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Soil information in support of policy making and awareness raising

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Soils play an important role in defining sustainable land-use options when facing major global environmental challenges such as food security, climate change, fresh water scarcity and biodiversity loss. Facing these problems, the 2006 EU Thematic Strategy for Soil Protection (TSSP), provides an important focal point for soil research and awareness raising. Unfortunately, the TSSP has not yet been followed up with a legally binding Framework Directive mainly because of political barriers. Two approaches are discussed to overcome these barriers: First, we *explore innovative ways to present soils and raise soil awareness.* Soil information in terms of atlases, associated databases and interpretations, focusing on major environmental problems, is presented by the EU Joint Research Center (JRC) for Africa and South America using modern digital techniques and, particularly, a user-oriented approach. This contrasts with the traditional approach that is more soil-centred. Soil science has not yet effectively tapped the genuine and basic affinity of mankind with their soils. Therefore, more attention to local knowledge and management of soils is needed. Creating more awareness, by sharing experiences with various citizen groups, is also an effective mechanism to mobilize the political arena as is demonstrated by some German examples. Second, we *show specific real-world examples as to the possible positive and innovative impact of the TSSP.* An example is presented of Functional Soil Planning, based on maximizing soil functions at national and international level by customizing soil management at local level, balancing 'supply' and 'demand' by defining tradeoffs between conflicting functions. Finally, a case study for Scotland is presented dealing with EU policies for so-called: 'Less Favoured Areas (LFA)'. The EU Court of Auditors required unified rules for the EU, while Scotland already had defined: 'Areas of Natural Handicap', as a basis for LFAs, emphasizing biophysical criteria. The ensuing discussions with the EU agencies illustrated the significance of the subsidiarity and proportionality principles, demonstrating that EU-wide rules and indicators could be fine-tuned and improved by considering local conditions. In both approaches, soil information is both key to the policies whilst at the same time the policies themselves provide excellent vehicles for awareness raising; a win-win situation.

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Introduction

Soils play an important role in defining sustainable land-use options in future as mankind is facing major global problems in terms of food security, climate change, fresh water scarcity and biodiversity loss. Facing these problems, the 2006 EU Thematic Strategy for Soil Protection (TSSP) [16] provides an important focal point for soil research and awareness raising [4•]. The Strategy reflects a policy statement and defines a number of soil threats, such as: erosion, contamination, loss of organic matter and of biodiversity, compaction and other physical soil degradation, salinisation, floods, landslides and sealing. To study threats, emphasis on the effects of threats on seven soil functions, also defined by TSSP, has provided a useful focus: (i) biomass production, including in agriculture and forestry; (ii) storing, filtering and transforming nutrients, substances and water; (iii) biodiversity, such as habitats, species and genes; (iv) physical and cultural environment for humans and human activities; (v) source of raw materials; (vi) Acting as carbon pool; and (vii) archive of geological and archeological heritage. The Strategy has so far not been followed up with a legally binding Framework Directive. In contrast to climate and water, the effects of which can directly be experienced by man, communicating the importance of soils faces problems because soils are only exposed at roadcuttings or in pits and are otherwise hidden below the surface. Questions can be raised as to whether: (i) the soil research community has produced enough enticing information for the policy arena and for broad audiences demonstrating the prominent effects of soils on food production, carbon sequestration, purifying effects on percolating liquids and on the habitat for soil flora and fauna [4•]. If not, how can this be improved? (ii) The TSSP can play a role in focusing soil research efforts that are successful in producing information in support of policy making and awareness raising at both the EU and national level. This

is particularly relevant as environmental policies tend to move towards more participatory, bottom-up approaches rather than the more traditional top-down, command-and-control procedures [5•].

In the following sections, attention will be paid firstly to various ways of improving soil awareness by discussing the importance of communication both within the scientific world with our own and other disciplines but also with the public and the policy arenas. We then discuss how two specific case studies illustrate the positive effect of applying the TSSP principles to aid communication and joint learning process between countries and EU agencies and ultimately to provide a more fit-for-purpose outcome resulting from this communication. This is an unusual manuscript. The title was derived from the name of a session at the Applied Soil Science Congress, as defined by the organizers and they selected the papers. Nevertheless, the papers could be arranged in two coherent and related themes, as indicated.

New ways to present soil data: Soil Atlases of Africa, Latin America and the Caribbean

Over the past decades, increased misuse and management of land has, particularly in Africa and Latin America, led to increased pressure on the environment. In turn, these pressures have led to the degradation of soils and many of the services that they provide [22,21].

Soil resources from Africa and Latin America are crucial for meeting the food, feed, fibre, and fuel needs of the fast growing human population. As highlighted recently in *Nature* [23,28], and in [24], current cropland could be more than doubled by adding 1.6 billion hectares – mostly from Latin America and Africa – without impinging on land needed for forests, protected areas or urbanization. But several experts [27] advise against substantially increasing cultivated land, arguing that this would damage ecosystems and biodiversity, and be accompanied by a disproportionately large increase in global agricultural greenhouse gas emissions. One possible option to reach a win-win solution can be what is generally defined as 'sustainable intensification' [8,34], which has become the priority of many agricultural research agencies. For instance, the Agricultural Outlook 2010–2019 [25] forecasts that Brazil's agricultural output will grow faster than that of any other country in the world in the coming decade, increasing by 40% by 2019. The associated increased pressure on soils requires a precautionary approach to the management of this key resource, in order to avoid, or at least to maintain within a sustainable threshold, the degradation processes.

A necessary starting point to achieve the objective of preserving soil resources is to reach an adequate level of knowledge on their status and to raise awareness on their importance [29,26,28]. In order to enlarge soil awareness of the public at large, stakeholders, policy makers, and other scientists, to the importance of soil in Africa and in Latin America, the Joint Research Centre (JRC) of the European Commission has produced the first ever Soil Atlas of Africa, and Soil Atlas of Latin America and the Caribbean (LAC). The Atlases compile existing information on different soil types in terms of easily understandable maps (both at regional and continental scale) covering the continents. The Soil Atlas of Africa illustrates the diversity of soils from the humid tropics to the arid deserts from an African perspective through a series of maps supported by explanatory texts, high quality photographs and descriptive graphics. Interactions between land use and soil conditions are emphasized. Derived maps are presented, reflecting interests of various intergovernmental, economic and political African organizations, describing, for example, vulnerability to desertification and soil erosion, soil nutrient status, carbon stocks and sequestration potential, irrigable areas and water resources. A new soil map at scale 1:3 000 000 was derived from the Harmonized World Soil Database [17]. Soil Atlas of LAC has basically the same structure and content as the Soil Atlas of Africa, but with a stronger emphasis on climate change. The soil maps shown in the Atlas will be based on the 1:5 000 000 SOTERLAC soil database [14], that will be updated and validated on the base of the information provided by the LAC countries. Soils will be discussed both at regional scale, on the base of ecoregions, and at national scale. A specific section will be devoted to ethnopedology. These Atlases highlight the diversity of soil in both continents and will help the reader to understand better the characteristics and land use potential of various soil types in this part of the world. The innovative character of these maps consists of a focus on users of soil information rather than on scientific peers, as in traditional soil survey reports of the past.

Together with the publication of the Atlases, the soil map and associated datasets on soil characteristics will be made freely available. These datasets will be useful for making broad distinctions between soil types and provide general trends at the global and regional scales. The datasets will be made accessible for free downloading from the portals of the SOIL Action (http://eusoils.jrc.ec.europa.eu/) and the ACP Observatory for Sustainable Development (http://acpobservatory.jrc.ec.europa.eu). In parallel to the publication of the Atlases, two calendars were produced: the 2010 Calendar on African Soil [20] and the 2012 Soil Calendar of Latin America and Caribbean [19].

The Atlases link the theme of soil with rural development and, at the same time, support the goals of the TSST in conserving a threatened natural resource that is vital to human existence.

Improving communication on Soil Policy in Europe

Improved communication on the role and function of soils in society has a different focus depending on the target group and the time frame to be considered. Most important, however, is the question as to what we communicate and how our soil information is derived. Teaching of soil science at different educational levels is usually rather technical in nature, emphasizing, for instance, chemical, physical and biological soil formation processes and soil classification. Though this represents essential information for the soil professional, it is too specialized to be of interest to the average lay-person. Above, we reported on applications of soil science focusing on major environmental problems in the context of the Soil Atlases of Africa and South America. But the TSSP [16] also defines function (iv): physical and cultural environment for humans and human activities and function (vii): archive of geological and archeological heritage. These topics are of broad interest and more efforts should be made to communicate the role of soils in this particular context. Everyone in society is a stakeholder in these functions as they relate to our shared cultural and societal heritage. However, different sectors of society require different methods of communication, requiring more contacts with social scientists and anthropologists. The other functions of soil such as food and fibre production are also clearly vital for society; soil science needs to express these benefits, not as complicated processes (although that is what they are) but as the end results of those processes [4•].

Communication of soil science – some generic issues

Soil scientists as a group

Soil scientists are usually good communicators in their special research fields, as they organize conferences and fill scientific journals with disciplinary papers. The current reward structure is such that such activities are most profitable for the individual scientist. But communication among soil physicists, chemists, biologists and spatial soil scientists should be improved if only because major environmental ('wicked') problems call for an integrated approach that will only be recognized as a significant contribution from soil science by their partners in *interdisciplinary* and *transdisciplinary* projects [4•,5•].

Soil scientists interacting with other scientists

Interdisciplinary and *transdisciplinary* research approaches are a challenge for any profession as they have to define a 'niche' for themselves in teams that study 'wicked' environmental problems. Some hydrology studies, modelling watershed hydrology, do not take account of soil parameters (e.g. examples in [6]). Similar examples can be given for climatology and ecology. Rather than be disturbed about this, soil scientists would be well advised to take part in *interdisciplinary* and *transdisciplinary* research projects demonstrating that inclusion of soil information significantly improves results obtained. This is best achieved by also including model simulations without soils input, which can act as a baseline.

Soil scientists and their interaction with practitioners, the public and policy makers

As a discipline, soil science has, in most cases, communicated rather poorly with practitioners, the public at large and policy makers. Many soil studies deal with soil protection but most of them are increasingly focused on modelling and do not involve much (expensive) field work, nor do they contribute to raising soil awareness because, as mentioned above, this yields little credit within the science community. On the contrary, those dealing with soils in their daily life as consultants or administrators responsible for soil protection have a much larger stake in communicating effectively with the public. Moreover, leaders of nature conservation organizations are increasingly aware of the importance of soils as, for example, indicated by their effective promotion of the Soil Framework Directive [2].

Bottom-up approaches from the local to the national level are needed in raising soil awareness in addition to top-down approaches from the international to the national level. One example for a bottom-up approach is ENSA, the European Network on Soil Awareness. The goal of ENSA is to bring together all people who are interested in soil awareness, not only soil scientists ([3]: http://www.eu-ensa.org/). Local groups of people dealing with raising soil awareness in a town or a region are the basis of the activities. The network collaborates with ELSA, the European Land & Soil Alliance (http://www.boden-buendnis.org/en/), and the ESBN Working Group on Soil Awareness and Education [33]. In Germany, the 'Aktionsplattform Bodenschutz', an alliance between the German Soil Science Society DBG, the German Soil Association BVB and the German Association for Environmental Remediation and Brownfield Redevelopment ITVA, works together with the Federal Environmental Agency of Germany. For example, every year one public event takes place in Berlin at the World Soil Day to present the 'Soil of the Year'. Similar activities between organizations working for soil protection are taking place in Austria. However, the stereotype 'bottom-up' versus 'top-down' metaphor hardly applies when injecting soil science expertise in real projects where communication practices among scientists, entrepreneurs and governmental and non-governmental agencies is complex as interactions move in different directions and are quite different for any particular project [5•].

Innovation in sustainable management of soils requires co-production of knowledge and technologies involving research scientists, policy-makers and land managers. Scientific research has produced a great deal of knowledge

about soil properties and management techniques, but much science remains disconnected from real practices in farmers' fields, both in terms of the generation of knowledge and the application of policy. In order to overcome this gap, applied soil science would be well advised to increase research on farmers' knowledge and practices in relation to soils, also known as ethnopedology [32,35]. This would entail integrating farmers' technical knowledge and practices as well as their normative positions vis-à-vis landscape planning and development [11]. Increasing use of local soil knowledge and practice would have major implications as to how applied soil science is conducted. Technical innovations or interventions are infused with implications of political and cultural transformations that often fall outside of modelling-based approaches [11,12]. While this approach is most often applied in developing countries [10], it can be equally important in Europe.

The time dimension

Communication of soil issues is difficult when dealing with policy makers and journalists. Most journalists are interested in soils only when catastrophes happen and because soil degradation, except for landslides, has a gradual rather than immediate character stretching for periods of ten years or more, soil scientists face clear disadvantages when formulating short-term communications. Harvests have a yearly/seasonal cycle but the policy cycle is usually four years or less. There is thus a key spatial, temporal and jurisdictional mismatch in space and time that has to be considered. Perhaps the most appropriate topic to draw attention are soil sealing and associated loss of land for agriculture, because of their highly visible impacts. We are sealing an area the size of Berlin every year (http://ec.europa.eu/environment/soil/sealing.htm). These topics also offer the opportunity to work together with the agricultural lobby on soil protection and in advancing acceptance of the TSSP. The topic of biodiversity is of broad interest for stakeholders and could also be a vehicle for the TSSP [31].

Long-term communication on soils can focus on showing the effects of soil degradation not only in terms of unfavourable environmental conditions, but also in terms of costs versus benefits when considering different protection measures. Seriously considering experiences of land users (ethnopedology) is also an important long-term activity as it requires a different state of mind of researchers involved. When facing the policy arena, it is important to formulate future land use 'options' rather than 'magic solutions'. The latter do not exist when dealing with sustainable development where conflicting economic, social and environmental issues have somehow to be balanced (e.g. [4•,5•]). The same approach may work for addressing the public at large, where particular emphasis on the younger generation may be wise, using a variety of new digital techniques. It will take a long time and lessons can be learned from attempts to create awareness in, for example, the problem area of water protection. So far, effective communication practices have hardly been developed for soil science and a professional campaign to improve this omission is needed.

Functional soil planning, addressing global challenges with local action

The concept of 'Functional Soil Planning' uses, and builds upon, the seven soil functions introduced in the EU thematic strategy on soils as presented in the introduction [16,13]. Society demands soils to deliver these functions, mainly through the definition of legislative and policy targets (e.g. Water Framework Directive, Kyoto Agreement, Sewage Sludge Directive). However, such targets are commonly set for individual functions only. Soils differ in their capacity to perform each of these functions, depending on soil type and land use. To date, it has been unclear whether these policy and legislative targets can be met simultaneously, that is, whether sufficient food can be produced while at the same time meeting targets for water quality, greenhouse gas emissions, habitat protection and nutrient cycling [18]. In an Irish pilot study, we uniquely analysed both the demand and supply of each of these soil functions, using the Republic of Ireland as a case study ([30], see also [7]). Proxy-indicators used to quantify the demand and supply of functions 1–5 were: stocking rate, denitrification potential, carbon sequestration by forestry, aerial extent of designated habitats and recycling of nutrients in pig slurry, respectively. The outcomes of this study showed that at national level, the supply of soil functions has the capacity to meet demand for each of these functions, but only if the management of soil functions is locally customized according to soil type and land use. In other words, some soil types have a higher capacity for carbon sequestration to offset agricultural greenhouse gas emissions, while other soil types may have a higher capacity for denitrification in order to meet groundwater nitrate targets. An assessment of EU environmental legislation showed that – in principle – most EU directives do not preclude member states from regionalising their approach to management of soil functions with a view to 'playing each soil to its strengths'. However, the extent to which such 'functional soil planning' is implemented into policy by individual member states is yet unclear.

Moreover, this analysis indicated that the current European policy framework does not allow for functional soil planning between member states. In other words, current European policies do not fully recognize intrinsic transnational differences in the capacity of soils to perform each of the individual soil functions, and are instead largely based on the principle of subsidiarity. While some soil functions (e.g. maintaining groundwater nitrate concentrations) operate at local scale, there is scope to extend the concept of functional soil planning to a European scale, following the methodology for quantifying supply

and demand for soil functions, presented in this study. It is worth noting that the EU thematic strategy on soils facilitates such an approach, as it based on the identification and management of soil functions. However, the proposed Soil Framework Directive (SFD) is, inversely, based on the identification and minimization of threats to soil quality. Unfortunately, soil quality is considered an alien 'abstract concept' by farm stakeholder groups and, as a result, the change in policy focus from maximising soil functions to minimising threats to soil quality has led to significant resistance by farm stakeholder groups to the adoption of the proposed SFD. A policy shift back to 'soil functions', emphasizing positive rather than negative aspects would increase the appeal of any future SFD.

The role of soil information in Scottish rural policy and support

Much of Scotland's agriculture receives financial support from The Less Favoured Area (LFA) support system [9] on mountain and hill farming and farming in certain less favoured areas. The EU Court of Auditors in 2003 heavily criticized the scheme with respect to the lack of transparency in LFA delineation and implementation in some countries and recommended that delineation of the LFA (renamed Areas of Natural Handicap (ANH) and subsequently renamed Areas of Natural Constraint (ANC)) be based solely on biophysical criteria with no socio-economic assessment.

The James Hutton Institute has been acting as the technical advisor to the Scottish Government in the ANH mapping process. At first, we tested the Land Capability for Agriculture (LCA) system [1] which is a long established classification system for determining the inherent agricultural capability of land in the UK. It is based on an assessment of the limitations that climate, soil and topography impose on agricultural land use. It was assessed as a mechanism for re-delineation, and although there was a clear and logical relationship between the existing LFA boundary and LCA class it subsequently transpired that the EU did not favour country-specific solutions and developed therefore a common system to be applied across Europe.

This common system was developed by the JRC producing a guidance document [15] for all member states to follow and to ensure that a consistent approach to ANH mapping and delineation was being followed.

Eight criteria were proposed: temperature, heat stress, drainage, soil texture and stoniness, soil rooting depth, soil chemical properties, soil moisture balance and slope. Furthermore, they all had a proposed threshold, to allow land to be classified into ANH (or not). For example, if the slope was greater than 15%, that piece of land would be classified as ANH. The system has close similarities to standard land evaluation methodologies, following assessment according to the agronomic law of the minimum (Liebig's law). As soon as one of the considered criteria is rated as 'severely limiting', the corresponding land is judged to present severe limitations for agricultural production. The criteria are not weighted or given a relative importance.

These new criteria have been tested in the Scottish context and the potential impact on the LFA boundary has been assessed. A number of them were of little relevance to Scotland, for example heat stress and soil moisture balance. Data on drainage, soil texture and stoniness and soil rooting depth were 'fit for purpose' and the national 1:250 000 scale soil map was used as the spatial carrier of the information to allow maps to be produced.

Comparison with the existing LFA boundaries has shown that the temperature threshold has been set too high and that some highly productive arable land was being wrongly classified as ANH. Discussions are continuing with the Scottish Government on how to deal with this and one option is to use the LCA classification to 'fine-tune' the broad-brush EU classification.

All member states have tested the original criteria and a second round of testing is about to commence, using a modified soil stoniness threshold, soil pH and, significantly, field capacity days, a measure of excess moisture balance. The original criteria dealt only with moisture deficit, but a high incidence of soils at field capacity has profound effects on soil management in NW Europe. When presented with new local evidence, the EU is prepared to show a flexible approach to accommodate it and this illustrates the learning procedure that results from exchanging information among countries by adopting the principles of the TSSP.

Discussion and conclusions

The TSSP can be seen as a welcome signal from the EU policy arena that soils are being considered in the policy process. The challenge is now to develop a legally binding EU SFD. Increasing soil awareness can contribute to this further development but many other aspects not related to soils are likely to have major effects on whether or not new EU regulations will be adopted in future. Be that as it may, this discussion paper has presented a number of activities that have raised awareness in quite different ways and importantly, to different audiences. For example, soil atlases take an innovative approach to presenting soil information. Rather than focus on soil information as such, as in traditional soil survey reports, now attention is paid to its relevance to major environmental problems and to local socio-economic conditions. Other examples review successful efforts to actively engage citizens in soil related activities in working groups and networks, taking a bottom-up approach. Engagement

is only successful when the users of soil information are approached as partners, acknowledging that their knowledge based on practical experience is important. More can and should be learned in this context about ethnopedology, defining local knowledge and this requires more contacts in future with social scientists and anthropologists.

The paper also shows that specific case studies are effective, and therefore needed, to demonstrate the relevance and effectiveness of the TSSP. Two examples are reviewed. An Irish study deals with using the TSSP soil function approach to a nationwide allocation of different forms of land use, acknowledging effects of management, and contains a plea to consider soil functions rather than 'threats to soil quality' in any future SFD, as the negative perceptions of threats to soil quality does not appeal to stakeholders. A Scottish study illustrates the challenge to adjust national schemes, defining 'Less Favoured Areas', when being asked to consider the introduction of proposed EU-wide schemes defining: 'Areas of Natural Handicap'. Both case studies demonstrate how EU policies such as the TSSP and Less Favoured Areas approach can be used as positive examples to focus discussions and exchanges between countries and EU agencies. When presented properly, national information can be and is used to modify EU-wide schemes and to define the boundaries of the subsidiarity principle: what is the minimum detail to be defined at EU level and what can best be defined at national or regional level? Summing up, the paper proposes an increasing openness, willingness and necessity within the soil science community to engage with a range of stakeholders, be they European or local policy makers, local land users who have expert practical knowledge, school children or the general public. Much of this activity has been prompted by the awareness raising objective of the TSSP and which is a key component of the proposed SFD.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Bibby JS, Douglas HA, Thomasson AJ, Robertson JS: *Land Capability Classification for Agriculture*. Aberdeen: The Macaulay Land Use Research Institute; 19910 7084 0508 8.

2. Broll G: Untergrundaktivitäten. Umwelt aktuell. Spezial ''Bodenschutz'' 08/09 2011, EU-Koordination, Deutscher Naturschutzring, 29–30; 2011. http://www.dnr.de/publikationen/publikationen-der-eu-koordination/bodenschutz-08-092011.html.

3. Broll G: The European Network on Soil Awareness (ENSA) – a veritable option to bundle common tasks, local land & soil news 32/33 I/10, 26–27; 2010. http://www.bodenbuendnis.org/fileadmin/docs/infozeitung/llsn32-33-col%20web.pdf.

4. • Bouma J: **Implications of the knowledge paradox for soil science.Advances in Agronomy**. USA: Academic Press; 2010: 143–171.

Much soil research is not applied in interdisciplinary and transdisciplinary studies of the major environmental issues of today even though it would be quite valuable. One reason is that soil scientists do not participate in teams studying these issues, partly because their input is not considered important enough to the partners in the team. A focus of soil research on the seven soil functions of the EU – Thematic Strategy for Soil Protection is suggested to make soil expertise more effective in an interdisciplinary and transdisciplinary context. Examples are provided to suggest possible research topics.

5. • Bouma J, van Altvorst AC, Eweg R, Smeets PJAM, van Latesteijn HC: **The Role of knowledge when studying innovation and the associated wicked sustainability problems in agriculture.Advances in Agronomy**. USA: Academic Press; 2011: 285–314.

Transdisciplinarity is essential when studying 'wicked' sustainability problems but even though many theoretical and conceptual studies are available on transdisciplinarity, theory and practice appear far apart. Four case studies are analysed, illustrating that interaction between various stakeholders, governmental agencies, entrepreneurs, NGOs, and scientists are more complex than suggested by the 'bottom-up' and 'topdown' analogies. Ultimate success of projects is only achieved thanks to the perseverance of entrepreneurs supported by 'knowledge brokers' functioning as intermediairies between the scientific and stakeholder communities ('Extension 2.0'). Suggestions are presented for new research approaches, needing a much longer time-span than currently applied.

6. Bouma J, Droogers P, Sonneveld MPW, Ritsema CJ, Hunink JE, Immerzeel WW, Kauffman S: **Hydropedological insights when considering catchment classification**. *Hydrol Earth Syst Sci* 2011, **15**:1909-1919.

7. Boyle G, Schulte RPO, Donnellan T, O'hUallachain D, Creamer RE, Fealy R, O'Donoghue C: **Food Harvest 2020: Green White Gold?** *Environment Ireland 2011 Conference*; *Dublin, 15 September 2011: 2011*.

8. Burney JA, Davis SJ, Lobell DB: **Greenhouse gas mitigation by agricultural intensification**. *Proc Natl Acad Sci USA* 2010, **107**:12052-12057.

9. COUNCIL REGULATION (EC) No 1257/1999 of 17 May 1999 on support for rural development from the European Agricultural Guidance and Guarantee Fund (EAGGF) and amending and repealing certain Regulations.

10. Crane TA: **If farmers are first, do pastoralists come second? Political ecology and participation in central Mali**. In *Farmer First Revisited: Innovation for Agricultural Research and Development*. Edited by Scoones I, Thompson J. Bourton on Dunsmore, UK: Practical Action Publishing; 2009:88-91.

11. Crane TA: **Of models and meanings: cultural resilience in socio-ecological systems**. *Ecol Soc* 2010, **15**:19.

12. Crane TA, Roncoli C, Hoogenboom G: **Adaptation to climate change and climate variability: the importance of understanding agriculture as performance**. *NJAS – Wageningen J Life Sci* 2011, **57**:179-185.

13. Creamer RE, Brennan F, Fenton O, Healy MG, Lalor STJ, Lanigan GJ, Regan JT, Griffiths BS: **Implications of the proposed Soil Framework Directive on agricultural systems in Atlantic Europe – a review**. *Soil Use Manag* 2010, **26**:198-211.

14. Dijkshoorn JA, Huting JRM, Tempel P: Update of the 1:5 million Soil and Terrain Database for Latin America and the Caribbean (SOTERLAC; version 2.0). Report 2005/01, ISRIC – World Soil Information, Wageningen; 2005.

15. Eliasson A, Jones RJA, Nachtergaele F, Rossiter DG, Terres J-M, Van Orshoven J, van Velthuizen H, Bottcher K, Haastrup P, Le Bas C: **Common criteria for the redefinition of intermediate less favoured areas in the European Union**. *Environ Sci Policy* 2010, **13**:766-777.

16. European Commission 2006. Communication from the Commision to the Council, the European Parliament, the European Economic and Social Committee and the Committee of Regions – thematic strategy for soil protection (COM 2006. 231.). Commission of the European Communities, Brussels.

17. FAO/IIASA/ISRIC/ISSCAS/JRC: *Harmonized World Soil Database (version 1.1)*. Rome, Italy/Laxenburg, Austria: FAO/IIASA; 2009.

18. Hartemink AE: **Soils are back on the global agenda**. *Soil Use Manag* 2008, **24**:327-330.

19. Jones A, Gardi C, Montanarella L (Eds): *Calendar 2012 – Soil of Latin America and Caribbean*. Luxembourg: Office for Official Publications of the European Communities; 2012. 16 pp..

20. Jones A, Spaargaren O, Zougmore R, Thiombiano L, Montanarella L (Eds): *Calendar 2010 – African Soil*. Luxembourg: Office for Official Publications of the European Communities; 2010. 16 pp..

21. Lal R: **Soils and food sufficiency. A review**. *Agron Sustain Dev* 2009, **29**:113-133.

22. Millennium Ecosystems Assessment: *Ecosystems and Human Well-being: A Framework for Assessment*. Washington, DC: Island; 2005.

23. Nature: **Food: the growing problem**. *Nature* 2010, **466**:546-547.

24. OECD-FAO; 2009. OECD-FAO Agricultural Outlook 2009–2018. http://www.agri-outlook.org/dataoecd/2/31/43040036.pdf. Accessed 15 November 2011.

25. OECD-FAO; 2010. OECD-FAO Agricultural Outlook 2010–2019. http://www.agri-outlook.org/dataoecd/13/13/45438527.pdf. Accessed 15 November 2011.

26. Palm CA, Smukler SM, Sullivan CC, P.K M, Nyadzi GI, Walsh MG: **Identifying potential synergies and trade-offs for meeting food security and climate change objectives in sub-Saharan Africa**. *Proc Natl Acad Sci USA* 2010, **107**:19661-19666.

27. Royal Society: *Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture*. London, UK: The Royal Society; 2009.

28. Sachs J, Remans R, Smukler S, Winowiecki L, Andelman SJ, Cassman KG, Castle D, Defries R, Denning G, Fanzo J *et al.*: **Monitoring the world's agriculture**. *Nature* 2010, **466**:558-560.

29. Sanchez PA, Ahamed S, Carré F, Hartemink AE, Hempel J, Huising J, Lagacherie P, McBratney AB, McKenzie NJ, De Lourdes Mendonça-Santos M *et al.*: **Digital soil map of the world**. *Science* 2009, **325**:680-681.

30. Schulte RPO, Donnellan T, O'hUallachain D, Creamer RE, Fealy R, Farrelly N, O'Donoghue C: **Functional Soil Planning: can policies address global challenges with local action?** *Proceedings of the Wageningen Conference on Applied Soil Science – Soil Science in a Changing World*; *Wageningen, 18–22 September 2011: 2011:139*.

31. Talawar S, Rhoades R: **Scientific and local classification and management of soils**. *Agric Hum Val* 1998, **15**:3-14.

32. Towers W, Creamer R, Broll G, Darboux F, Duewel O, Hallet S, Houskova B, Jones A, Lobnik F, Micheli E, Zdruli P: **Soil awareness and education – developing a pan European approach**. In In *Proceedings of the 19th World Congress of Soil Science.* Edited by Gilkes RJ, Prakongkep N. *Proceedings of the 19th World Congress of Soil ScienceAugust 1–6, 2010, Brisbane, Australia, IUSS, published on DVD: 2010. http://www.iuss.org/19th%20WCSS/Symposium/pdf/2106.pdf*.

33. UNEP: *Global Environmental Outlook GEO4 – Environment for Development*. Nairobi: United Nations Environment Programme; 2007:. 540 pp..

34. West PC, Gibbs HK, Monfreda C, Wagner J, Barford CC, Carpenter SR, Foley JA: **Trading carbon for food: global comparison of carbon stocks vs. crop yields on agricultural land**. *Proc Natl Acad Sci USA* 2010, **107**:19645-19648.

35. WinklerPrins AMGA, Sandor JA: **Local soil knowledge: insights, applications, and challenges**. *Geoderma* 2003, **111**:165-170.