs.

3 Problem statement

Article 50.3 of EC-Regulation 1698/2005 requires the delineation of “Intermediate Less Favoured Areas (iLFA)”. According to the Regulation, iLFA are “zones affected by low soil productivity and/or poor climate conditions for agriculture” which co-justify financial support to farmers. The Regulation foresees payments for areas “affected by significant natural handicaps, notably a low soil productivity or poor climate conditions and where maintaining extensive farming activity is important for the management of the land”. This document refers only to natural handicaps.

There are several issues which make this apparent simple endeavour less evident:

1. *Agriculture in Europe encompasses a wide range of crops.*

Requirements for services from soil and climate are mostly crop dependant. In its original and revised frameworks for land evaluation, FAO (1976; 2007) highlighted the difficulty to assess detailed suitability maps for agriculture as such. In line with the framework, suitability maps would have to be created for all individual crops or cropping systems present in the EU, then combined and interpreted. As a result it is hardly possible to present one single suitability map encompassing the huge variety of crops in a territory as large and diverse as EU27.

2. *Many soil and climate characteristics co-determine suitability and mutually interact*.

A great many elementary soil and climate characteristics affect the behaviour of crops and they do so in multiple ways (Thomasson and Jones, 1989). For example, soil depth is not only a measure of the volume which is available for growing roots, hence creating stability, but also co-determines the capacity to supply water and nutrients. In addition, many of the characteristics interact strongly. In general, the presence of a clayey layer limiting root development reduces suitability, but the presence of such layer at medium depth may be beneficial for sandy soils to create a perched water table that can compensate for the low water storage capacity of these soils. In order to overcome the potentially complex problem of matching multiple and interacting land characteristics (LC) with crop requirements, FAO (FAO 1976) introduced the concept of Land Quality (LQ). A LQ is defined as a combination of land characteristics which acts upon the suitability of the land for a given use (an agronomic function). A typical example of a land quality is “Water supply capacity”. This LQ is determined by soil characteristics such as depth, granulometry, bulk density, stoniness and by climatic characteristics such as amount and regime of precipitation and evaporative demand. The definition and quantification of all relevant LQs and their matching with the requirements of the multitude of crops is however beyond the scope of most land evaluation exercises covering large zones like EU27.

3. *Delimitation of zones is conditioned by available data.*

Soil and climate characteristics are land attributes which typically show gradual change over space. For example, average temperature gradually decreases with increasing elevation, and average winter temperature increases with decreasing distance from the sea, while the opposite is often true for summer conditions. One consequence is that measurements of depth to rock or temperature are valid only for the measurement location (soil sample locations, meteo-stations). In order to define land units and delimit zones, the point observations must be interpolated using specific techniques. These may be mathematical equations or based on expert-judgement. Soil maps are routinely created by an expert-based approach, by which soil polygons are delineated with the point observations as reference marks and landscape features providing the spatial basis for interpolation. The amount and density of data and the semantic detail available from the point observations determine the spatial and semantic resolution of the results that can be obtained. Few available point data, with few characteristics recorded with little detail, can only give rise to coarsely delineated areas. Climatic data are often interpolated in a mathematical way. The assumption of gradual change of the climate characteristics between the available measurement locations is however often not in line with reality since also elevation, slope and orientation of slope i.e. co-determine climatic values (Ragg et al., 1988).

As a consequence, the problem of defining and delimiting land areas with low soil productivity and poor climate conditions can be resolved into 3 sub-problems:

- What are the soil and climate characteristics or qualities having a major and sufficiently independent contribution to the suitability of land for agriculture in a European perspective? How can these characteristics or qualities be assessed?

- What are the threshold values or critical scores for these characteristics or qualities to distinguish soils with low productivity from other soils and climates with poor conditions for agriculture from other climates?

- How can the scores for each of the selected characteristics or qualities be used and combined as criteria to classify and rank land?

4 Materials and methods

In order to address the stated objectives, a panel of soil, climate and land evaluation experts was established by the EC's Directorate General Joint Research Centre (JRC). Between May 2006 and December 2007, this panel met, on three occasions, with representatives of EC's DG Agriculture and Rural Development and JRC's Rural, Water and Ecosystem Resources Unit (RWER). DG AGRI is administratively in charge of implementing Regulation 1698/2005 while JRC is coordinating the scientific support.

The starting point for the expert panel was a review of possible land evaluation methods including the Land Capability Classification (Klingebiel and Montgomery, 1961), Framework for Land Evaluation (FAO, 1976; 2007), Agro-Ecological Zoning (FAO, 1978; 1996; Fischer et al., 2002), Agricultural Problem Land Approach (FAO, 1990 and Nachtergaele, 2006), Expert System for Constraints to Agricultural Production in Europe - ESCAPE (Le Bas et al., 2001; 2002).

A JRC Scientific and Technical Report (European Commission, 2007) and several working documents were produced to summarize progress made and conclude these discussions.

5 Results

With the aim of supporting the designation and delimitation of "Intermediate Less Favoured Areas", based on a set of simple harmonized and EU-wide applicable soil and climate criteria, the expert panel reached a consensus on an approach according to the following statements:

1. *No crop specificity*. Suitability was considered for a European conventional capital-intensive, mechanised, family unit of adapted grain crops or adapted grasses for hay or silage;

2. *Suitability assessment is based on a limited selection of soil and climate characteristics complemented with one topographic characteristic (Table 1), in line with the agricultural problem-land approach (FAO, 1990; Nachtergaele, 2006).* A restricted selection of elementary soil and

climate characteristics is made which are judged to be most pertinent for distinguishing land according to its suitability for the generic agricultural activity, and the interaction of the selected land characteristics on the growth of crops is accounted for by one additional characteristic, the soil water balance. The reasons for choosing the modified “Problem Land approach” rather than a more elaborated Land Quality approach (apart from its simplicity) can be explained by the objectives pursued i.e. to identify areas with constraints to agriculture and not to identify all necessary conditions to reach optimal production for each type of crop;

3. *Characteristics are either not limiting, severely or very severely limiting.* Two critical limits are proposed to classify the value of each of the selected individual characteristics into 3 sub-ranges (Table 1). Below the severe threshold value, the characteristic is judged not to be sufficiently limiting to be considered as a handicap for agriculture. Above the ‘Very Severe’ threshold, the characteristic is judged to be very difficult for agriculture so that corresponding areas should not be envisaged for agriculture. Values of the characteristics in the range between the severe and very severe thresholds are considered to present a biophysical handicap to agriculture, without making agriculture impossible;

4. *Criteria are combined according to the agronomic law of the minimum (Liebig’s law).* After classification in one of the 3 sub-ranges, characteristics can be used as diagnostic criteria to identify areas with constraints to agriculture from other types of land. The guiding principle for combining the criteria is the law of the minimum. As soon as one of the considered criteria is rated as ‘very severely limiting’, the corresponding land is judged to present very severe limitations for agricultural production. Similarly, as soon as one criterion is rated as ‘severely limiting’ and no other criterion is rated as ‘very severely limiting’, the corresponding land is assessed to be severely limiting;

5. *Climate-related criteria are treated in a probabilistic way.* In order to account for between-year variability of temperature accumulation, heat stress and soil water balance, determining the length of the growing season, those three characteristics are classified as either not limiting, severely limiting or very severely limiting in a probabilistic approach. A characteristic is classified as being severely limiting if the probability of exceedance of the severe limit is more than 20% and if the probability of exceedance of the very severe limit is lower than or equal to 20%;

6. *Maps are not produced.* Although the biophysical criteria and their critical limits are ultimately meant to produce suitability maps, they were defined and selected based on scientific and agronomic considerations independent from a concrete mapping exercise. Mapping is left at the discretion of other stakeholders to apply the criteria and threshold values presented here to available soil and climate geo-datasets.

Table 1: Overview of diagnostic criteria and critical limits

	Criterion	Definition	Threshold value separating non limiting from severely limiting	Threshold value separating severely limiting from very severely limiting
CLIMATE	Low Temperature	. Length of Growing Period (number of days) defined by number of days with daily average temperature > 5°C (LGP_{t5}) . Heat sum (degree-days) for Growing Period defined by accumulated daily average temperature > 5°C	180 days or 1500 degree-days	150 days or 1200 degree-days
	Heat Stress	Number and length of continuous periods (number of days) within the growing period for which daily maximum temperature (Tmax) exceeds the threshold	One or more periods of at least 10 consecutive days with daily Tmax > 35°C	One or more periods of at least 10 consecutive days with daily Tmax > 40°C
SOIL	Drainage	Areas which are water logged and/or flooded for significant duration of the year (lack of gaseous oxygen in soil for root growth or land not accessible for tillage).	Poorly drained (class3 as defined by FAO 1994, guide for soil description) OR wet soil within 80 cm for over 6 months but not wet within 40 cm for over 11 months	Very poorly drained (class 4 as defined by FAO 1994, guide for soil description) OR wet soil within 40 cm for over 11 months
	Texture and Stoniness	Relative abundance of clay, silt, sand, organic matter (weight %) and coarse material (volumetric %) fractions in top soil material.	Soils classified as sandy or organic; or 15% of topsoil volume is coarse material or Heavy clay (>60% clay) or Vertic soils	40% of topsoil volume is coarse material or Rock outcrop, boulder within 15cm of the surface
	Rooting depth	Depth (cm) from soil surface to coherent hard rock or hard pan	30 cm	15 cm
	Chemical properties (Salinity, sodicity, toxicity)	Presence of salts, exchangeable sodium and gypsum in the topsoil	Salinity : 4 dS/m Sodicity: 6 ESP Gypsum: 15%	Salinity : 16 dS/m Sodicity: 15 ESP Gypsum: 40%
Integrated soil and water criterion	Soil Water Balance	Number of days within growing period as defined by temperature > 5°C (LGP_{t5}), for which the amount of precipitation and water available in the soil profile exceeds half of potential evapotranspiration (computed with Penman-Monteith method)	90 days	60 days
TERRAIN	Slope	Change of elevation with respect to planimetric distance (%)	15%	30%

6 Discussion

The method presented here is mostly in-line with FAO's agricultural problem land approach (FAO, 1990; Nachtergaele, 2006). The difference is that the FAO approach:

- Does not include an integrated soil-climate criterion such as the soil water balance;
- Has defined for each criterion one threshold value only, to distinguish between no-problem and problem land;
- Does not include a probabilistic approach for dealing with climate-related criteria;
- Includes the soil characteristic 'Heavy cracking clay' as a separate criterion. Here it is merged with the 'Soil texture and stoniness' criterion.

The assumption of mutual independency of the characteristics and the application of the law of the minimum is common to both.

The climatic criteria pertain to the need for sufficient heat in the absence of damaging hot periods.

The soil drainage criterion is selected based on the need for sufficient but not too much water being available.

Texture, stoniness and rooting depth are selected for their influence on nutrient availability, available water capacity, drainage and plant stability.

The three chemical soil characteristics refer to the required absence of toxic agents. The integrated soil-climate criterion ‘soil water balance’ expresses the fundamental interaction between soil and climate for water availability. Water will be supplied outside periods of precipitation by the soil water store.

Finally, slope has been retained as the sole topographic criterion for its decisive impact on the potential use of agricultural machinery. All this follows a very similar rationale adopted for forestry (e.g., Ray 2001).

Given the generalized nature of this exercise, the ‘problem land’ approach was selected for its simplicity, robustness, transparency, ability to identify areas with natural handicaps (rather than estimating agronomic potential) and was adapted to be non crop specific. The Land Capability system (Klingebiel and Montgomery 1961) has been developed for farm planning purposes assuming an implicit hierarchy of desirability of crops rather than for regional assessments. The Land Quality (LQ) approach as prescribed by the FAO framework for land evaluation (FAO 1976) was not adhered to for its explicit crop specificity and the complexity of identifying and assessing the LQs. Although suitability assessment by the ESCAPE system (Le Bas et al. 2001 and 2002) starts from similar elementary land characteristics as the problem land approach, it adds the definition of combinations of characteristics in a crop-specific matching exercise. From the Agro-ecological zone approach (FAO 1978; 1996), the innovative concept of length of growing period and soil-water balance and the probability-based approach for climate-related characteristics have been adopted for the adjustment of the methodology proposed here.

The application of the ‘law of the minimum’ to the criteria presented here, with associated threshold values, is a simple but consistent way of categorizing locations or areas for which the selected characteristics have been observed, measured or estimated with a compatible semantic resolution, as locations or areas with (or without) significant soil and climatic constraints to agriculture.

Both for the semantic and the spatial dimensions, the accuracy of applying the criteria to separate constrained areas from other zones, is data dependent. If the semantic resolution of the available observations, measurements or estimates is higher (more classes) or different (class boundaries) than what is proposed, a re-assessment by (dis)aggregation is necessary. This implies a certain loss of information and increase of uncertainty. If the available observations, measurements or estimates pertain to specific points in space, interpolation to contiguous areas is required in order to produce maps which can be further processed using GIS-technology, e.g. to estimate the share of agricultural land use on these areas. The amount and density of the available point data will determine the applicable, meaningful spatial resolution for interpolation.

Member States or other responsible agents will be required to apply the criteria using the most appropriate available data sets. The results will differ from those obtained by applying the criteria with available pan-European soil (European Soil Database-King et al., 1994; 1995) and climate data sets (MARS-Vossen and Meyer-Roux, 1995), although the general patterns and proportions should be consistent. If applied judiciously, results of national or regional applications will outperform the pan-European application in terms of accuracy of the position of boundaries between zones, the accuracy of the labels attributed to the zones and in terms of omission or commission of zones.

Changing climate is a reality in Europe (IPCC, 2007). Zones for which current climate and combined soil-climate conditions justify their designation as constrained to agriculture, may no longer match the criteria in the near future and vice versa. However, the set of diagnostic soil and climate criteria presented, with critical limits, remains valid. Application of the criteria to updated climate data, or to "likely" data as derived from climate change scenarios, will help to estimate future changes to the extent of the natural constraints to agriculture and to revise boundaries accordingly.

7 Conclusions

A panel of experts in physical land evaluation has reached agreement on a set of soil and climate characteristics, with associated critical limits, and on Liebig's law of the minimum for their combination, so that they can be used as criteria to classify land in three broad classes: land *without* soil and climate constraints to agriculture, land with *severe* soil and climate constraints and land with *very severe* soil and climate constraints that preclude agricultural activity. The set of criteria are in-line with an extension of FAO's agricultural 'problem land' approach, while the threshold values have been derived from and justified by state-of-the-art scientific knowledge and expert peer-review. The results can be used to effectively delimit the three types of areas and portray them in map form on condition that reliable base data (observations, measurements or estimates) are available with a sufficient spatial and semantic resolution. The amount and density of point observations, the spatial resolution of area estimates and the semantic resolution of all data do inevitably have a decisive influence on the spatial and semantic quality of the final maps.

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8 Annexes:

Fact Sheets of the proposed criteria

Criterion 1 “Low temperature”

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Agronomic importance

Low temperatures limit crop growth and development through the impact on important physiological processes such as photosynthesis and leaf appearance. Land in which thermal-time accumulation systematically is not sufficient for crops to complete the production cycle is unfavorable for agriculture.

Definition

Low temperature is defined as the condition in which crop performance or survival is compromised by temperatures during the growing period which are insufficient for optimal growth and development of crops.

In the context of less favourable areas for agriculture in Europe, low temperature is a characteristic of land for which thermal-time accumulation during the growing period is insufficient for plants to complete the production cycle.

Scientific background

Agricultural crops are able to grow and develop only within well defined ranges of temperature (Porter and Gawith, 1999). The most common agricultural crops in Europe are (i) C3 crops adapted to cool temperatures ranging from 5-30^{o}C (e.g. wheat, potato), C3 crops adapted to warm temperatures ranging from 15-35^{o}C (e.g. soybean, rice) and (iii) C4 crops adapted to moderately warm temperatures ranging from 10-35^{o}C (e.g. maize, sorghum) (FAO, 1978-81). These climatic thresholds are mostly explained by the impact of temperature on enzymatic activities that regulate the rates of important plant physiological processes, such as photosynthesis and leaf appearance (Bonhomme, 2000). Growth rates and yields are maximized when crops are grown near the species-specific optimal temperature (T_{opt}) but gradually decrease at lower temperatures until the base temperature (T_b) is reached, at which no development occurs. Similarly, at temperatures higher than T_{opt} development rates decline until a critical temperature (T_{crit}), near lethal levels (Hodges, 1991). Negligible growth occurs for most agricultural crops at temperatures below 5^{o}C or above 35-40^{o}C (Porter and Semenov, 2005). When crops are grown under lower than optimal temperatures, yields can be reduced by various mechanisms (Porter and Gawith, 1999) including: limited light interception (e.g. due to slow leaf area expansion), inefficient conversion of intercepted light into biomass (i.e. reduced photosynthesis rates), or direct damage to plant tissues caused by early or late frosts.

To successfully complete the growth cycle and fully attain their yield potential at harvest, crops have to be able to reach full canopy expansion and pass through specific phenological stages such as germination, flowering and maturity (Hodges, 1991). The rate of progress towards each of these phenological stages is largely regulated by temperature (Jamieson *et al.,* 1995; Bonhomme, 2000). This explains why the length of the growth cycle of crops is variable when expressed in ‘days’ from emergence to maturity but conservative when expressed in ‘thermal-time’ (degree-days, ^{o}Cd) (Hodges, 1991). Specific thermal-time accumulations are needed for the completion of each phenological stage, until crops complete an entire production cycle.

The combination of temperature thresholds and thermal-time accumulation requirements can be used to characterize land areas with temperature limitations.

Assessment

To assess low temperature as a land characteristic, the concepts of length of temperature growing period (LGP_t, days) and thermal-time sums (TS_b, degree days, ^oCd) are used in combination.

Firstly, the length of the temperature growing period (LGP_{t5}), i.e. the number of days with daily average temperatures (T_{avg}) above 5^oC is calculated for each year. The LGP_{t5} characterizes the days in which temperatures are conducive to crop growth.

Secondly, for the days within LGP_{t5}, thermal-time sums (TS_b), above a base temperature (T_b) of 5^oC, are calculated by accumulating the difference between daily T_{avg} and T_b.

Finally, calculated values[8] of LGP_{t5} and TS_b are compared with reference thresholds for severe and very severe limiting conditions.

For this calculation, it is recommended to use data-sets with daily average temperature (T_{avg}) from time-series.

Values for severe and very severe threshold

Temperature thresholds and thermal requirements for plant development vary among crop species and cultivars (Hodges, 1991). For European conditions, thermal-time sum requirements can be used as a reference to delimit thresholds for the development of agricultural crops.

In general, optimal thermal-time requirement for most agricultural crops is above a TS_5 of 1500^oCd (Boons-Prins *et al.* 1993). A TS_5 of 1200^oCd coincides with the most northern distribution of cereal crops in Europe. Below this TS_5 threshold of 1200^oCd, crops cannot grow because of very marginal thermal-time accumulation and increased risk of early and late frosts (Fischer G. *et al.* 2008 forthcoming).

Therefore

- Severely limiting low temperature is said to occur if LGP_{t5} is between 150-180 days or TS_5 is between $1200\text{-}1500^oCd$
- Very severely limiting low temperature is said to occur when LGP_{t5} is ≤ 150 days or TS_5 is $\leq 1200^oCd$ ($T_b=5^oC$).

In order to take account of between year variability of meteorological conditions, a probabilistic approach is required. It is proposed to use the 80% / 20% probability exeedance / non exceedance approach: if in 3 or more years out of 10, the threshold value for severe or very severe low temperature condition is not reached, the land is classified as being under (very) severe low temperature limitation.

A time series of daily meteorological data preferably over 30 (or more) recent years is required to assess the probability of exceedance.

Final remarks and conclusions

Low temperatures have an important impact on crop yield by limiting plant growth and development processes. Land areas where thermal-time sums are insufficient for crops to complete their production cycle are considered unfavorable for agriculture. This can be evaluated by using thresholds of thermal-time requirement.

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[8] *As a refinement, for computation of LGP_{t5} and TS_b, one could estimate the likely start and end dates of the growing season. Start date may be calculated as the latest date of frost in spring based on a probability of non*

exceedance equal to or larger than 8/10 (based on at least 30 years). End date may be derived as the earliest date of frost in autumn, again with a probability of exceedance equal to or larger than 8/10.

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Criterion 2 "Heat Stress"

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Agronomic importance

Episodes of high temperature, particularly during critical plant development stages drastically reduce yields of field crops. Land in Europe that is subjected systematically to one or more periods of continuous days within the growth period, for which maximum temperatures exceed 35^{o}C, must be recognised as less suitable for agriculture.

Definition

Heat stress is defined as the condition in which crop performance or survival is compromised by periods of exposure to high temperatures (Wheeler *et al.* 2000).

In the context of less favourable areas for agriculture in Europe, heat stress is a characteristic of land which is subjected to one or more periods of continuous days within the growing period, for which maximum daily temperature (T_{max}) exceeds 35^{o}C.

Scientific background

Temperature largely controls the rates of growth (e.g. photosynthesis) and development (e.g. leaf appearance, flowering) in crops (Hodges 1991). Heat stress occurs when the temperature experienced by the plant exceeds critical thresholds for optimal functioning of these physiological processes to operate (Porter and Semenov 2005). The temperatures conducive for plant growth and development range from 5 to 35^{o}C for the most common crop groups in Europe, with optimal yield performances obtained from 15 to 30^{o}C (Table 1).

Table 1. Temperatures conducive for growth and for optimal agronomic performance in the most common crop groups in Europe (FAO 1978-81).

Crop Group*	Growth temperatures (^{o}C)		Optimum temperatures (^{o}C)		Examples
	Min	Max	Min	Max	
C3 I	5	30	15	20	Wheat, barley, potato, beet, rape.
C3 II	15	35	25	30	Soybean, rice, cotton.
C4 II	10	35	20	30	Maize, sorghum, millet.

* Criteria based on crop photosynthetic pathway and optimal temperature regimes. Crop groups are adapted to cool (C3 I), warm (C3 II) or moderately warm (C4 II) conditions.

Warmer than optimal mean seasonal temperatures may limit photosynthesis rates and accelerate crop development (i.e. shorten crop cycle length) with consequent reduction in light interception and yield (Batts et al. 1997; Bonhomme 2000). Of particular importance, is the occurrence of high temperatures during critical phases of crop growth, notably the reproductive stage (Wheeler et al. 2000). Near the time of flowering, crops are particularly sensitive to high temperatures. Exposure to short episodes of high temperature during this thermal-sensitive period reduces the set of fruits and grains and limits grain filling. Possible impacts include a reduction in the number of flowers, number of pollens, pollen tube growth, pollen release, pollen viability and flower fertility (Prasad et al. 2006a). Overall, yield is more affected than total biomass accumulation which implies a lower harvest index in crops subjected to heat stress (Prasad et al. 2006b).

The impact of heat stress may be exacerbated in conditions of drought stress. This occurs when canopy evaporation is limited and there is an increase in the temperature of plant tissues.

Assessment

Heat stress as a land characteristic can be assessed by (i) comparing ambient temperatures with thresholds for optimal plant functioning and (ii) identifying the period for which these temperature thresholds are exceeded (e.g. Challinor et al. 2005). For several crops, temperatures above 35^oC were shown to cause damage to yield and reproductive development (Wheeler et al. 2000; Porter and Semenov 2005). The thermal-sensitive period usually spans from one to two weeks around flowering (Brammer et al. 1988).

Even short periods of exposure to high temperatures, to the order of days or hours, are sufficient to reduce crop yield significantly (Matsui and Omasa 2002). Therefore, to quantify heat stress, it is necessary to use data-sets with a time resolution sufficiently short to characterize peaks of temperature. For such, it is recommended to use historical time series-data containing 'daily maximum' temperatures (T_{max}) instead of, for example, averaged seasonal data or the use of mean temperatures (T_{mean}).

Values for severe and very severe threshold

Thresholds for heat stress have been identified for important crops including wheat (Ferris et al. 1998), rice (Matsui et al. 2000), brassicas (Young et al. 2004), tomato (Sato et al. 2004), barley (Wallwork et al. 1998) and soybean (Salem et al. 2007). These thresholds are different among crops and also vary within species, i.e. tolerant and sensitive cultivars were identified for several crops (e.g. Prasad et al. 2006b). In general, yield loss is observed at temperatures above 30^oC while the magnitude of damage increases with the period of exposure. Yield loss is usually severe above 35^oC increasing at higher temperatures until complete damage is observed at above 40-45^oC, near lethal temperatures (Porter and Gawith 1999; Challinor et al. 2005).

Therefore:

- Severe heat stress is said to occur when "one or more periods of at least 10 consecutive days with daily maximum temperatures above 35^oC" are observed;
- Very severe heat stress is said to occur when "one or more periods of at least 10 consecutive days with daily maximum temperature above 40°C" are observed.

In order to take account of between year variability of meteorological conditions, a probabilistic approach is required. It is proposed to use the 80% / 20% probability exeedance / non exceedance approach: if in 3 or more years out of 10, the threshold value for severe or very severe high temperature condition is reached, the land is classified as being under (very) severe heat stress limitation.

A time series of daily meteorological data preferably over 30 (or more) recent years is required to assess the probability of exceedance.

Final remarks and conclusions

Heat stress is an important constraint to crop production. Episodes of heat stress may become more frequent and widespread with global warming (Tebaldi et al. 2006). Water limitation may aggravate the impact of heat stress. Future selection and breeding of tolerant species and cultivars may minimize the impact of heat stress (Challinor et al. 2007).

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Criterion 3 “Soil drainage and flooding”

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Agronomic importance

Poor drainage reduces the space for the gaseous phase, in particular gaseous oxygen, in the rooting zone. It increases the incidence and severity of soil-borne pathogens and makes tillage impossible. A main additional effect of flooding on agriculture is to make the land inaccessible while flooding may also physically damage standing crops. Coastal flooding with brackish water can result in the same damage as salts in the soil.

Definition

Soil drainage refers to the maintenance of the gaseous phase in soil pores by removal (or non-addition) of water. In the FAO Guidelines for Land Evaluation (Rainfed agriculture) (FAO, 1983) it is referred to as LQ4 “Oxygen availability to roots (drainage)”.

A soil has *internal* drainage, i.e. the facility for removing excess water by gravity, and *external* drainage, i.e. the amount of water removed (or not added) by its position in the landscape with respect to contributing overland areas (runoff) or groundwater.

Flooding refers to the submergence of the land surface by water overflowing from rivers and streams or along tidal estuaries. The resulting temporary water bodies occupy flat areas adjoining these drainage systems, known as floodplains. Therefore flooding is a site, rather than a soil characteristic, and in the FAO Guidelines for Land Evaluation (Rainfed agriculture) (FAO 1983) it is referred to as LQ11 “Flood hazard”.

Scientific background

Surplus water in the rooting zone is normally the result of a high ground water table, following periods of heavy precipitation or flooding, for example during the wet winters characteristic of north west Europe, or a perched water table resulting from surplus water in the upper layer of the soil stagnating above a very slowly permeable or impermeable subsoil horizon. The latter type of soil water regime is quite common in the lowlands of England.

The main effect of poor drainage is to reduce the space for the gaseous phase, in particular gaseous oxygen, in the rooting zone. Crops suffer severely when their roots are deprived of gaseous oxygen. The notable exception is rice. The length of time without oxygen that causes severe damage varies among species.

A second effect is to increase the incidence and severity of soil-borne pathogens such as *Pithium* spp. fungi and root rotting bacteria such as *Erwinia* spp.

A third effect is to make tillage impossible, because machinery becomes bogged down or the soil structure is easily destroyed if tilled when too wet.

A main effect of flooding on agriculture is to make the land inaccessible, thus tillage and harvesting are impossible. All the effects of poor soil drainage also, their severity depend on the duration of flooding. Flood water must either evaporate or drain (internally) through the soil or runoff as overland flow. Water draining internally carries nutrients (e.g. nitrates) and sometimes pollutants, which can seep into the ground water. Flooding, if rapid may also physically damage standing crops, by flattening them or coating them with sediments. Coastal flooding with brackish water can damage the soil, turning it saline.

Surface water, whether from flooding or very high or perched water tables, must be allowed to thoroughly dry before the soil is trafficked or worked. In practice, this condition may not be fully realized. Any subsequent traffic and tillage commonly will degrade the soil, leading to compaction, massive structures and surface crusting.

Assessment

Ideally, drainage status is determined by monitoring wells (Daniels et al., 1971) or measurements of the soil redox potential. However this is impractical except at research sites. Therefore soil morphology is commonly used to assess drainage. These morphological indicators have been related to actual drainage status by research.

Drainage can be described as a natural drainage class that refers to the frequency and duration of wet periods under conditions similar to those under which the soil developed (i.e. ignoring any artificial drainage). In the USDA-NRCS system (Soil Survey Division Staff 1993), there is no distinction made between internal and external drainage, so that soil drainage is determined by a combination of the internal saturated hydraulic conductivity, water table level, additional water from seepage, water gained or lost by runoff, evatranspiration and rainfall.

Relevant classes from Soil Survey Division Staff (1993) are:

- “**Somewhat poorly drained**. Water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. The occurrence of internal free water commonly is shallow to moderately deep and transitory to permanent. Wetness markedly restricts the growth of mesophytic crops, unless artificial drainage is provided. The soils commonly have one or more of the following characteristics: low or very low saturated hydraulic conductivity, a high water table, additional water from seepage, or nearly continuous rainfall.”
- “**Poorly drained**: Water is removed so slowly that the soil is wet at shallow depths periodically during the growing season or remains wet for long periods. The occurrence of internal free water is shallow or very shallow and common or persistent. Free water is commonly at or near the surface long enough during the growing season so that most mesophytic crops cannot be grown, unless the soil is artificially drained. The soil, however, is not continuously wet directly below plow-depth. Free water at shallow depth is usually present. This water table is commonly the result of low or very low saturated hydraulic conductivity of nearly continuous rainfall, or of a combination of these.
- “**Very poorly drained**. Water is removed from the soil so slowly that free water remains at or very near the ground surface during much of the growing season. The occurrence of internal free water is very shallow and persistent or permanent. Unless the soil is artificially drained, most mesophytic crops cannot be grown. The soils are commonly level or depressed and frequently ponded. If rainfall is high or nearly continuous, slope gradients may be greater.”

Drainage status is also reflected in many soil classification systems. The USDA Soil Taxonomy (Soil Survey Staff 1999, 2003) describes the soil moisture regime for each soil individual as part of the soil family name. These are defined by the ground water level and the seasonal presence or absence of water held at tensions less than 1500 kPa in the defined moisture control section, under a crop or vegetation typical for the soil. The *aquic* moisture regime is a reducing regime in a soil that is virtually free of dissolved oxygen because it is saturated by water during some period when biological activity is possible. This is reflected in the soil morphology.

The World Reference Base (IUSS Working Group WRB 2006) does use the concept of soil moisture regimes *per se*, but defines several soil properties directly related to poor drainage, namely *gleyic* and *stagnic* features based on soil colour variations. These features are used to define Reference Groups (Gleysols and Stagnosols). Other reference groups are associated with poor internal drainage: the

Planosols, Solonetz and Vertisols.

Flooding is described by its frequency (return period) and duration (time the water stays on the land). The USDA-NRCS (Soil Survey Division Staff 1993) classifies frequency as none, rare (1 to 5 times per 100 years), occasional (5 to 50 times), and common (>50 times), and duration as extremely brief (< 4 hours), very brief (4 – 48 hours), brief (2 – 7 days), long (7 days to 1 month), and very long. The FAO Guidelines for soil description (FAO, 2002) do not record flooding.

The World Reference Base (FAO-IUSS-ISRIC, 2006) includes the Fluvisol reference group for genetically young soils developed in recent alluvial deposits. However, there is no direct link to current flooding frequency or duration, although many Fluvisols under natural conditions are indeed flooded periodically.

Values for severe and very severe threshold

These thresholds identify land areas that are waterlogged and/or flooded for significant periods during the normal growing season and thus affect normal farming operations or crop yields. The *very severe* threshold is designed to identify soils that are too wet to allow normal farming operations for adapted crops, or which have a high risk of crop failure, either due to direct damage or prevention of normal farming operations, due to flooding. The *severe* threshold is 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, or a substantial risk of crop damage due to flooding.

Therefore:

- Soil drainage or flooding is said to be severely limiting if with regard to drainage the soil is classified as wet within 80 cm for over 6 months, but not wet within 40cm for over 11 months OR classified as poorly drained (soils are commonly wet for considerable periods; ground water table commonly <40 cm;

  and/or with regard to flooding the land is occasionally flooded (5 to 50 times per 100 years).

- Soil drainage or flooding is said to be very severely limiting if with regard to drainage, the soil is wet within 40cm for over 11 months OR classified as very poorly drained (wet at shallow depths for long periods; ground water table is commonly <10 cm;

  and/or if with regard to flooding the land is commonly flooded (>50 times per 100 years).

Final remarks and conclusions

Soil drainage (oxygen status) and flood hazard are two major constraints to agriculture, generally requiring expensive technical adaptations (artificial drainage, ditching, pumping, flood control); in that sense areas with these limitations can be considered ‘less favoured’ for agriculture. Such areas are often best left to seasonal pasture, specialty crops, or nature.

In case of very severe constraint, the short potential period of reasonable oxygenation in the shallow root zone, makes it impossible to plant, grow and harvest a crop. With an equal chance of flooding in a given year, the producer faces a high risk of crop failure.

Given severe constraint, poorly-drained soils can support only shallow-rooted crops, and only for limited periods, with a small window for tillage, growth and harvesting, without artificial drainage. The indicated flooding hazard can be tolerated but leads to a significant economic loss over the medium or long term.

In many areas of Europe with natural drainage problems, soils have been artificially drained, often for centuries. If these drainage works are considered now part of the landscape, the drained soil units should be evaluated as if they were better drained than without the installed drainage systems. Normally artificial drainage systems improve the water regime by at least one class.

Drainage classes may be inferred from soil classification or directly from soil morphology by national experts; however there is not always a direct relation between a taxonomic class (e.g. Gleysols) and actual drainage conditions; this is always an inference.

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Criterion 4 "Soil texture and Stoniness"

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Agronomic importance

Soil texture is directly related to water-holding capacity and nutrient supply. Texture affects workability (ease of tillage), water infiltration, runoff, and movement within the soil (both down and up).

Definition

The texture of a soil refers to the relative proportions of different-sized soil particles in the bulk soil. It is more correctly called the particle-size distribution. Conventionally it is divided into two parts: coarse fragments > 2 mm effective diameter, and the fine soil. Both parts are further subdivided. Commonly-used classifications are from the USDA-NRCS (Soil Survey Division Staff 1993) and the FAO (FAO 2006).

Another definition of soil texture is the feel or perceived resistance to various manipulations of loose soil samples in the field. This perception is mostly controlled by particle-size distribution, as well as the type of clay, the amount of organic matter (mostly in surface horizons) and the presence of calcium carbonate. The difficulty with this definition is the subjective field determination, using descriptive keys (e.g. Table 25 in FAO 2002), although experienced field scientists generally agree with each other and can estimate the clay and silt contents with considerable accuracy (Hodgson et al., 1976).

Scientific background

Soil texture is a soil characteristic which plays an important role in many land qualities. In the FAO Guidelines for Land Evaluation (Rainfed agriculture) (FAO 1983) it is important in LQ3 "Moisture availability", LQ4 "Oxygen availability to roots", LQ5 "Nutrient availability", LQ6 "Nutrient retention", LQ7 "Rooting conditions", LQ16 "Soil workability", LQ24 "Erosion hazard" and can play a role in several others. It is quite difficult to isolate the effects of soil texture without reference to these land qualities.

Soil texture is directly related to water-holding capacity and nutrient supply. Soil colloids (clays) hold almost all the nutrients supplied by the mineral soil, whether the products of weathering or as added fertilizers or manures. Pores hold water hygroscopically at different tensions against plant extraction and gravity; the size of pores is directly related to the particle-size distribution. Texture controls soil structure, affecting workability or ease of cultivation (Thomasson and Jones, 1989), water infiltration, runoff, and movement within the soil (both down and up); although the type of clay mineral also has an important effect.

The silt and very fine sand fraction is associated with a high susceptibility to accelerated water and wind erosion (Hudson 1995). Soils with high proportions of these fractions require intensive soil conservation practices.

Coarse fragments directly reduce the volume of soil exploitable by roots, thus reducing. water-holding capacity and nutrient supply. Sufficiently large coarse fragments prevent tillage, and even smaller coarse fragments wear on tillage implements. However, coarse fragments can help aerate and heat the soil, provide paths for rapid water entry, and slow runoff.

An important aspect of "texture" is the physical reaction of the soil to wetting and drying. This is recognized in soil classification systems such as the World Reference Base (WRB) (IUSS Working

Group WRB 2006) by defined soil properties, in particular "vertic" properties. Vertic properties severely limit tillage options: the soil changes from hard and dry to plastic and sticky over a narrow range of water contents, leaving only a small window for conventional tillage. Shrinking and swelling during the growing season can also damage plant roots (Wilding et al. 1988).

Assessment

Textural class of the fine earth and coarse fragments are both expressed as classes defined by the FAO (FAO, 2006), based on the proportions of the particle-size separates (fractions) in the soil sample.

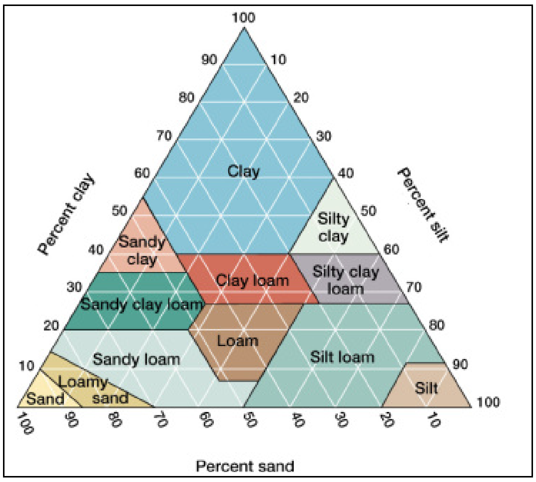

Figure 1: FAO Texture triangle

Coarse fragments (> 2 mm) are described by their abundance (volume %), size, shape, state of weathering, and nature. Abundances are none, very few (2 % v/v upper limit), few (5 %), common (15%), many (40 %), abundant (80 %), and dominant (100 %). Sizes are fine gravels (upper limit 0.6 cm largest dimension), gravels (2 cm), coarse gravels (6 cm), stones (20 cm), boulders (60 cm) and large boulders (200 cm); larger fragments are considered continuous rock. Coarse fragments are generally estimated in the field, except for gravels, which are collected with the soil sample and weighed in the laboratory (van Reeuwijk 2002).

Fine earth (<2mm) is defined by the relative proportions (by weight) of sand, silt and clay as determined in the laboratory (e.g. van Reeuwijk 2002). The upper limits used here correspond to the FAO norms (FAO 2006) and are 2000, 63, and 2 micrometers. This differs from the other most commonly used system, USDA-NRCS (Soil Survey Division Staff 1993) which uses 50 instead of 63 micrometers to separate sand from silt. Other national systems may use different limits but it is possible to harmonise data using transfer functions. Laboratory methods, while apparently objective, are subject to relatively wide discrepancies even among certified laboratories (van Reeuwijk 1984).

Vertic properties are defined by the WRB (IUSS Working Group WRB 2006) as having either (1) >= 30 % clay throughout a thickness of at least 15 cm and one or both of the following: (a) slickensides or wedge-shaped aggregates; or (b) cracks >= 1 cm wide that open and close periodically; or (2) a coefficient of linear expansion (COLE) of 0.06 or more averaged over depth of 100 cm from the soil surface. Cracks and slickensides are observed in the field; COLE is measured in the laboratory (Dane et al. 2002).

Values for severe and very severe threshold

Over 40% coarse fragments reduce water-holding capacity by at least 40%, exacerbating seasonal droughts in most European climates. In addition, coarse fragments damage tillage equipment whereas rock outcrops and boulders prevent tillage altogether. Coarse sand has almost no water-holding capacity, due to the large pores, and almost no nutrient holding or supplying capacity such that normal fertilization practices are ineffective. Heavy clays are difficult to cultivate and, although the available water capacity is neither large nor small, the water is held at large suctions (high tension) making it difficult for plant roots to extract it. Most clay soils also have very slow permeability so that excess water ponds on the soil surface after even moderate rains rather than draining downwards through the soil profile. Silts are very susceptible to water and wind erosion and difficult to protect against these processes of soil loss. Vertic properties limit tillage options and may result in direct physical damage to plant roots on wetting and drying.

Therefore:

- Soil texture is said to be severely limiting if any of: (1) 15 - 40% volume of coarse fragments of any kind in topsoil; or (2) average texture class of rooting zone is (a) unsorted or medium sand, coarse loamy sand, (b) heavy clay (> 60% clay); or (3) organic soil[9] as defined with organic matter (>30%) of more than 40 cm either extending down from the surface or taken cumulatively within the upper 80 cm of the soil (FAO Problem soil data base); or (4) texture class of clay, silty clay, or sandy clay with vertic properties as defined by the WRB (2006).
- Soil texture is said to be very severely limiting if any of: (1) > 40% volume of coarse fragments of any kind in topsoil; or (2) any proportion of rock outcrops, boulders or large boulders within 15 cm of the surface;

Final remarks and conclusions

Soil texture is a major determinant of soil suitability for any land use, as evidenced in its influence on many land qualities. The fairly extreme textures selected for the thresholds ensure that areas so identified are indeed less favorable for conventional agriculture.

It should be recognized that texture interacts strongly with water holding capacity (available water capacity of the soil) and climate, such that soil moisture deficits are often associated with textural limitations. Stony or coarse-textured soils in cool, cloudy climates with regular small rain showers may suffer moisture deficits; conversely, loamy soils in hot, cloudless conditions with widely-spaced and irregular rainfall may show strong water deficit. Additionally, effective rooting depth interacts directly with texture limitations to determine the available water capacity of the soil. A water-balance model incorporating actual rainfall and solar radiation, a crop calendar with growth-stage specific coefficients, and available water capacity of the soil provide an objective basis for the estimation of water deficits.

Different types of clay minerals, having similar particle size, have greatly different nutrient-holding capacity. Soil structure (aggregation of the fines) can have a large effect on effective pore-size distribution and hence water-holding capacity. Organic matter can supply nutrients and hold water. All of these affect the tilt of the soil.

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[9] Organic soils are very fragile ecosystems and improper management can drastically affect them (mineralization of organic matter). Moreover, they act as organic carbon pools and play an important role in carbon sequestration; therefore they should be properly treated, preferably left in their natural condition.

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Criterion 5 “Rooting Depth”

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Agronomic importance

Roots grow into the soil to provide a physical anchor for the plant, and to extract soil-bound water and nutrients. For annual grain crops and grasses, the anchoring function does not require great depth (except for tall varieties of maize); the first 10 cm or so provide enough stability. However, water is rapidly exhausted from shallow depths by the growing plant. Potential evapotranspiration rates of 1 to 4 mm water per day, combined with a typical available water capacity of 150 mm water per vertical meter of soil profile, imply that water will soon be exhausted in shallow soils.

Rooting depth is generally constrained by coherent hard rock or hardpans (dense soil layers).

Physical limitations to rooting depth are also impediments to normal tillage, such that if plant roots cannot grow easily, it is unlikely that the plough can cut easily into the soil. Standard tillage depth is 15 to 25 cm.

Definition

Rooting depth is the maximum depth from the soil surface to where most of the plant roots can extend during a growing season. In the FAO Guidelines for Land Evaluation (Rainfed agriculture) (FAO 1983) it is referred to as LQ7 “Rooting conditions …. for the development of an effective root system”. In the current definition, we restrict ourselves to the soil characteristic “rooting depth”, defined both by the effective soil depth above any barrier to root extension, excluding impediments to root extension as such compact (massive) structure.

Scientific background

Provided there is no barrier to root extension, in the form of hard rock or a cemented (pan) layer, most crop plants roots extend to depths in the range 60cm to 1.2m, although in some cases rooting can be deeper, for example sugar beet 140cm (Hall *et al.*, 1977; Jones *et al.*, 2000). Some perennial plants, particularly in arid areas, can exploit the soil to much greater depths (5-10m), usually to extract water.

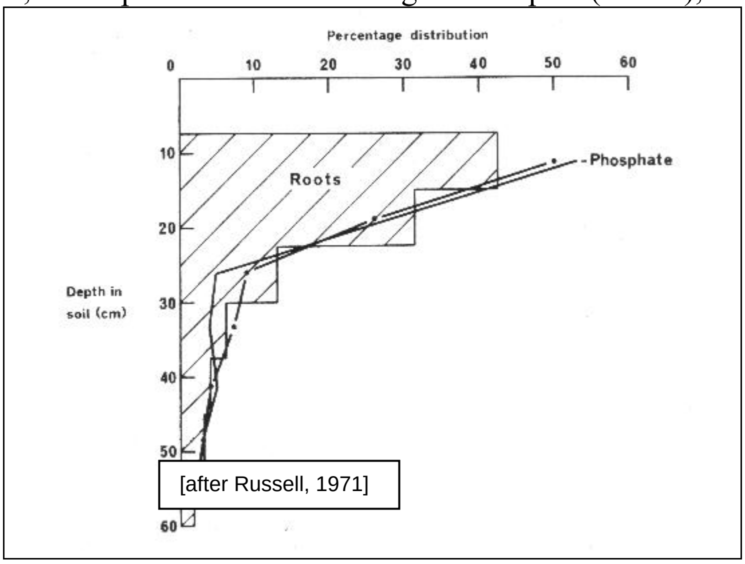

Figure 1 Distribution of roots in the soil compared with uptake of nutrients

With a physical rooting depth < 15 cm, normal tillage is impossible and even short dry periods will cause severe water stress.

With a physical rooting depth < 30 cm, normal tillage to 15 cm is marginal. If the representative depth is 30 cm within a field, it almost certain that the depth of soil in parts of the field will be less than 30cm, thus creating conditions that would damage tillage implements. Water stress in such shallow soils is likely to occur in most environments with an actively-growing crop. For example, a 30 cm deep soil with a typical available water capacity of 17% v/v can store a maximum of 51 mm water available to plant roots; this will be exhausted within 8 to 16 days under typical evapotranspirative demands (3 to 6 mm d^{-1}) of grain crops in temperate climates (Olejnik et al. 2001). However, stress will occur earlier as plants roots have to work harder and harder to extract water as the wilting point is approached. This is an important consideration because periods without rain during the growing season can be expected in much of Europe.

Water deficit interacts with rooting depth and climate, mediated by available water capacity of the soil. Shallow soils in cool, cloudy climates with regular small rain showers may show little or no water deficit. Conversely, deep soils in hot, cloudless climates, with widely-spaced irregular rainfall, may suffer large water deficits. Furthermore, a shallow sandy soil holds less water than a silty or loamy soil of the same depth. A water-balance model, incorporating actual rainfall and solar radiation, a crop calendar with growth-stage specific coefficients, and available water capacity of the soil, can give objective water deficit data. However, since the decision has been taken to use simple soil parameters rather than using crop specific information, rooting depth is used as a surrogate.

Assessment

During routine field survey, rooting depth is typically assessed by augering. The observed depths are then interpolated with reference to the landscape structure to produce rooting depth estimates for land areas or map units.

Values for severe and very severe threshold

- Severe: Physical rooting depth: 15 - 30cm:
- Very severe: Physical rooting depth: < 15 cm

Final remarks and conclusions

Shallow rooting depth is a serious constraint for conventional agriculture, adversely affecting crop growth (nutrient and water are limiting) and restricting tillage operations necessary to cultivate the soil. Therefore, shallow soils can certainly be considered ‘less favoured’ for conventional agriculture.

It is beyond doubt that a rooting depth of < 15 cm is very severely limiting to crop growth. Even deeper soils can have severe or even very severe root development problems due to massive or platy structure, *vertic* properties, and chemical environment. So not all soils without this limitation as here evaluated have in fact satisfactory rooting conditions.

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Criterion 6.1 “Soil salinity”

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Agronomic importance

With regard to agriculture, the consequences of soil salinity include:

- Significant losses of productivity, with some land entirely out of production. With increasing soil salinity, plants always find it more difficult to extract water from the altered soils. Most normal crop and pasture plants are not highly salt-tolerant and will eventually die out under saline conditions;
- Damaged soil structure and increasing content of toxic substances that may be limiting to plant growth;
- More serious soil erosion, both by wind and by water, due to worsening soil structure and reducing vegetation cover.

Definition

Salinity is the presence of soluble salt in the land surface, in soil or rocks, or dissolved in water in rivers or groundwater. Salinity can develop naturally, but where human intervention has disturbed natural ecosystems, the movement of salt into rivers and onto land has been accelerated. Soil salinity refers to the total amount of soluble salt in soil.

In the context of less favourable areas for agriculture in Europe, soil salinity is a characteristic of land for which the total amount of soluble salt in soil is too high for plants to perform or survive.

Scientific background

Soil salinity may impact on agriculture, water quality, public infrastructure and urban households and on biodiversity and the environment.

Dryland salinity occurs where there is removal or loss of native vegetation, and its replacement with crops and pastures that have shallower roots. This results in more water reaching the groundwater system. The groundwater rises to near the surface in low-lying areas. It carries dissolved salts from the soil and bedrock material through which it travels. As saline groundwater comes close to the soil surface (within 2m), salt enters the plant root zone. Even where the groundwater does not bring much salt with it, the waterlogging of the plant root zone alone can damage or kill vegetation.

As soil salinity levels increase, plants extract water less easily from soil, aggravating water stress conditions. High soil salinity can also cause nutrient imbalances, result in the accumulation of elements toxic to plants, and reduce water infiltration if the level of one salt element -sodium- is high.

There is a large amount of literature on crop responses to salinity levels and extensive research has been undertaken, particularly in dryland countries (USA and Australia). A selected list of references is given below.

Assessment

Soil salinity is determined by measuring the electrical conductivity of a solution extracted from a water-saturated soil paste. Salinity is abbreviated as EC_e (Electrical Conductivity of the extract) with units of deci-siemens per meter (dS/m).

Values for severe and very severe threshold

Salinity tolerance is influenced by many plant, soil, and environmental factors and their interrelationships. Generally, fruits, vegetables, and ornamentals are more salt sensitive than forage or field crops. In addition, certain varieties, cultivars, or root stalks may tolerate higher salt levels than others. Plants are more sensitive to high salinity during seedling stages, immediately after transplanting, and when subject to other (e.g., disease, insect, nutrient) stresses. A general response list is given in Table 1.

Table 1. General guidelines for plant response to soil salinity.

Salinity (EC_e, dS/m)	Plant response
0 to 2	mostly negligible
2 to 4	growth of sensitive plants may be restricted
4 to 8	growth of many plants is restricted
8 to 16	only tolerant plants grow satisfactorily
above 16	only a few, very tolerant plants grow satisfactorily

Although crop response to soil salinity is crop specific, overall there are good arguments to accept that:

- Levels over 4dS/m severely affect many plants while
- Levels over 16dS/m very severely affect many plants so that land characterized by such salinity levels are excluded for most agricultural uses.

Final remarks and conclusions

Although excessive soil salinity in the EU is constrained to zones in Hungary, Romania and Spain, its effects are very real.

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Criterion 6.2 “Soil Sodicity”

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Agronomic importance

Soil sodicity has two main effects on soils and indirectly on its agricultural capacity to produce. Note that sodicity effects are often indirect as they affect vital soil properties rather than crop growth itself.

1. **Sodic soils are prone to waterlogging.** Sodicity at the soil surface results in soil crusting and decreased hydraulic conductivity and available rooting depth. Consequently soils become prone to water logging. If sodicity occurs below the root zones of plants, its effect on crop productivity may be less apparent, but it can still cause significant problems. For example, in a high rainfall area on sloping land, subsurface water will flow over the sodic layer and be lost in lateral drainage. On flatter land, the sodic layer may not permit water to drain, leading to waterlogging at the surface.
2. **Sodic soils erode easily**. Sodic topsoils in dry regions are subject to dust storms. Sodic soils on sloping land are also subject to water erosion, which means that important fertile topsoil is lost from agricultural land. When water flows in channels or rivulets, soil is washed away along these lines forming furrows called rills. In some cases, even larger channels of soil removal, called gullies, develop. In other situations where only the subsoil is sodic on sloping land, subsurface water flowing over this sodic layer will create tunnels, leaving cavities that eventually collapse to form gullies.
3. **General effects.** In Australia sodicity is estimated to costs agriculture as much as $2 billion each year in lost production. And its impacts extend to water catchments, infrastructure facilities and the environment. Run-off from sodic soils carries clay particles into waterways and reservoirs causing water turbidity, or cloudiness. The effects of turbidity, and its removal, are very costly for industrial and domestic water users. Turbidity also causes environmental problems in rivers and wetlands. In addition, run-off from sodic soils is more likely to carry higher levels of nitrogen and phosphate into waterways and reservoirs. These are the nutrients that contribute to algal blooms, another significant environmental problem.

Definition

Sodicity refers to the presence of a high proportion of adsorbed sodium in the clay fraction of soils. Sodic soils are normally characterized by a dense, strongly structured, clay illuviation horizon that has a high proportion of adsorbed sodium ions.

In the context of less favorable areas for agriculture in Europe, soil sodicity is a characteristic of land for which the proportion of adsorbed sodium in the soil clay fraction is too high for plants to perform or survive.

Scientific background

In sodic soils**,** much of the chlorine has been washed away, leaving behind sodium ions (sodium atoms with a positive charge) attached to tiny clay particles in the soil. As a result, these clay particles lose their tendency to stick together when wet – leading to unstable soils which may erode or become impermeable to both water and roots.

Assessment

Soil sodicity is determined by measuring the exchangeable sodium proportion of the cation exchange capacity (ESP – Exchangeable Sodium Percentage) or by comparing the soluble sodium proportion with the sum of soluble Calcium and Magnesium in a soil solution (SAR – Sodium Adsorption Ratio).

ESP = exchangeable Na x 100 / CEC (Na and CEC in meq/100 g soil)

$$SAR = \frac{[Na^{+}]}{\sqrt{\frac{1}{2}([Ca^{2+}]+[Mg^{2+}])}}$$

Values for severe and very severe threshold

Sodicity tolerance is influenced by many plant, soil, and environmental factors and their interrelationships. As the effect is often indirect it is difficult to suggest precise thresholds. The effect of exchangeable sodium percentage (ESP) on the yield, chemical composition, protein and oil content and uptake of nutrients by groundnut showed that ESP over 15 delayed germination and emergence of flowers. There was continuous decrease in dry matter yield at 30 and 60 days of growth, grain and straw yield after harvest and protein, oil and kernel percent with increase in soil ESP. A 50% reduction in groundnut yield was observed at an ESP of 20. The uptake of all the nutrients decreased with increase in soil ESP. On the other hand cotton experiments showed relatively little effect of sodicity, until levels over ESP 25 are reached.

Whilst an ESP of six was proposed by Northcote and Skene (1972) to be the lower limit of soil sodicity, values of five (van Beekom *et al*., 1953) and two (Mitchell, 1976) have been suggested to cause a deleterious effect on soil structure. Spontaneous clay dispersion occurred in Ca-Na aggregates at an ESP of five, but was observed in Mg-Na samples when the ESP was only 3 (Emerson and Bakker, 1973).

Given the interactions with other factors there are few scientific studies that isolate ESP as a single causal factor for yield decline (see above for some specific ones). However, overall soils with sodic problems, in particular when ESP levels over 15 are reached have generally characteristics such that they should be avoided for any intensive agricultural practices.

Therefore:

- Severe soil sodicity is set to an ESP > 6 but <=15 while
- Very severe soil sodicity is set to ESP > 15

Final remarks and conclusions

Although severe and very severe soil sodicity in the EU is constrained to zones in Hungary, Romania and Spain, its effects are very real.

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Criterion 6.3 “Soil gypsum content”

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Agronomic importance

Many factors affect plant growth in gypsiferous soils, including gypsum content within the root zone, depth to a gypsic layer, depth to impermeable layers, crop tolerance level and gypsum solubility. Also physical properties are often unfavorable, causing low water availability, slaking of loamy top soils, piping and collapse of irrigation canals. In soils with gypsum, almost all crops show deficiency of most plant nutrients, in particular phosphorus and micronutrients.

Definition

Gypsiferous soils are soils that contain sufficient quantities of gypsum (calcium sulfate dihydrate) to interfere with plant growth (FAO,1990).

In the context of less favourable areas for agriculture in Europe, gypsum content is a characteristic of land for which the amount of gypsum in soil is too high for plants to perform or even survive.

Scientific background

Generally gypsum soils are located in dry climates and are relatively unproductive. They are considered marginal for crop production and are primarily used for livestock grazing, and wildlife habitat. The soils are droughty and infertile and support uniquely adapted plant communities.

Gypsiferous soils are found in arid and semi-arid areas on gypsiferous rocks and sediments of different origin, where rainfall is insufficient to leach the gypsum out of the soil mantle. They usually occur in the same regions as calcareous soils but are much less widespread.

Crops can be classified according to their sensitivity to gypsum: (1) tobacco is sensitive; (2) cotton, groundnut, potato and sunflower are semi-sensitive; (3) broad beans, sugar beet, sorghum, corn, soybean and sesame are semi-tolerant; (4) alfalfa, trifolium, wheat, barley, lentil, oat, tomato and onions are tolerant. When the gypsum content in the root zone is more than 40%, land is considered unsuitable for cropping.

Van Alphen and de los Rios Romero (1971) conclude that up to 2 percent gypsum in the soil favours plant growth, between 2 and 25 percent has little or no adverse effect if in powdery form, but more than 25 percent can cause substantial reduction in yields. They suggest that reductions are due in part to imbalanced ion ratios, particularly K:Ca and Mg:Ca ratios. Hernando *et al.* (1963, 1965) studied the effect of gypsum on the growth of corn and wheat by varying the gypsum level in the soil up to 75 percent. They show that high levels of gypsum caused poor growth of corn, especially as the soil moisture was maintained at 80 percent of field capacity. However, wheat showed minimum growth where the soil contained 25 percent gypsum at all soil moisture levels ranging from 15 to 100 percent of field capacity. Akhvlediani (1962) concludes in general, that agricultural production on gypsiferous soils is not affected when the gypsum content is between 15 and 30 percent. Bureau and Roederer (1960), report that 30 percent gypsum content in soils of Tunisia is toxic to plant growth. Van Alphen and de los Rios Romero (1971) state, from field observations in the Ebro Valley of Spain, that plant growth is reduced where the gypsum content exceeds 20 to 25 percent.

From intensive field observations of gypsiferous soils in Iraq, Smith and Robertson (1962) found that root growth was inhibited where the gypsum content of soil was over 10 percent. This is apparently because of the poor transmission of air and water caused by poor structure. They also found that soils containing more than 25 percent gypsum in the rooting zone give poor growth. In the spring, wheat crops wilt on shallow gypsiferous soils when other crops on deeper soils show no signs of distress. Roots do not penetrate the gypsum layer, even when it is quite wet. Kovda (1954) and other workers observe that plant roots do not penetrate a soil layer containing 25 percent of gypsum or more. Boyadgiev (1974) notes that the presence of well-crystallized gypsum within the first metre of soil, affects the performance of cotton crops significantly. Boyadgiev (1974) also noted that crops such as alfalfa could grow very well and give high yields even in soils containing up to 50 percent of powdery gypsum as long as no gypsic layer impeding root elongation and extension is present in the soil profile at shallow depth. Similar effects have been noted by Amami *et al.* (1967) in the oasis at Tozeur in Tunisia, where good yields of alfalfa and date palms were obtained in the highly gypsiferous soils. Similar results were obtained in the Ebro Valley of Spain with crops such as alfalfa, wheat and apricots.

It appears from the above results that the gypsum content of soils is only one of several factors which affect plant growth and yield of crops. The other factors are:

a) The depth of the topsoil over a gypsic layer;

b) The hardness and degree of crystallization of the gypsic layer;

c) The total and active calcium carbonate contents;

d) The availability of plant nutrients and moisture content in the root zone;

e) The type of crops grown and their relative tolerance to gypsum;

f) The drainage conditions and salinity of the soil.

Assessment

Gypsum is determined by the differential water loss method which estimates the gypsum percentage from the loss of water in the soil sample between 70 and 90°C. It can also be estimated with gravimetric determinations of precipitated $BaSO_4$.

Values for severe and very severe threshold

As can be seen from the above, there are many factors which make the use of a single threshold debatable. Overall results would indicate that apart from special crops (certain fruit trees), gysiferous soils

- present a severe limitation to crop production once the gypsum percentage exceeds 15 % while
- more than 40% of gypsum constitutes a very severe limitation for most crops.

Final remarks and conclusions

Although severe and very severe limitation due to presence of gypsum in soils in the EU is constrained to zones in Spain, their effects are very real.

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Criterion 7 "Soil Moisture Balance"

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Agronomic importance

The soil water balance is a critical parameter for assessing the potential for crop production. Agricultural production is seriously impaired if soil water is limiting during the growing season and the 'Soil Water Balance' criterion identifies land at risk of this causing adverse affects on plant growth and crop yields.

Most agricultural crops offer varieties which vary in their general and specific climatic requirements and in their length of total growing period from sowing to harvest. This variation allows a crop to be adapted to a wide range of climatic conditions and to the time period required and available for crop production. One of the important crop requirements, the available growing period is determined by the amount and duration of water supply.

It is assumed that in areas with irrigation water resources and irrigation infrastructure in place no water stress occurs and that the number of days available for crop growth is generously sufficient. Irrigated areas are considered as favourable areas for agricultural production (from perspective of soil moisture balance criteria) and therefore only rainfed agriculture is considered here.

Definition

Deficitary soil moisture balance is defined as the condition in which crop performance or survival is compromised by limited water availability during the growing period, which is insufficient for optimal growth and development of crops.

In the context of less favorable areas for agriculture in Europe, deficitary soil moisture balance is a characteristic of land for which the "number of days, within growing period as defined by temperature, for which the amount of precipitation and moisture available in the soil profile is not sufficiently high as compared to the reference evapotranspiration, for plants to complete the production cycle".

Scientific background

In most parts of Europe rain-fed agricultural production is possible during a part of the year only. The growing period available for rain-fed crop cultivation is defined by the period with favorable temperatures and soil moisture conditions. Crop growth cycles vary between 60 days (e.g. buckwheat) and all year round (e.g. banana). Most European annual agricultural crops have growth cycles between 90 and 210 days.

The start of the growing period is defined by temperatures exceeding 5^{o}C and accumulation of sufficient rainfall to moisten the topsoil to sustain growth of germinating crops. The moisture required at this early crop development stage is well below the evapo-transpiration demand of crops at maximum canopy cover. For establishing crops, 0.4-0.5 times the level of reference evapo-transpiration is considered sufficient to meet crop water requirements. (FAO 1978-81, Doorenbos and Kassam 1979, FAO 1992, FAO 1998). Therefore the minimum available moisture to define the start of the rain-fed growing period has been set to half of reference evapotranspiration.

The growing period for most crops may continue beyond the rains. Crops may mature on moisture stored in the soil profile. However, the amount of moisture stored in the soil profile and available to a crop varies, e.g., with depth of the soil profile, the soil's physical characteristics and the rooting pattern of the crop. Depletion of soil moisture reserves causes the actual evapotranspiration to fall short of the crop requirements.

Assessment

This number of days available for rain-fed agricultural production in individual locations can be estimated using the FAO/IIASA concept of Length of Growing Period (LGP)[10], which is defined as: "the period during the year when both moisture availability and temperature are conducive to crop growth" (FAO 1978, Fischer *et al.,* 2002, 2006, 2008). The calculation of LGP is based on a simple moisture-balance comparing rainfall and moisture stored in the soil profile available to agricultural crops, with crop water requirements in terms of reference crop evapotranspiration rates[11].

The climatic parameters required for calculating the 'soil water balance' are defined in Fischer et al. (2008) in LUC/0803.

The soil properties that are required for calculating plant available water in the soil profile, which Thomasson (1995) has defined as Soil Water Available to Plants (SWAP), are:

- Volume of water retained at suctions of 5 kPa (notionally field capacity) and 1500 kPa (wilting point) – see Hall *et al.*, (1977); Smith and Thomasson, (1982)
- Soil (rooting) depth – depth in the soil to which plant roots can extend, largely unimpeded

If soil water retention properties have not been measured (from undisturbed cores) for an area of interest, SWAP may be estimated in regional or national cases from pedotransfer functions relating water retention at field capacity and wilting point to contents of silt, clay, organic carbon and bulk density (Hall *et al.*, 1977). At European scale, for which less accurate data might suffice, pedotransfer rules have been developed (van Ranst et al., 1995) and applied (King et al., 1995; Jones et al., 2000).

Values for severe and very severe threshold

Short growing periods either due to moisture deficits, cold temperature limitations or both provide unfavorable conditions for agriculture. On the basis of minimum crop cycle durations, the following critical limits have been established:

- Severe threshold: LGP < 90 days but >= 60 days
- Very severe threshold: LGP < 60 days

To account for inter-annual variability of moisture conditions the 80% percentile of exceedance of the proposed thresholds is suggested, i.e., a very severe soil moisture limitation would render an area unfavorable if the calculated rain-fed LGP would be less than 60 days in three or more years out of ten years. A severe limitation occurs if in only three or more years out of ten years the rain-fed LGP fall below 90 days and not more than 2 years fall below 60 days.

Final remarks and conclusions

The climatic suitability of land for rain-fed crops is governed to a large extent by the number of growing period days available in a location. As long as crop growth cycles fit within the available

[10] In a formal sense LGP refers to the number of days with average daily temperatures above 5 ^{o}C when moisture conditions are considered adequate, i.e., available soil moisture results in actual evapotranspiration of at least half potential evapotranspiration.

[11] For the calculation of reference evapotranspiration, the Penman-Monteith equation (FAO 1992) is recommended

growing period as determined by temperature and soil moisture condition are favorable for crop growth.

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Criterion 8 'Slope'

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Agronomic importance

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. In particular mechanisation is hampered while access to land and all agricultural operations become more time consuming. Steeper slopes are also associated with shallower soils in general (Leptosols, Regosols) and with a higher risk for soil degradation (erosion) and land slides.

Definition

Slope is the angle the soil surface makes with the horizontal. It can be expressed in degrees or as a percentage (45 degrees = 100 percent). The form of the slope may be important and influence the moisture status of the underlying soils, as happens in concave or convex slopes. A particular important characteristic for agriculture is the aspect (direction of exposure) of the slope that may result in significant higher temperatures on south-exposed slopes as compared to northern exposed ones, at least in the northern hemisphere.

Scientific background

Slope is frequently used as a criterion to assess capability and suitability of land for agriculture. In the British land capability classification, slope is recognized to have a marked effect on mechanical farming as follows in Table 1:

Table 1: slope classes according to Bibby and Mackney, 1969.

Slope (degrees)	Slope (percent)	Slope class	Problems
0-3	0-5,2	Gently sloping	None
3-7	5,2-12,3	Moderately sloping	Difficulties with weeders, precision seeders and some mechanised root crop harvesters
7-11	12,3-19,4	Strongly sloping	Use of combine harvester restricted
11-15	19,4-26,8	Moderately steep	Limit of use of combine harvester and of two way ploughing (depending of field configuration)
15-25	26,8-46,6	Steep	Not suitable for arable crops, with slopes over 20° being difficult to plough, lime or fertilise
>25	>46,6	Very steep	Mass movement occurs, animal tracks across slope appear and mechanisation impossible without specialised equipment

Klingebiel and Montgomery (1966) distinguish four classes: 0-2%, 2-6%, 6-12% and >12%. For sugar beer and potatoe crops, Sys et al. (1991) distinguish between 5 classes (0-2%, 2-4%, 4-8%, 8-16% and >16%) where the 5th one is considered to make land unsuitable for these crops. For wheat production, the classes are 0-2%, 2-8%, 8-12%, 12-16% and >16%. Again the >16% class is considered to be unsuitable. However, medium to low intensive pastures are the advisable land uses and still possible on these steeper slopes.

Assessment

Several instruments have been developed over time to determine the angle of the land. Topography has been estimated through photogrammetry techniques. Most national cartographic institutes have Digital Elevation Model (DEM) with a horizontal resolution of 10-20m. A particular recent development is the availability of radar and satellite obtained elevation measurements with a high resolution (90 meters resolution is available for the whole world between 60 degrees North and South, and 30 meter resolution data are also used). For a given location, the estimation of the slope will be affected by the resolution of the DEM (coarse resolution DEM will under-estimate the real slope).

From neighboring altitude data, slope can be determined by algorithms. The resulting 'local' slopes must be averaged over a larger area (typical field size) to be applicable as an indicator of land suitability.

Values for severe and very severe threshold

From the above can be stated that:

- Slopes between 15 - 30% pose severe problems for mechanized cultivation, specific equipment is required;
- The problems posed by slopes over 30% are very severe so that they cannot be used for mechanized agriculture, given the high risk for equipment reverse and soil erosion.

Final remarks and conclusions

Slope of land clearly affects its suitability for agricultural production; mainly through the restrictions steeper slopes impose on mechanization of crop management and on their vulnerability to soil erosion. Terracing is a way of overcoming the slope restrictions but is at the expense of huge investments and has in addition to cope with limitation due to soil depth. Furthermore, steep slopes will accelerated water erosion if not managed appropriately.

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Abstract

A panel of soil, climate and land evaluation experts reviewed a set of land evaluation methods in order to elaborate an approach which can support the definition and delineation of the so called “Intermediate Less Favoured Areas for agriculture (iLFA)” in EU27. The driver for this exercise is Article 50.3 of EC-Regulation 1698/2005 calling for the revision of the existing system based on criteria related to low soil productivity and poor climate conditions for agriculture.

FAO’s agricultural problem land approach was selected and adjusted to come forward with the requested approach. The FAO approach was deemed appropriate because it is not crop-specific and for its simple assumptions regarding the mutual interaction of land characteristics on the overall suitability of the land, making it applicable for a territory as large and diverse as EU27. Two climatic and four soil criteria were retained and complemented by one integrated soil-climate criterion (soil water balance), with slope as the sole topographic criterion. For each criterion two critical limits were defined dividing the criterion range into three sub-ranges: *not limiting*, *severely limiting* and *very severely limiting* for agriculture.

The criteria and the associated critical limits or threshold values can be used anywhere to discriminate land with biophysical constraints to agricultural production on the basis that soil and climate data of sufficient spatial and semantic detail are available. Whereas such datasets are held at regional and national levels, Pan-European soil and climate data sets also exist to which the criteria and threshold values can be applied. However, their spatial and to a lesser extent semantic resolution is too restricted to classify land fully in line with terrain reality. The pan-European assessments are however useful as a reference backdrop for assessment of consistency of exercises which use national or regional data sets.

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