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Advances in soil conservation research: challenges for the future

Avances en conservación de suelos: retos para el futuro
Avanços da investigação em conservação do solo: desafios para o futuro

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ABSTRACT

Increased human influences on soils frequently result in widespread land and soil degradation. The processes of soil and water degradation are closely linked through unfavourable alterations in the hydrological processes determining soil water regimes. In the last 15-20 years there has been increased interest in human-induced climate change, associated with increased atmospheric concentrations of greenhouse gases. Most of the present and future problems of land and soil degradation, water supply and natural disasters are mainly attributed to these climate changes. At the same time, and probably related to it, there has been a change in the focus of research on soil and water conservation. From the late 1960s there was an increasing interest in stimulating studies related to soil and water conservation. This was a great change from the previous emphasis on more static studies of the characteristics of the soil resource, mainly for soil classification and mapping, and for land evaluation related to agricultural and other uses. This situation was due to the increasing evidence of the global problems of land, soil and water degradation, and their effects on food production and the environment. Particular attention was paid to the processes of soil and water degradation in relation to their use and management for agricultural purposes. These efforts led to the development of models and evaluation systems mainly using empirical approaches. Later studies demonstrated the limitations of the generalized universal use of these empirical approaches. Concurrently there was an increase in related organizations, conventions, congresses and conferences associated with the renewed interest on soil and water conservation. A global assessment of human-induced soil degradation (GLASOD) demonstrated the paucity, difficult accessibility and poor quality of basic information. This information, however, is essential for adequate planning and effective application of practices to prevent soil and water degradation. The most recent conventions and programs at international and regional levels are generally based on re-interpretations, and a different processing method or representation of old information using "new" terminology. In other cases, new information has been mostly generated through indirect or remote sensing deductions, usually without adequate ground-truthing. The decreasing public or private support for more integrated interdisciplinary studies and the compulsion to quickly publish papers has resulted in a very specialized and isolated consideration of different aspects related to the degradation of soil functions. This frequently results in over-simplifications, failures and even contradictions in the proposed strategies to control soil degradation. Currently we have reached quasi-stagnation in soil conservation research and a new series of soil conservation terms (soil quality, desertification, tillage erosion) and clichés ("C sequestration", "no-tillage") have been introduced. These are derived from different interests, but generally they are very empirical approaches without a strong scientific basis. However, they attract increased attention from organizations setting policies and providing funds for research in soil and water conservation, and as a consequence many research activities in the last 20 years have been concentrated in such topics.

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Regretfully, these approaches have very limited accuracy and are insufficient for developing adequate policies for land use and management. Climate, soil and socio-economic conditions differ greatly from one location to another and are changing continuously. There cannot therefore be simple universal prescriptions regarding practices of sustainable soil management for crop production and environmental protection or for mitigation of the greenhouse effect by "C sequestration" in soils. The adequate selection of those sustainable practices must be based on research with a broader vision of soil conservation, where all the system components and their interactions are considered and understood with a far-sighted approach, to ensure that short term gains in one aspect or location do not induce long-term losses in other aspects or elsewhere. Research needs to be directed to better the understanding of the processes and reactions in soils related to chemical recycling and water balance over a range of spatial and temporal scales, with the common objective of improving crop production and environmental protection. Lasting solutions will only be found if adequately trained researchers in soil science and hydrology, who recognize the complexity of the problems, develop appropriate strategies.

KEY WORDS
Soil degradation, hydrological processes, clichés in soil research, integrated approaches

PALABRAS CLAVE
Degradación del suelo, procesos hidrológicos, clichés en investigación de suelos, aproximaciones integradas

PALAVRAS-CHAVE
Degradação do solo, processos hidrológicos, clichés em investigação do solo, abordagens integradas

RESUMEN

La creciente influencia humana sobre los suelos a menudo resulta en procesos generalizados de degradación de tierras y suelos. Los procesos de degradación de suelos y aguas están estrechamente relacionados, ya que las alteraciones desfavorables de los procesos hidrológicos afectan los regímenes hídricos del suelo. En los últimos 15-20 años ha habido un interés creciente por el cambio climático inducido por el hombre, asociado al incremento de la concentración en la atmósfera de los gases invernadero. La mayoría de los problemas presentes y futuros debidos a la degradación de tierras y suelos, suministros de agua y desastres naturales se atribuyen principalmente a estos cambios climáticos. En relación a ello, ha habido un cambio en los enfoques de los estudios e investigaciones sobre conservación de suelos y aguas, que aumentaron desde finales de la década de los sesenta. En ellos se observa un gran cambio con respecto a enfoques previos centrados en estudios más estáticos de las características del recurso suelo, principalmente dedicados a clasificación y cartografía de suelos, y también a evaluación de tierras en relación a usos agrícolas y otros. Esta situación se vio propiciada por las crecientes evidencias de la degradación global de tierras, suelos y aguas, y sus efectos sobre la producción alimenticia y el medio ambiente. Se prestó especial atención a los procesos de degradación de suelos y aguas relacionados con su uso y manejo con fines agrícolas. Estos esfuerzos llevaron al desarrollo de modelos y sistemas de evaluación que utilizaban fundamentalmente aproximaciones empíricas, cuyas limitaciones para un uso generalizado se demostraron posteriormente. Al mismo tiempo se produjo un incremento en el número de organizaciones, convenciones, congresos y conferencias asociadas con este interés renovado por la conservación de suelos y aguas. El proyecto GLASOD (valoración global de la degradación de suelos inducida por el hombre) demostró la escasez, el difícil acceso y la poca calidad de la información básica, la cual se requiere para una planificación adecuada y una aplicación eficaz de las prácticas para prevenir dicha degradación. En los programas y congresos más recientes a nivel internacional y regional a menudo se están reinterpretando y realizando distintos procesamientos o representaciones de información previa, utilizando terminología "nueva". En otros casos, se ha generado nueva información mediante deducciones indirectas o por control remoto, sin la suficiente validación de terreno. La disminución de fondos públicos o privados para realizar estudios interdisciplinarios integrados y la obligación de publicar rápidamente trabajos de investigación ha dado lugar a un trato muy especializado y aislado de los diferentes aspectos de la degradación de las funciones del suelo, lo cual suele derivar en una sobre-simplificación, en errores e incluso en contradicciones en las estrategias propuestas para el control de su degradación. En la actualidad hemos llegado casi a un estancamiento en la investigación sobre conservación de suelos: se han introducido nuevos términos (calidad del suelo, desertificación, erosión por laboreo) y clichés ("secuestro de carbono", "no laboreo"), que derivan de diferentes intereses y suelen ser aproximaciones muy empíricas sin suficiente base científica. No obstante, atraen la atención de los programas de actuación de organizaciones y proporcionan financiación para la investigación en conservación de suelos y aguas y, en consecuencia, muchas de las actividades de investigación de los últimos veinte años se han concentrado en estos temas. Por desgracia, estas aproximaciones son muy poco exactas y son insuficientes para desarrollar políticas adecuadas para el uso y manejo del territorio. Se concluye que, debido a que el clima, el suelo y las condiciones socioeconómicas difieren enormemente de unos lugares a otros, y al hecho de que están en continuo cambio, es imposible establecer preceptos universales simples relacionados con las prácticas de manejo sostenible del suelo para la producción de cultivos y la protección del medio ambiente, y para ayudar a *mitigar el efecto invernadero mediante el "secuestro de carbono" en los suelos. La selección adecuada de estas prácticas sostenibles debe estar basada en investigaciones con una visión amplia sobre conservación de suelos, donde todos los componentes del sistema y sus interacciones sean consideradas y entendidas con una aproximación previsora para asegurar que las ganancias a corto plazo en un aspecto o lugar no induzcan pérdidas a largo plazo en otros aspectos u otras zonas. Hay que enfocar la investigación hacia una mayor comprensión de los procesos y reacciones en los suelos en relación con el reciclado químico y el balance de agua a lo largo de un rango de escalas espaciales y temporales, con el doble objetivo de mejorar la producción de los cultivos y la protección del medio ambiente. Sólo se podrán encontrar soluciones duraderas mediante el reconocimiento de la complejidad de los problemas por investigadores entrenados adecuadamente en ciencia del suelo e hidrología, que puedan desarrollar estrategias apropiadas.*

RESUMO

O aumento da intervenção humana nos solos resulta frequentemente numa mais generalizada degradação da terra e do solo. Dado que alterações desfavoráveis nos processos hidrológicos afetam os regimes de água do solo os processos de degradação do solo e água encontram-se fortemente ligados. Nos últimos 15-20 anos observou-se um aumento do interesse nas questões que envolvem as alterações climáticas induzidas pelos seres humanos, associadas a um aumento das concentrações atmosféricas em gases de estufa. Muitos dos atuais e futuros problemas da degradação do solo, o fornecimento de água e desastres naturais, são atribuídos essencialmente a estas alterações climáticas. Simultaneamente e provavelmente relacionado com isso, verificou-se uma mudança nos objetivos da investigação em conservação do solo e da água. A partir do final dos anos 60 ocorreu um aumento do interesse em estimular estudos relacionados com a conservação do solo e da água, o que representou uma importante mudança relativamente à maior enfase dada anteriormente a estudos de natureza mais estática sobre as caraterísticas do solo com o objetivo de fazer a classificação e mapeamento destes bem como a sua avaliação para uso na agricultura e outros usos. Esta situação deveu-se ao aumento da evidência dos problemas globais da terra, à degradação do solo e da água, e seus efeitos na produção de alimentos e no ambiente. Foi dada particular atenção aos processos de degradação do solo e da água relacionados com o seu uso e gestão para fins agrícolas. Este esforço conduziu ao desenvolvimento de modelos e avaliação de sistemas usando essencialmente abordagens empíricas. Verifica-se atualmente um aumento de organizações, convenções, congressos e conferências associados ao renovado interesse nos estudos de conservação do solo e da água. Uma avaliação global da degradação do solo induzida pelos seres humanos (GLASOD) veio demonstrar a escassez, difícil acessibilidade e fraca qualidade da informação básica. Contudo, esta informação é fundamental para um adequado planeamento e para a aplicação efetiva das práticas para impedir a degradação do solo e da água. As mais recentes convenções e programas a nível regional e internacional baseiam-se em geral em reinterpretações com recurso a um método diferente de processamento ou representação da informação antiga usando uma "nova" terminologia. Noutros casos a nova informação foi maioritariamente gerada através de deduções indiretas ou por deteção remota, geralmente sem a adequada verificação "in loc. A redução dos apoios públicos e privados para mais estudos interdisciplinares integrados e a compulsão para rapidamente publicar artigos resultou numa muito especializada e isolada apreciação dos diferentes aspetos relacionados com a degradação das funções do solo. Isto resulta frequentemente em simplificações, falhas e até contradições nas estratégias propostas para controlo da degradação do solo. Atualmente atingiu-se um estado de quase estagnação na investigação sobre a conservação do solo e tendo sido introduzida uma nova série de termos associados à conservação do solo (qualidade do solo, desertificação) e clichés ("sequestro de C), com base em diferentes interesses, mas regra geral com recurso a abordagens empíricas sem um forte suporte científico. Contudo captaram a atenção de organizações responsáveis pelo estabelecimento das políticas e que disponibilizam fundos para a investigação em conservação do solo e da água, pelo que muitas das atividades de investigação nos últimos 20 anos se concentraram nestes tópicos. Infelizmente, estas abordagens têm uma precisão muito limitada e são insuficientes para permitir o desenvolvimento das políticas adequadas para o uso e gestão do solo. O clima, solo e condições socioeconómicas diferem significativamente de um local para outro e estão em permanente mudança. Assim não poderá recorrer-se a simples e universais receitas para conseguir uma gestão sustentável do solo, produção de culturas e proteção ambiental ou para a mitigação do efeito de estufa por "sequestro de C" nos solos. Uma adequada seleção destas práticas sustentáveis deve ser baseada numa investigação com uma visão alargada da conservação do solo onde todos os componentes do sistema e suas interações sejam consideradas e entendidas numa perspetiva de longo prazo, para assegurar que ganhos a curto prazo num determinado aspeto ou localização não induzem perdas a longo prazo noutros aspetos ou locais. A investigação deve ser dirigida para um melhor entendimento dos processos e reações no solo relacionados com a reciclagem química e balanço hídrico numa gama de escalas temporais e espaciais, com o objetivo comum de melhorar a produção de culturas e a proteção do ambiente. Só serão encontradas soluções finais se investigadores adequadamente treinados em ciência do solo e hidrologia, que reconhecem a complexidade dois problemas, desenvolverem as estratégias apropriadas.

1. Introduction

Soil is a vast reservoir of living organisms and controls the global geochemical cycles. The biophysical functions of soils are fundamental to the necessities of human life and play a central role in determining the quality of environment. The importance of soils and soil cover in crucial aspects for human life (food production, hydrological cycles, air composition) will progressively increase in the future. To protect those functions we must evaluate and predict the behaviour of soils in time and space under a wide range of both agricultural and non-agricultural land uses, in relation to crop production, water supply and environmental quality (**Figure 1**).

Human influences on soils are increasing due to the expansion and intensification of agricultural activities with inappropriate land management practices, and the growth in the number and size of populated areas. These frequently result in widespread land and soil degradation processes and the increased production of domestic and industrial wastes. Associated with land and soil degradation is a decreased biodiversity and a decrease in available good quality water for agriculture, urban and industrial needs. There are increased risks and problems of dryness, leading to desertification, and "natural" disasters such as droughts, flooding, landslides, and mass movement, mainly due to land and soil degradation and the associated hydrological changes. Changes in soil cover and soil degradation will influence global climate changes (Pla 2002b).

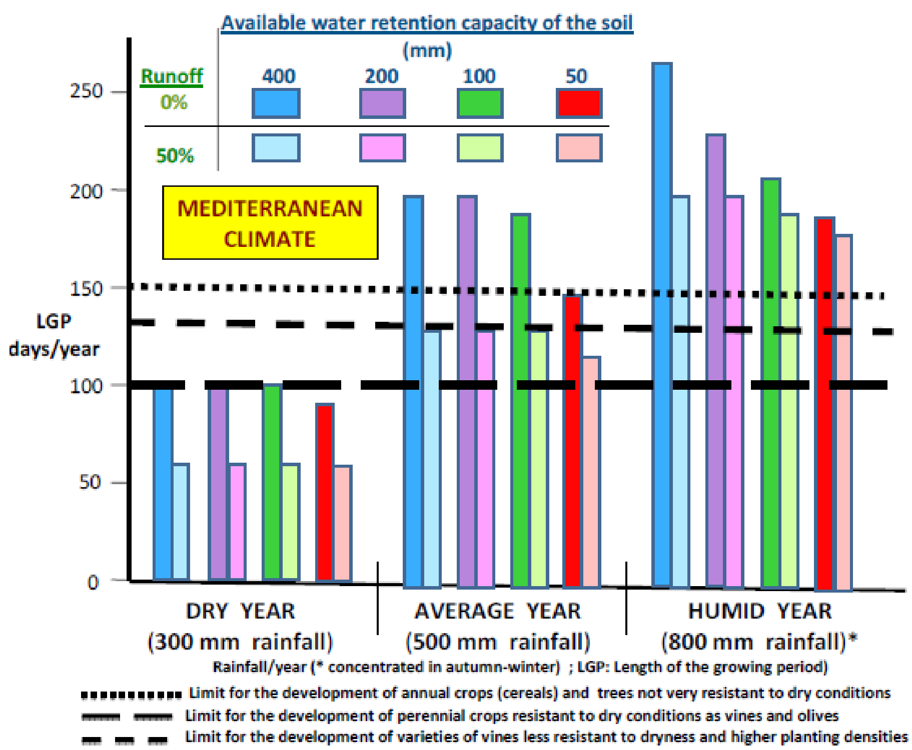

Figure 1. Potential length of the growing period in days/year (LGP) under semiarid Mediterranean climate conditions, as affected by the main critical factors derived of climate changes, land use and management and soil degradation (Pla 2010).

Soils play a crucial role in the hydrological cycle. They form the main reservoirs of fresh water, and transform discontinuous and often erratic rainfall inputs into a continuous supply of water to the plant roots and continuous discharges of water to groundwater, streams and rivers. Hydrological processes determine the transport of water soluble materials and pollutants, both naturally-occurring and human derived. Naturally occurring constituents within the soil are mobilized and transported as a result of the infiltration and flow of rainfall and irrigation water. Pollutants are partially retained, released and transformed in the soil before reaching ground water. Therefore, the quality of water resources is greatly influenced by soil hydrological processes. Continuing shrinkage of quality water supplies for different uses (i.e. human consumption and irrigation) highlight the importance of water conservation. An integrated approach to the use, management and conservation of soil and water resources is further justified by the close relationship between soil and water quantity and quality.

The processes of soil and water degradation are closely linked, with unfavourable alterations in the hydrological processes determining soil water regimes. They are also both influenced by climatic conditions and the use and management of soil and water resources. Although the close interaction between the conservation of soil and water resources is being increasingly accepted, they are still usually evaluated separately. Consequently, the prediction and prevention of the effects derived from their degradation are often inadequate. This will become more important under the projected effects of global climatic changes, which will mainly affect hydrological processes on the land surface, mostly related to the field water balance (Figure 2).

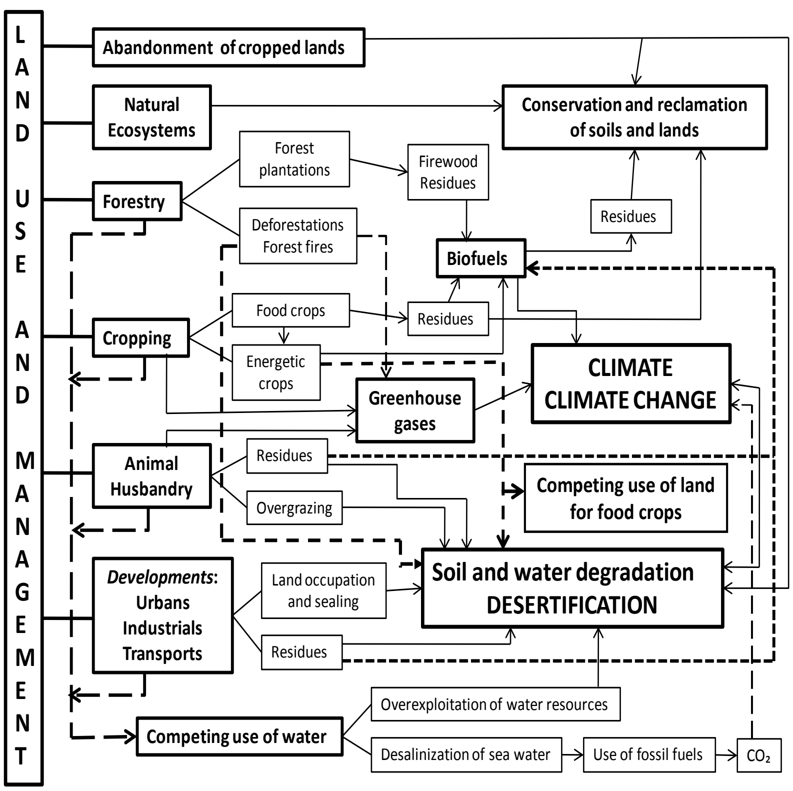

Figure 2. Relationships between land use and management, climate and climate change, and soil and water degradation.

The degradation of soil and water resources at global, regional and local scales has been steadily increasing in recent decades, especially since the 1950s. This degradation is mainly due to the increased world population and socio-economic and technological developments and the associated increasing requirements for food, water and energy. In the last 15-20 years there has been increased interest in human-induced climate change associated with increased atmospheric concentrations of greenhouse gases. With no well-defined cause-effect relationships, most of the present and future problems of land and soil degradation, water supply and natural disasters (i.e. droughts, flooding and landslides) are mainly attributed to these climate changes. At the same time, and probably related to it, there has been a change in the focus of research on soil and water conservation.

2. Evolution of soil conservation research

From the late 1960s, prompted by the growing global problem of land, soil and water degradation and its effect on food production and the environment, there was an increasing interest in stimulating studies related to soil and water conservation. Particular attention was paid to the processes of soil and water degradation in relation to their use and management for agricultural purposes. This was a great change from the previous emphasis on more static studies of the characteristics of the soil resource, mainly for soil classification and mapping, and for land evaluation related to agricultural and other uses. Among the new studies and approaches related to soil and water conservation, one must especially recognize those developed in specialized research centers, on soil erosion and soil salinization in the USA. These efforts led to the development of models, like the USLE (USDA-ARS 1965; Wischmeier

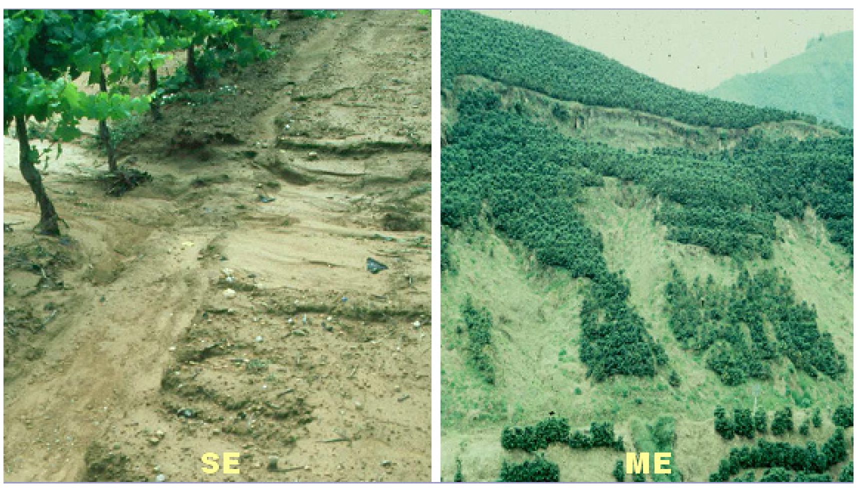

Figure 3. Surface erosion (SE: Vineyard-Spain) and mass erosion (ME: Coffee plantation-Colombia).

and Smith 1978) to predict soil erosion and to systems for evaluating and predicting risks of soil and water salinization (USDA 1954) (**Figures 3** and **4**). Such models and evaluation systems mainly used empirical approaches, based on statistical relations between accumulated information of the contributory factors (climate, soils, water) and their observed or measured effects on soil degradation processes under very specific conditions. Therefore, the evaluation or predictive capacity of such models and systems could only be effective under conditions (climate, soils, topography and management) similar to their provenance.

These early approaches were an initial and crucial contribution to both the understanding of soil and water degradation processes and to the application of some standardized conservation measures. Later studies, however, investigated the dynamic processes involved in soil and water degradation under varied conditions and demonstrated the limitations of the generalized universal use of these empirical approaches. Revisions or additions have been introduced more recently to these approaches (Renard et al. 1991; Ayres and Wescot 1976, 1985) with the intended purpose of solving some of the original limitations. The most recent development of alternative non-empirical physically-based models for the evaluation of soil erosion risks, include EUROSEM (Morgan et al. 1998) and WEPP (Nearing et al. 1989). These have tried to include very detailed descriptions of most of the factors involved in the surface erosion processes, but generally either do not adequately consider the hydrological processes involved, or use empirical approaches for deducing parameters related to the crucial process of rainfall infiltration without considering the soil surface dynamics within the storm. The uncertainty of the parameter values and not adequately considering their spatial and temporal variability leads to great uncertainty in the results. Furthermore, the requirement of a very detailed and accurate database, which is usually not available, limits their application.

Figure 4. Saline soil (irrigated alfalfa-Spain) and sodic soil (irrigated banana-Venezuela).

Concurrently with the renewed interest in soil and water conservation, there was an increase in related congresses and conferences. In addition, several international scientific organizations were created (SWCS: Soil and Water Conservation Society, ISCO: International Soil Conservation Organization, WASWC: World Association for Soil and Water Conservation, ESSC: European Society for Soil Conservation) and Commissions and Sub-Commissions on Saline Soils, Soil Conservation and Environment and Soil and Water Conservation within the International Society of Soil Science (now International Union of Soil Sciences). Simultaneously, under the direction of "United Nations Environmental Program" (UNEP) and the "International Soils Reference and Information Center" (ISRIC), a Global Assessment of Human-Induced Soil Degradation (GLASOD) was created prior to the United Nations Conference on Environment and Development (UNCED) in 1992. This organization prepared Agenda 21, a global program for sustainable development. Several international conventions and programs were created in association with GLASOD, including UNCED (United Nations Convention to Combat Desertification), UNFCCC (United Nations Framework Convention on Climate Change), LADA (Dryland Land Degradation Assessment), and WOCAT (World Overview of Conservation Approaches and Technologies).

GLASOD (Oldeman et al. 1991) was founded as a consequence of the need to evaluate the actual and potential problems of soil degradation at the global scale in order to provide international organizations with general overviews of the importance, extent and nature of the problems. The expectation was that it would lead to increasing support to research and development activities focusing on prevention and control. This has not been the case, at least at the required levels, but even today these assessments are often used as a basis for environmental policies related to soil degradation problems at global, national and regional levels. Of course, due to the limitations of GLASOD, such information cannot be used for planning or defining strategies for soil and water conservation at any level. During the progress of GLASOD, the paucity, difficult accessibility and poor quality of basic information has been realized. Further information is required for adequate planning and effective application of practices to prevent soil and water degradation. In many cases the paucity of information was such that the assessments were mainly based on personal information or the opinions of local “experts”. For objective assessments, improved quantitative ground evaluations and measurements are needed.

The most recent conventions and programs at international and regional levels are generally based old information that has been re-interpreted and differently processed or represented, using some times “new” terminology. In other cases, new information has been mostly generated through indirect or remote sensing methods, usually without adequate ground-truthing. Many past international assistance projects addressing soil conservation in developing countries have failed to reach their objectives, mainly due to the lack of appropriate information at a local level and the use of empirical applications of experiences obtained under very different biophysical and socio-economic conditions without adequate local validation. In some cases, such assistance programs incorporated inappropriate equipment for laboratory or field measurements or for processing such information. Therefore, such programs commonly experience a lack of continuity and the equipment becomes dysfunctional once the temporary economical and technical assistance ceases.

In recent decades, there has been an increasing interest in soil conservation across multiple disciplines. This is due to increasing evidence for the central role of soils in our environment, and the realization that the welfare and survival of our species in the coming centuries is intimately connected to soils (Janzen et al. 2010). Although, in principle, this situation could benefit the required interdisciplinary approach to the problems of human-induced soil degradation, in reality it has led to a very specialized and isolated consideration of different aspects related to the degradation of soil functions. These problems frequently result in over-simplifications, failures and even contradictions in the proposed strategies to control soil degradation. This is also due to the decreasing public or private support for more integrated interdisciplinary studies. Simultaneously, this lack of support could also be due to the failure of researchers to demonstrate the role of soils and the requirement of those interdisciplinary studies to achieve sustainable future development at multiple spatial scales. Related to this, it is surprising how many of the increasing frequent and damaging “natural” disasters (i.e. catastrophic landslides and floods) are solely attributed to factors related to global climatic changes, when usually the main cause is associated with previous changes in land use and management leading to soil degradation processes.

3. Stagnation and clichés in soil conservation research

Currently we have reached quasi-stagnation in soil conservation research and a new series of soil conservation terms and clichés have been introduced. These are derived from different interests, but generally they are very empirical approaches without a strong scientific basis. Some of them like "soil quality", "soil health" and "desertification" lack a precise quantifiable meaning. However, they attract increased attention from organizations setting policies and providing funds for soil and water conservation research, and as a consequence many research activities in the last 20 years have been concentrated in such topics. Regretfully, these approaches have not increased the required studies or developed adequate measures to prevent or correct specific problems of soil and water degradation and their effects. Related to this, there has been an increasing tendency to rely on qualitative data and concepts based on expert judgments like indices of soil quality. These have very limited accuracy and are insufficient for developing adequate policies for land use and management.

3.1. Soil quality

Many of the proposed concepts of soil quality are based on the original contributions of Larson and Pierce (1991), whose purpose was protecting the environment and sustaining the soil resource. This approach has since led to developments of subjective soil quality indices, promoting over-simplification of the complex dynamic interactions occurring in soils (Sojka and Upchurch 1999; Letey et al. 2003). Furthermore, soil use and management frequently have more influence on crop production and environmental protection than the predictions based on the inherent soil quality indices.

3.2. Desertification

The term "desertification" was introduced to emphasize the problem of extreme land degradation. Adoption of the term has led to confusion between what is a natural process exclusively caused by climate factors, and what it is human-induced through changes in land cover, use and management. It also distracted resources for the study and control of such extreme conditions, when from socio-economic and environmental perspectives there could be more important levels of land and soil degradation on more productive lands with more humid climates (**Figure 5**).

3.3. Soil erosion processes

The "newly- introduced" processes of soil erosion such as "tillage erosion" (Lindstrom et al. 1992; Govers et al. 1994; Van Oost et al. 2003), and

Figure 5. "Desertification" under dry climate conditions (DC: Fuerteventura island-Spain) and under humid climate conditions (HC: Caroni river watershed-Venezuela).

"land leveling erosion" are simply mechanical soil displacements controlled by human actions. They have nothing in common with the traditional water erosion (surface or mass erosion) related to hydrological processes, and with wind erosion processes that are derived from mainly uncontrolled natural phenomena. Tillage operations in sloping lands and land leveling may result in considerable soil redistribution within fields, but soil is not directly lost from fields. Besides artificially "increasing" the areas affected by erosion in some regions, the introduction of these "new erosion processes" have created further confusion and weakening of the research efforts related to the "traditional" more complex soil erosion processes, where the interaction between the resources soil and water is fundamental. Furthermore, there could be some contradiction when the soil displacements (i.e. land leveling, terracing, ridging) made to prevent water erosion and enhance soil conservation, may be considered "erosion" (Figure 6).

Figure 6. Soil displacement (tillage erosion? Leveling erosion?) caused by land leveling in vineyards (NE Spain) (Pla and Nacci 2011).

Among the new clichés associated with soil and water conservation, the more commonly considered are "C sequestration" and "zero tillage". They have become dominant paradigms, without due consideration and research about both the beneficial and detrimental effects in relation to various environmental and productive soil functions.

3.4. Carbon sequestration

The term "C sequestration" has been generally used to describe the increase in soil organic matter and carbon content caused by a change in land use and management (Figure 7). It has been suggested and accepted that a method to reduce atmospheric CO_2, capable of offsetting a substantial portion of anthropogenic CO_2 emissions and leading to a pretended mitigation of climate change, is to increase the global storage of C in soils (Lal 2008). This has become very popular among policy makers and soil scientists, motivating a disproportionate research in the area of soil conservation and degradation in relation to climate change, with very different and sometimes contradictory approaches. In general, misconceptions often lead to overestimation of benefits of C sequestration in soils in relation to potential emission reduction of CO_2 (CAST 2011). Sequestering C in soils is largely an uncertain process, with difficulties in measuring impacts on a large scale (Baker et al. 2007).

In order to deduce whether an ecosystem will sequester C, it is important to understand the sources and sinks of CO_2 in that particular ecosystem. Frequently it is not recognized that there are limitations in the amount of C that can be sequestered in a soil under different conditions, and that land management leading to increased soil organic C may increase the flux of other greenhouse gases like N_2O and CH_4, with a greater warming potential than CO_2 (Li et al. 2005). There are also contradictions between the objective to increase "C sequestration" in order to control anthropogenic climate change, and the proposed future use of most crop residues to produce cellulose based biofuel (i.e. ethanol), also with the purpose of influencing climate change through decreasing net emissions of CO_2 to the atmosphere (Fargione et al. 2008; Lal 2009). Adverse impacts of residue removal on soil properties must be considered prior to their use for cellulosic ethanol. The over-emphasis on research centered on the benefits of soil C sequestration undermines the attention given to studies involving the over-all assessments of other measures aimed at maximizing the different ecosystems and services supported by the soil (i.e. crop production, environmental protection), and which may be more effective in combating climate change.

Figure 7. C sequestration in the highlands (4000 m a.s.l.) of Ecuador.

3.5. Zero tillage

The term "zero tillage", also called "no-till" or "direct seeding" refers to a technique of planting crops directly over the previous crop residues without disturbing the soil with tillage. Herbicides (i.e. glyphosates) are used to replace tillage to control weeds, and that is why "zero tillage" has been aggressively promoted and encouraged by some agro-multinationals. The management of agricultural lands under "zero tillage" practices has been empirically proposed and generally accepted without discussion by many (as a cliché or quasi dogma), as the universal recommended soil conservation practice to control soil erosion and to control anthropogenic climate change through increased C sequestration, under any conditions. Without due consideration and research on the long-term effects of such management under different combinations of soils, climate, drainage, crops and herbicide use, the projected beneficial effects could not be achieved. It has been found that in many cases no-till fields sequester no more C than plowed fields, when it is measured not only in surface soil, but in the whole rooting depth (Baker et al. 2007; Hou et al. 2012). In some situations, the increased emissions of N_2O under "no-till" neutralize any increment in stored C (Li et al. 2005). Furthermore, it has been predicted that among the effects of global climate changes on production (specially in C3 plant types), and in hydrological processes, due to increased CO_2 levels in the atmosphere, we have to include increased photosynthesis and reduced respiration. This would increase water use efficiency, independently of tillage (Taub 2010). But some other evaluations suggest that those effects may be offset by the concurrent temperature rise (FAO 2011).

The largest areas farmed with "no-till", supported by glyphosate-based systems to control weeds, are with crops, mainly bio-engineered, like soybeans, corn and cotton. Recently, due to different problems developed in many continuously cropped areas with that system, which includes soil degradation (physical, chemical and biological) and the appearance of several weed species that have become resistant to herbicides (glyphosate), it has been questioned if no-till may be or not a sustainable farming practice (CAST 2012). Many of these problems are now found, after more than 20 years of continuous soybeans with "zero tillage" glyphosate based systems, in large areas of cropped lands in Argentina. Frequently the problems have aroused because it has been forgotten that a sustainable system of land management, besides no-till must include rotations, cover crops, good soil management, and the understanding of how they work together. It is now realized that the acceptance, without the required critical analysis and discussion, as a "cliché" or "absolute true", that "no-till" by itself is the best or more effective worldwide land management practice for conserving soils, has prevented the required research on integrated management practices, where tillage can fit into effective weed control, with minimal or no impact on soil degradation. In some cases tillage may be required to keep or restore beneficial soil physical conditions for better and sustainable crop production (Figure 8).

Figure 8. Long-term effects (20 years) of "no-tillage" on surface soil degradation (compaction (**a**), sealing (**b**)) and in the appearance of herbicide-resistant weeds (**d**) in fields continuously cropped with soybeans (**c**) without rotations, in Argentina.

It may be concluded that as climate, soil and socio-economic conditions differ greatly from one location to another, and as these are changing continuously, there cannot be simple universal prescriptions regarding practices for sustainable soil management for crop production and environmental protection and to help mitigate the greenhouse effect by C sequestration in soils. The adequate selection of those sustainable practices must be based on a research with a broader vision on soil conservation, where all the system components and their interactions are considered and understood with a far-sighted approach, to ensure that short term gains in one aspect or location do not induce long-term losses in other aspects or elsewhere (Janzen et al. 2010).

3.6. Soil erosion models

As clear proof of the stagnation in soil conservation research, the USLE (Wischmeier and Smith 1978) or the revised version RUSLE (USDA-ARS 1997), has continued to be used for modeling soil erosion in many places, sometimes complemented by locally specific, likewise empirical models conceptually similar to USLE. Most of the soil erosion risk maps at different levels have been prepared using the USLE or RUSLE models, often in association with GIS, and using information from past soil surveys. The most recent estimation of soil erosion on cultivated land in Europe has been using RUSLE (JRC-EC-EEA 2012). One of the "improvements" of RUSLE over the USLE is the inclusion of the influence of rock fragments on infiltration and soil loss. This is based mainly on empirical relations, sometimes deduced from studies in soil columns with glass spheres simulating rock fragments. These show a reduction of saturated hydraulic conductivity and water infiltration in soils with increasing rock fragments, while in most of the cases, under field conditions, the reverse is true (Pla and Nacci 2003).

Other more recent models like SWAT (Soil and Water Assessment Tool), based more on hydrological processes, have been also extensively used in USA and Europe, in projects supported by various European Community (EC)

Figure 9. Bench terracing in vineyards (Priorat-NE Spain), promoted and subsidized with "European Community" funds for the control of surface erosion.

agencies for simulation of the water balance in a wide variety of conservation practices, irrigation management, flood prevention structures and erosion control (Gassman et al. 2007). In SWAT, the NRCS curve number (USDA-SCS 1972) is used to calculate surface runoff, as a way of adapting the model to a wide variety of hydrologic conditions. The empirical nature of this curve number approach may lead to very poor results under many conditions, critically affecting the hydrological balances simulated by SWAT, and therefore the related applications and deductions of soil erosion and flooding processes. The existing information from previous soil surveys, generally used in most of the models, provides only limited information about the dynamic soil properties required for functional interpretations. As a simpler alternative, the dynamic soil properties, mainly hydrological, are frequently derived from already existing static field data using empirical models, pedotransfer functions and inference systems, with erratic results. These empirical approaches for the diagnosis of soil and water conservation problems usually lead to gross errors in planning land use and management. They also lead to recommendations and application of generalized conservation practices and structures poorly adapted to the very varied local conditions of topography, soils, climate, land use and cultural habits. As an example, bench terracing in vineyards of the Priorat (NE Spain) (**Figure 9**), were promoted and subsidized with "European Community" funds, based on wrong generalized evaluations and predictions of surface soil erosion using empirical models, not taking into consideration the real hydrological conditions of these very permeable stony soils, but increasing at the same time the risks of mass movements (Pla 2010; Pla et al. 2011).

3.7. Salinization models

The same stagnation happens with the evaluation and prediction of salinization in irrigated and dryland areas, where in many cases the diagrams and indices proposed by the USSL in 1954 (USDA 1954) are still used, because some of the more recently proposed models (Rhoades 1992; Oosterbaan 1997; Suárez 1997) require information that is not available in many cases. Additionally, these models, with mostly empirical components, do not have the flexibility required to deduce alternative irrigation and drainage management practices for salinity and sodicity control. This is required under changing physical, social and economic conditions, especially considering the increasing concern about environmental issues, climate change, direct competition for water of good quality for urban areas, industries and recreation, and the increased use of residual waters for irrigation. These require more flexible approaches (Pla 1989, 1997a, 2006) that take into consideration the changing physical and chemical processes leading to soil salinization and sodification under the different natural and management imposed conditions.

Concurrently there have been considerable changes in land use and management. Agriculture, urban development, industry and mining have resulted in a continued degradation of soil and water resources. Much of the present research in soil and water conservation related to those changes is dedicated to isolated aspects and fails to address integrated problems. This is mainly due to limitation of time and funds, to the difficulties of interdisciplinary co-operation, and the compulsion to quickly publish papers. The large volume and diversity of contributions to conferences and publications (books, journals, articles and technical manuals) consists mostly of empirical and theoretical approaches to describing, preventing or reclaiming soil degradation, with very few new practical approaches. Based on this vast amount of "information" it is assumed that we already technically know more than we apply, but soil and water degradation problems continue to escalate. This could partially be attributed to ignoring the quantitative hydrological approach for the evaluation of soil and water degradation processes, and to the use of mainly empirical approaches for such evaluations.

There has been greater emphasis on the identification, description and mapping of actual soil degradation and erosion -generally using geomorphologic approaches, remote sensing and GIS- than in identifying the causes and processes required for the development and appropriate selection of sustainable land management practices. Most studies have focused on problems of surface erosion and only in the last decade there have been some attempts to study the important processes of mass movements. However, few cases consider associated hydrological processes (Hervas et al. 2007), and as a consequence in many cases there has been confusion in the identification of processes leading to surface or mass erosion (Pla1997b; Sidle et al. 2006). Recommended practices (i.e. contour tillage, strip cropping, reduced tillage, ground-cover, terracing) that are effective in controlling or reducing surface erosion, may actually increase risks of landslides and mass erosion in general. In landslide-risk evaluation and mapping in Europe (Hervas et al. 2007) the areas prone to susceptibility are only based on slope, land cover and land use, without considering hydrological processes related to climatic conditions.

With a reduction in the number of students reading for higher degrees in soil science, many of today's researchers, extension workers and consultants in soil and water conservation have trained in engineering, geography, ecology and environmental sciences. Generally, they are able to identify and map processes and the extent of soil degradation, but they are not able to identify and apply effective responses. Adequate training in soil science and hydrology is required to provide the knowledge and analytical skills to solve the current soil problems.

4. Conclusions and recommendations for the future

Future research in soil conservation needs to be more integrated with research on water conservation. The research studies need to be directed for a better understanding of the processes and reactions in soils related to chemical recycling and water balance over a range of spatial and temporal scales. The common objective has to be the improvement of crop production and of environmental protection (Baveye et al. 2011). Of particular importance is the improved analysis of dynamic processes in soils. This is critical for more efficient use of soil water and energy addressed to increased crop production, overcoming depletion and minimizing risks of soil, water and environmental degradation, as affected by external temporal factors such as climate, land use and management.

A hydrological approach to the evaluation and prediction of the conservation of soil and water is essential for adequate development, selection and application of sustainable and effective land use and management practises (Pla 2002a). The main objective must be to evaluate such hydrological processes, and to select and develop methodologies and techniques to correct or to control them under different conditions of soils, topography and climate. This is required for suppressing or alleviating the negative effects of soil and water degradation on plant growth, sustainable agricultural production, the supply of an adequate quantity and quality of water, and also on catastrophic events such as flooding, mass sedimentation and landslides. Moreover, a hydrological approach facilitates strategies for developing sustainable and integrated management of ecosystems, both managed and natural, at the catchment scale. The soil moisture regime is also fundamental for modeling the dynamics and translocation of contaminants such as nitrates, heavy metals and pesticides, (with or without irrigation), which may lead to drastic changes in the soil water regime and in the balance of water and solutes in soil systems.

The currently used empirical models must be replaced with process-based event models, which require better understanding of changing hydrological properties as influenced by soil management, cropping sequences, vegetation,

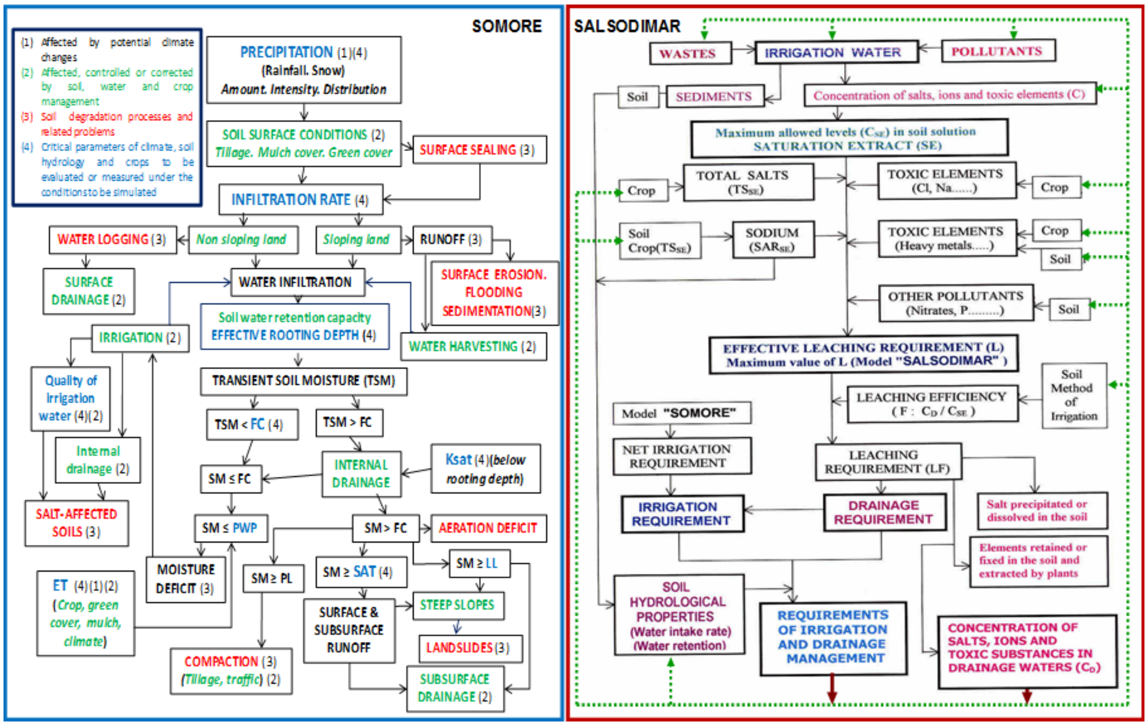

Figure 10. Flow diagrams of conceptual hydrology-based models that were the basis for the SOMORE (Pla 1997, 2002, 2006, 2010) and SALSODIMAR (Pla 1989, 1997, 2006) models (SM: Soil moisture at root depth; SAT: Saturation; FC: Field Capacity; PWP: Permanent Wilting Point; PL: Plastic Limit; LL: Liquid Limit; ET: Evapo-Transpiration).

and climate (**Figure 10**). These models must enable detailed quantification of hydrological processes for both actual and potential conditions, answering the major questions about soil degradation and crop production, in different land management scenarios. While they are being developed, the main benefit of these models is the identification of gaps of knowledge and data, and improved understanding of degradation processes. Process-based prediction models, based on equations that represent fundamental hydrological and degradation processes (including rainfall, infiltration, drainage and runoff) may solve the limitations of the empirical soil loss prediction models (including site specificity and limited transferability). The models SOMORE (Pla 1997b, 2002b, 2006, 2010) and SALSODIMAR (Pla 1989, 1997a, 2006), used to simulate and predict processes and problems of soil and water degradation by erosion, salinity-sodicity and related effects, follow this approach (**Figure 10**).

Although modern indirect techniques like remote sensing, computerized data processing, GIS and simulation models may assist the required evaluations, they will always require actual and accurate direct measurements or estimates of soil hydraulic parameters. Better and simpler methods to evaluate and monitor important hydraulic properties of soils and their dynamics on a field scale are especially urgent for both diagnostic and prediction purposes (Pla 2002a).

Soil degradation processes invariably have geological, chemical, physical, hydrological and biological dimensions. Lasting solutions will only be found if adequately trained researchers in soil science and hydrology, who recognize the complexity of problems, develop appropriate strategies. More soil scientists are required with advanced training in fundamental sciences (physics, chemistry, biology, geology, hydrology) who able to work with agronomists, engineers, geographers, ecologists and other specialists.

Structural improvements in soil science education must adopt a more holistic approach, integrating theory and field work. This would be necessary not only for soil scientists, but for other professionals involved in the design and planning of land use and management strategies at different levels. There must be increased co-operation between soil scientists and scientists in related disciplines, and among institutions involved in research and the application of soil and land use and management. This is imperative to guarantee an interdisciplinary and integrated approach in the study and implementation of soil and water conservation. Finally, it is necessary to facilitate and stimulate the publication in soil science journals and related disciplines of papers based on more integrated and interdisciplinary field studies on soil and water conservation.

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