Environmental Sustainability through Soil Conservation

—Editors—

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Prefacio

No hay duda que los recursos suelo y agua son esenciales para la suplencia actual y futura de los alimentos requeridos por la creciente población humana a nivel mundial y para la preservación del medio ambiente en general. Para ello es indispensable que dichos recursos no sean negativamente afectados por problemas de degradación de tierras, derivados principalmente de prácticas de uso y manejo no adecuados y de posibles cambios climáticos a nivel global. Por otro lado, los suelos y su manejo son un factor fundamental en el control de la emisión y captura de los gases con efecto invernadero, que pueden ser determinantes de alteraciones en el clima. De las interacciones entre el clima y los recursos suelo y agua se derivan además muchos de los procesos conducentes a grandes desastres naturales (deslizamientos de tierra, inundaciones, sedimentaciones, sequías), que afectan directa e indirectamente a la población y al medio ambiente. Todo esto hay que analizarlo frente a una creciente población mundial, que se espera se incremente en unos dos mil millones de habitantes en los próximos cincuenta años. la cual requerirá de crecientes suministros de alimentos y agua, cuya producción y regulación dependen fundamentalmente del recurso suelo.

La disponibilidad de tierras de calidad para la producción agrícola requerida para las crecientes necesidades de la población humana se ha reducido, y ya en la mayoría de los países la incorporación de nuevas tierras para la producción agrícola y ganadera supone un riesgo creciente de degradación de suelos y daños ambientales relacionados. En los últimos 50 años se calcula

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que más de dos mil millones de hectáreas de tierras agrícolas (30% del total disponible a nivel mundial), han dejado de ser productivas por procesos de degradación física, química y biológica de los suelos, o por ocupación por desarrollos urbanos e industriales y por vías de comunicación. El recurso agua de buena calidad es cada vez más escaso, tanto por su degradación asociada a la degradación del recurso suelo, como por su creciente uso competitivo para usos urbano, industrial y agrícola. Hoy en día, 45% de la producción de alimentos en el mundo depende de agricultura de riego, la cual utiliza casi un 70% de los recursos hídricos de buena calidad disponibles, y en cualquier caso hay que considerar que en la actualidad se requieren casi 2000 litros de agua para la producción de los alimentos diarios (2000 Kcal) para una sola persona.

Como consecuencia de todo lo anteriormente señalado, con el fin de asegurar la suplencia de los alimentos y agua requeridos para las crecientes necesidades de la población mundial, surge la necesidad de la conservación y de un uso más eficiente de los recursos suelo y agua. Para ello, la conservación, uso y manejo adecuados del suelo son factores fundamentales. Ello a través de prácticas y sistemas de producción, que mantengan e incrementen la capacidad productiva de las tierras ya cultivadas o recién incorporadas a la producción, con un uso más eficiente de los nutrientes y agua, todo ello sin deteriorar el medio ambiente. Esto a su vez requiere de estudios e investigaciones a corto y mediano plazo, con equipos interdisciplinarios que contemplen adecuadamente todos los posibles efectos y sus interacciones, a veces contradictorios, que se deriven de los nuevos desarrollos, sistemas de producción y prácticas de uso y manejo de las tierras para la agricultura y otros fines.

La Organización Internacional de Conservación de Suelos (ISCO) es un organismo que desde su fundación en 1982 ha tratado de promover y divulgar estudios e investigaciones con las características antes señaladas, a través de reuniones periódicas realizadas en diferentes países del mundo con dichos fines. Este libro contiene una selección de los trabajos presentados y discutidos en la reciente 17ª Conferencia de ISCO, realizada exitosamente en Medellín (Colombia), los cuales reflejan la orientación, naturaleza, calidad e incluso contradicciones y deficiencias de los trabajos que actualmente se realizan en el área de conservación de suelos y agua en todo el mundo. Entre ellos destacan las conferencias plenarias presentadas por un selecto y destacado grupo de investigadores y que versan sobre los siguientes temas:

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- Políticas sobre uso, manejo y conservación de suelos y agua
- Enfoques, evolución, aspectos positivos y deficiencias en los estudios e investigaciones actuales en conservación de suelos y agua
- Relaciones e influencias actuales y futuras de los cambios climáticos globales previstos para el futuro sobre la degradación y conservación de suelos y aguas
- Evaluación y diagnóstico de procesos y problemas de deslizamientos de tierras bajo diferentes condiciones y con diferentes efectos
- Enfoques en la aplicación de planes de conservación de suelos y agua a diferentes niveles

En cuanto al resto de las presentaciones, dominan los trabajos que enfatizan los temas de labranza conservacionista, de secuestro de carbono, y el de los efectos de cambios climáticos en general. Igual que en anteriores conferencias de ISCO, tanto en la presentación de trabajos y discusiones generadas, se enfatizó la necesidad de que se utilicen enfoques menos empíricos, tanto en el estudio como en la aplicación de prácticas de manejo y conservación de suelos y agua.. En su lugar, los enfoques deberían basarse en procesos y en información y evaluaciones actualizadas realizadas in situ, tratando de llegar a la solución de problemas a corto y mediano plazo, que en cualquier caso también servirían para mitigar los posibles cambios climáticos a largo plazo y sus efectos. Referente a lo anterior, destacan los trabajos dirigidos a la solución, con la participación directa de las comunidades afectadas, de problemas de conservación de suelos y agua, con efectos tanto sobre la producción de bienes y servicios (en especial alimentos), como sobre las vías de comunicación y la preservación ambiental.

Destaca el tratamiento que tiene el desarrollo de temas relacionados con los deslizamientos de tierras, incluyendo los de carácter catastrófico, en tierras agrícolas, en vías de comunicación y en zonas urbanas, en los cuales se destaca el papel fundamental de los suelos, clima y uso y manejo de las tierras y sus efectos sobre los procesos hidrológicos, tanto en la génesis del problema como en el nivel de riesgos y su prevención. Esto no es casual, sino que ha estado motivado en parte por la creciente incidencia de este tipo de procesos de erosión en Colombia y en muchas otras partes del mundo, muchas veces con carácter catastrófico. En especial se enfatiza que dichos procesos no deben confundirse con los procesos de erosión superficial, ni en su evaluación

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y diagnóstico de los procesos hidrológicos involucrados, ni mucho menos en las prácticas para su prevención y control. Se ha podido comprobar que esta confusión ha sido muy frecuente en los estudios y evaluaciones realizadas sobre procesos de erosión, en las áreas afectadas en diferentes partes del mundo.

Cómo algo que merece destacarse, y que se refleja en algunos de los trabajos publicados, están algunas controversias que fueron motivo de discusión en el desarrollo e las diferentes sesiones de la Conferencia de ISCO. Estas se presentan en el enfoque de los estudios y aplicación de prácticas de conservación de suelos y agua, pensando o basados fundamentalmente en unos hasta ahora hipotéticos o seguros (según sea el caso), actuales y futuros cambios climáticos globales (con algunas divergencias en cuanto a sus causas y consecuencias), o con un enfoque dirigido más a la solución de problemas actuales o a corto plazo, tanto de producción de alimentos como cambios ambientales, que afecten a la población en comunidades bajo determinadas y particulares condiciones biofísicas, sociales y económicas.

Relacionado con lo anterior, también se presentan ciertas controversias, con argumentos más o menos basados en evidencias y resultados experimentales a corto o mediano plazo, sobre el papel desempeñado por algunas prácticas de uso y manejo de las tierras, incluyendo la labranza, uso de enmiendas, etc. sobre la conservación del suelo y del agua, y sobre el control o atenuación de posibles cambios climáticos derivados de la acumulación de gases con efecto invernadero en la atmósfera. Por ejemplo, el enfoque del manejo de la materia orgánica del suelo dirigido fundamentalmente a acumular o "secuestrar" carbono en el suelo, o más bien dirigido a la mejora de las propiedades químicas y físicas del suelo para determinados fines de producción y ambientales. Destacan las posibles contradicciones entre la reducción del CO_2 atmosférico y el posible incremento de emisiones de gases con mucho mayor efecto invernadero como CH_4 y N_2O. Otras contradicciones destacadas son las existentes entre el papel de los llamados "bio-combustibles" de origen agrícola en la reducción de emisiones netas de CO_2 a la atmósfera y las emisiones derivadas de las transformaciones de tierras, incluyendo deforestaciones, y de las prácticas de manejo de tierras para su producción.

Todas estas controversias no deben considerarse como algo negativo, sino como algo que contribuye positivamente a la comprensión de que para el uso, manejo y conservación de suelos y agua, con objetivos de produc-

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ción y protección ambiental, no existen enfoques ni prácticas de aplicación universal. En cada caso deben analizarse e investigarse cuidadosamente las interacciones de los diferentes factores, procesos y aspectos involucrados, y así llegar a la aplicación de sistemas y prácticas de manejo y conservación de suelos y aguas más eficientes y sostenibles, para cada combinación particular de condiciones biofísicas, sociales y económicas.

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Preface

There is no doubt that soil and water resources are essential for the present and future food supply of the world's growing population, and for the preservation of the environment in general. For that reason, it is crucial that said resources not be negatively affected by land degradation problems, which are mainly derived from inadequate land-use and management practices and by potential global climate changes. On the other hand, soils and their management are a fundamental factor in the control of emissions and capture of greenhouse gases, which can be determinants of climate change. Among the interactions between climate and the resources of soil and water, from which many processes derive may lead to great natural disasters (landslides, floods, sedimentations, droughts), which may directly or indirectly affect the population and the environment. All of these different aspects have to be analyzed taking into consideration the world's growing population, which is expected to increase about two billion people in the next fifty years, requiring increasing supplies of food and water, both mainly produced and regulated by soils.

The availability of good quality lands for agricultural production required for the increasing population has been reduced, and in most countries new land development for agricultural production or for livestock increases the risks of soil degradation and of other related environmental damages. In the last 50 years, an estimate of more than two billion hectares of agricultural lands (about 30% of the total available at world level) have lost their produc-

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tive capacity as a result of physical, chemical and biological degradation, or through occupation by urban, industrial and communication developments. Good quality water is every day more scarce, due to both its deterioration associated to the degradation of soil resources as well as the increasing competitive use for urban, industrial and agricultural purposes. Nowadays, 45% of the world's food production is based on irrigated agriculture, which uses about 75% of all available good quality water resources, and we have to take into consideration that presently there almost a 2000 liter water requirement for the production of the average daily food requirements (2000 Kcal) of one person.

As a consequence of the previously mentioned arguments, and the purpose to ensure the food supply and water required to satisfy the growing needs of the world's population, comes the great need of preserving and a more efficient use of the existing soil and water resources. This requires a more adequate land use and management. This is achieved through production systems and practices that maintain or increase the productive capacity of the already cropped land or recently incorporated production lands, with a more efficient use of water and nutrients, without deteriorating the environment. This also requires studies and research with clear short and medium term objectives, through inter-disciplinary teams and taking into consideration all the different factors involved and their interactions, sometimes contradictory, derived from new developments, systems and practices of land use and management for agriculture or other purposes.

The International Soil Conservation Organization (ISCO) is an organism created in 1982, whose main objective has been the promotion and disclosure of studies and research in the fields of Soil and Water Conservation with the previously specified characteristics, through periodical meetings in different parts of the world. This publication contains a selection of the papers presented in the recently successfully held (2013) 17th ISCO Conference (Medellín, Colombia), which reflect the orientation, nature, quality and even contradictions and deficiencies of the studies and research work presently being done in the field of soil and water conservation worldwide. Among all, some of the outstanding keynote speakers and most representative research groups discussed topics, such as:

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- Policies regarding the use, management and conservation of soils and water resources
- Approaches, evolution, positive and negative aspects of the present studies and research on soil and water conservation
- Relations and present and future influences of global climate change forecasts for the future on the deterioration and conservation of soils and water
- Evaluation and diagnosis of processes and problems of landslides under different conditions and with different effects
- Approaches in the application of soil and water conservation planning on different levels

As for the rest of the presentations, many emphasize the topics of conservation tillage, carbon sequestration and the effects of climate change in general. Similar to previous ISCO conferences, on the submission of papers and generated discussions, the need to use less empirical approaches was emphasized, in the study as well as in the application of soil and water management and conservation practices. Instead, the approaches must be based on updated processes and information and and also on direct in-situ assessments, looking for solutions to actual problems on a short and medium term, which in many cases may be useful to mitigate the potential problems derived from future climate change and their effects. In regards to this, there is a special mention for papers addressed to solutions, with direct participation of the affected communities, of soil and water conservation problems, with effects both in the production of goods and services (mainly food) and on other aspects like roads, housing, and environmental damages.

The different treatments implemented throughout the development of certain related issues are highlighted, for example, landslides, including the catastrophic kind, in agriculture, on roadways and urban areas, where the important roles are played by the soil, climate and land use and their effects on hydrological processes, in the beginning of the problem as well as in the the risk and prevention levels. This is not casual, and it has been motivated by the growing occurrence of the catastrophic erosion processes in Colombia and in many other parts of the world. It is particularly emphasized that such processes must not be confused with processes of surface erosion, nor in their evaluation and diagnosis of the related hydrological processes, and much less

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in their prevention and control practices. It has been found that such confusion has been very frequent in many studies and evaluations that have been done regarding erosion processes around the world.

Another aspects to be highlighted, and which are reflected in some of the published papers, are some controversies which were subject of debate during some sessions of the ISCO Conference. They are related to the approaches in the studies and application of soil and water conservation practices, mainly based on or thought of from the until now hypothetical or certain (depending on the researcher) present or future global climate changes (with some divergences regarding their causes and consequences), or with aimed approaches mainly directed to the solution of present or short term problems of food production such as environmental changes, that affect the population in communities under specific and particular biophysical, social and economic conditions.

Related to the previous aspects, there are also some controversies with arguments roughly based on evidences and experimental results at short and long term, regarding the different role and effects of different land use and management practices, including tillage, use of amendments, among others in regards to soil and water conservation and on the control or mitigation of potential climate changes derived from the accumulation of greenhouse gases in the atmosphere. For example, the management approach of organic matter in soils mainly addressed to carbon accumulation or sequestration in soil, or addressed to the improvement of the physical and chemical properties in soil for specific production or environmental needs. Possible contradictions are mentioned between the reduction of atmospheric CO2 and the potential increase of emissions of other gases with greater greenhouse effects such as CH4 and N2O. Other mentioned contradictions worth are about the roles of the so called agriculturally based "bio-fuels" in the reduction of net CO2 emissions in the atmosphere, and the derived emissions from land transformations, including deforestations, and the land management practices required for their production.

These controversies should not be considered negative, but rather as contributions to the understanding that the use, management and conservation of soil and water resources, with production and environmental protection objectives, do not have universal application approaches or practices. Each case must be carefully analyzed and the interactions among the different

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factors, processes and aspects involved should be investigated, in order to reach the application of more efficient and sustainable soil and water management systems and practices for each particular combination of biophysical, social and economic conditions.

Ildefonso Pla Sentís
Universitat de Lleida (Spain)

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Introduction

ISCO and the Global Conservation Movement
Samir A. El-Swaify
Founding Member and Coordinator, ISCO Board of Directors
Emeritus Professor, Department of Natural Resources and Environmental Management. University of Hawaii at Manoa, Honolulu, Hawaii, USA

It was my distinct pleasure to participate in the 17th Conference of the International Soil Conservation Organization (ISCO), July 2013 at Medellin, Colombia and the wonderful Pre-Conference field tour that focused on coffee culture at Manizales and upland vicinity. While I was privileged to attend all 17 ISCO conferences, new colleagues are always present at every meeting. It is instructive, therefore, to share some of ISCO's background with the readers of this book of Proceedings.

ISCO was formed at the third soil erosion/conservation conference in 1983 in Hawaii, after two similar earlier meetings in Belgium and the UK; both were without an organizational entity label. Our goal is to promote the conservation, sustainable management and wise use of soils, water and associated natural resources. ISCO's activities are overseen by a Board of Directors composed primarily of former presidents. Since its formation, the ISCO has met on every continent at least twice and has attracted thousands of participants and supporters to its mission from around 100 countries. ISCO is now widely regarded as the world's leading professional forum on soil conservation and our members and cooperators have many years of technical informa-

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tion on soil and land degradation, and mitigation of their impacts. ISCO's format of rotating among different countries and continents has been successful not only in allowing us to share valuable scientific knowledge and professional experience, but also to enjoy new friendships and learn about different cultures. All along, participants have been unified by strong commitments to the sustainable use of global natural resources while meeting essential human needs. I urge you to access our Website for many more details about ISCO (***http://tucson.ars.ag.gov/isco/index.php***).

Why is ISCO still globally relevant? Many difficult global challenges are posed by ever-increasing human populations and ever- shrinking productive resource base. The per capita grain producing land now stands at about 0.10 ha, and serious human-induced land and soil degradation continues nearly unabated on every continent. In addition to food security concerns, degradation is instrumental in damaging the earth's life support system. Soil protection concerns must be central to the success of global efforts for sustainable development, including the three global "conventions" that emerged from the UNCED, namely the Convention for Combating Desertification (CCD), the Framework Convention on Climate Change (FCCC), and the Convention on Biological Diversity (CBD). Let us renew our resolve to work together to assure the sustainable use of precious global soil and water resources and to combat their ongoing degradation. For example, as you read these proceedings, you will note that the conference theme of ***Environmental Sustainability through Soil Conservation*** was very well covered, with renewed emphasis on topical issues, especially mass movement and climate change.

On behalf of ISCO's Board of Directors, I offer my sincere congratulations and thanks to the ISCO 17 Organizing Committee for managing a successful conference and to our Colombia colleagues for being such wonderful hosts. Their hospitality will be long treasured by all participants and I. Special thanks go to ISCO 17 President Juan Carlos Loaiza Usuga and Conference Academic Coordinator Adriana M. Quinchía Figueroa for their effective leadership, and to Carmen Soledad Morales Londoño for planning and leading an excellent pre-conference field trip.

I take this opportunity to invite you to make every effort to join us at future conferences of our wonderful ISCO organization, beginning with ISCO 18 in 2015 in the USA.

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Chapter 1

Effects of vegetation management and related practices on slope stability

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Abstract. Woody vegetation increases the stability of shallow soil mantles by affecting the water budget through evapotranspiration processes and providing root reinforcement within the soil mantle. Effects of evapotranspiration on the soil-water budget primarily include: (a) canopy interception of rainfall or snow, and subsequent evaporation loss to the atmosphere; and (b) transpiration of infiltrated water via vegetation roots. Transpiration effects are not particularly important for shallow landslides that occur during an extended winter rainy season because soils are typically very wet and transpiration processes are reduced. In the tropics and sub-tropics where evapotranspiration is high throughout the year, such effects may become more significant. Root reinforcement imparts a greater contribution to slope stability by: (a) anchoring; (b) providing a membrane of lateral strength; (c) lateral reinforcement across zones of weakness; and (d) buttressing. Timber harvesting reduces vegetation rooting strength gradually; effects on landslide initiation appear from 3 to 15-20 years after cutting. Depending on site conditions and tree cover, clearcutting causes a 2 to 10-fold increase in landslides during the period of minimum root strength. Aerial photo studies in Japan showed that clearcutting significantly increased landslides during the first 10 years, while some effects continued for 25 years after clearcutting. Compared to older forests, landslide volume increased 4-fold in recently cut forests. Modeling studies show that uncut 'leave areas' in hollows and steep slopes can reduce landslides. Forest conversion to exotic plantations in the tropics, where trees are sparsely distributed and have shallower root systems, may induce longer-term slope instability.

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Introduction

Numerous investigations throughout the world have recognized the potential benefits of forest cover on soil and water conservation. Nevertheless, management practices often focus on controlling surface erosion in steep terrain rather than mass erosion (landslides). Compared to their effects on surface erosion, vegetation management practices in steep temperate forests exert a much greater impact on the timing and magnitude of mass wasting [1]. Even in tropical forests, where surface erosion is more significant because of sparse organic horizons and intense monsoon storms, landslide erosion can be comparable or even the dominate erosion process when extensive forest clearing occurs [2].

The objective of this paper is to clarify how woody vegetation helps stabilize steep terrain and how management practices impact this stability. Central to this discussion are the issues of root reinforcement and soil water modification by vegetation, as well as how these can change, both in time and space, under different land management practices. Knowledge of these interactions will promote improved forest management in steep unstable landscapes.

How does vegetation influence slope stability?

Vegetation has been documented to stabilize hillslopes via two primary mechanisms: (a) contributing rooting strength within the regolith; and (b) reducing pore water pressure response within the soil mantle [3-5]. Rooting strength tends to be the most important stabilizing mechanism in most steep mountain environments. Woody vegetation, particularly trees, are most effective in stabilizing slopes by both mechanisms because of their deep, extensive, and strong root systems and dense canopies. In some environments, the root mass and lower bole of trees (or even stumps) can lend some additional stability to hillslopes via a buttressing or arching effect [6-7].

Hydrological effects

Woody vegetation is particularly effective in preventing water from reaching potential failure planes of unstable soils by: (a) canopy interception of rainfall or snow and subsequent evaporation loss to the atmosphere; and (b) transpiration of infiltrated water via dense and deep root networks [4]. For shallow landslides, forest canopy interception of rainfall is generally not

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a major influence on rapid pore water pressure increases during rain storms because the intercepted losses are typically small and the slightly higher intensity rainfall inputs in cleared sites [8] are buffered within the upper soil depths. As such, the pore water pressures that develop near the potential failure plane in soils should be unaffected. Intercepted rainfall is mostly stored on the surface of foliage and stems, but snowfall can bridge across gaps between closely spaced trees, thus accumulating snow over a large surface area. Dense evergreen forest cover can intercept up to 30-50% of snowfall if it remains in the canopy for extended periods [4, 9], and much of this may evaporate. Seasonal dormancy of broadleaf forests greatly reduces canopy interception. Because this dormant period typically coincides with winter, rainy and snowmelt seasons in temperate climates, this mechanism provides little amelioration of water inputs into soils; thus, deciduous canopy interception does not significantly mitigate landslide occurrence. In contrast to temperate deciduous forests, tropical forests intercept more rainfall due to their multi-tiered structure and evergreen nature [10]. The amount of rainfall intercepted by all forest canopies is inversely related to former wetness, rainfall intensity, and wind.

Transpiration effects have little influence on shallow landslide initiation in temperate forests during extended winter and rainy seasons (when landslides usually occur) because soils are typically very wet and transpiration is reduced. Studies in British Columbia show that while small increases in shallow groundwater response occurred during moderate-size storms after forest cover was removed, during larger storms that would potentially trigger landslides, such increases were not apparent [11]. In these temperate zones, transpiration by deep-rooted trees may reduce the "window of susceptibility" for landslides if a large storm occurred near the beginning or end of the rainy season [12, 13]. In most environments, when large landslide-producing storms occur during drier conditions, evapotranspiration by trees can provide protection against shallow landslide initiation by reducing previous soil moisture. In the tropics, where evapotranspiration is high throughout the year, it may provide more significant benefits for mitigating landslides [2, 14]. However, simple simulations of soil moisture in a Malaysian rain forest showed that evapotranspiration had little effect on reducing peak pore water pressure during large storms that would potentially trigger landslides. More benefits of tropical forest cover were apparent for deep-seated landslides (e.g., earth-

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flows) where the period of seasonal movement may be extended in the absence of transpiration (Figure 1).

Effects of root reinforcement

Root reinforcement provides a more significant and global contribution to slope stability compared to hydrological benefits of woody vegetation, primarily due to: (a) anchoring surface soils into bedrock or other stable substrate; (b) providing a membrane of lateral strength within the soil; (c) lateral reinforcement across zones of weakness; and (d) imparting a buttressing effect via the root mass and basal tree bole [4]. The first two mechanisms appear to be the most important for stabilizing hillslopes. Root anchoring is facilitated by fractures in bedrock allowing root penetration; however, such fractures may either dissipate or enhance pore water pressures near the potential failure plane by promoting deep infiltration or exfiltration, respectively.

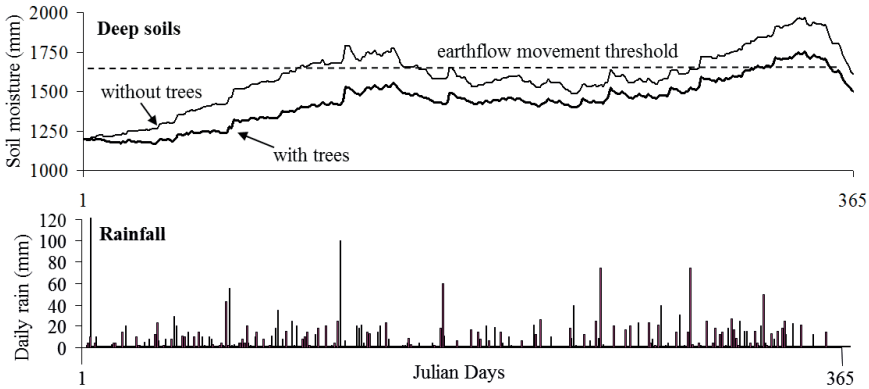

Figure 1. Modeled changes in seasonal soil moisture based on rainfall data in Malaysia with and without forest cover in 5 m deep soils (water holding capacity = 2500 mm) vulnerable to earthflows; adapted from [4].

Forest soils typically have dense interwoven root mats which provide reinforcement and stabilize hillslopes [15, 16]. When slope failure occurs, roots either break in tension or pull out of the soil via slippage. While some controversy exists about the dominant mechanism, field investigations of landslide scars indicate that most of the roots break in tension, indicating that the pull-out resistance exceeds the tensile strength of roots in many cases [3, 6, 16-18].

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Because the majority of the root biomass of most woody species concentrates in the upper several meters of the soil mantle, root reinforcement against landslides is most significant in relatively shallow soils (< 2 m) where roots can penetrate the entire soil mantle and anchor into more stable underlying substrate. In deeper soils, where the potential failure plane is located well below the depth of root penetration, root systems offer little protection against landslides, except where large roots tie across lateral planes of weakness [4, 19].

Effects of Vegetation Management

Timber harvesting and subsequent regeneration with trees

Unlike the more immediate effects of ground cover disturbance on surface erosion, timber harvesting reduces vegetation rooting strength more gradually; effects on landslide initiation typically begin to appear about 3 years after tree removal and continue to increase the likelihood of slope failure up through 20 years after cutting until substantial regeneration of trees occurs [4, 20, 21] (Figure 2). The reduction in soil shear strength caused by the temporary decline in root cohesion lowers the threshold level of rainfall or snowmelt inputs needed to trigger a shallow landslide [22]. This phenomenon was first revealed in field observations in large clear-cuts following major storms. Later, this was confirmed by combinations of laboratory and field shear tests on root-permeated soils and mechanical straining of individual roots coupled with surveys of root distribution. Coupling these small-scale mechanical test data with field-scale root distribution data, we can now approximate the spatial distribution of root strength at a site for various management practices [23, 24] (Figure 3).Understanding root strength decay and regrowth characteristics of different woody species is important for managing vegetation at potentially unstable sites [4]. Depending on site conditions and tree cover, forest clearing has resulted in a 2- to nearly 10-fold increase in landslide activity during susceptible 'window' when root strength is reduced. In a steep managed forest basin in Japan with fairly uniform geology and slope gradients, 40 years of landslide data from small catchments that had been clear-cut at various times were evaluated using nine aerial photo periods [21]. This study differed from most other field comparisons because of: (1) similarity of topography, soils, geology, and vegetative cover in the subcatchments; (2) wide range of forest stand ages that were evaluated because harvesting was managed at an individual catchment scale; and (3) long documented history of stand management. The major in-

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fluence of forest clearing on landslide initiation occurred during the first 10 years, while some effects continued up through 25 years after clearcutting (Figure 4). Compared to older forests, landslide volume increased 4-fold in recently cut forests (≤ 25 years old). This value is near the median of values reported elsewhere.

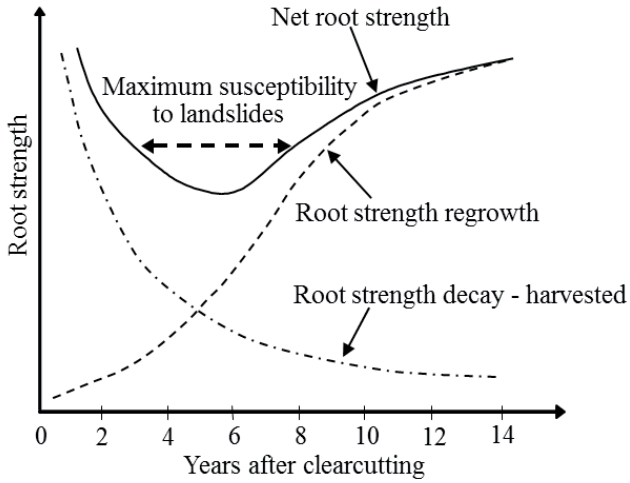

Figure 2. Hypothetical example of root strength decay (after tree cutting or death) and recovery (after regeneration) curves. Net rooting strength (solid line) is the sum of these curves; after [4]

Modeling studies at the catchment-scale have confirmed that the period of maximum landslide susceptibility is between 3 and 17 yr after clearcutting [25, 26]. Modeling the effects of rooting strength on the probability of landslides allows for long-term predictions of possible management trajectories as well as different silvicultural and forest protection alternatives. Leaving as little as 10% of the residual forest stand after harvesting (partial or shelterwood cutting) can reduce the potential for shallow landslides by >35% compared to clearcutting [26]. Sidle [22] demonstrated that the probability of slope failure was 5-times lower in a partial cut scenario (75% of a Rocky Mountain Douglas-fir stand cut) compared to clearcutting. Rotation length exerts an important control of long-term root reinforcement, especially for tree root systems that regenerate slowly. Sakals and Sidle [23] modeled small-scale changes in patterns of Douglas-fir root strength related to different silvicultural practices and

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found that a random selection cutting (25% of mature trees harvested every 20 yr) caused the smallest decrease in rooting strength, followed by strip cutting, and then clearcutting.

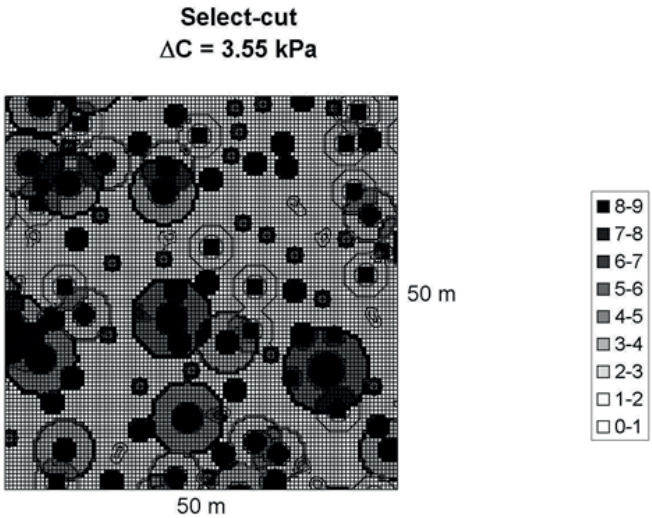

Figure 3. Modeled spatial distribution of root strength (kPa) in a Douglas-fir forest managed by selection cutting (200 yr after first cutting); 25% of trees >60 yr old removed every 20 yr; average root cohesion = 3.55 kPa; after [3].

Increasing the length of harvest rotations over multiple cutting cycles provides long-term benefits to slope stability assuming regeneration proceeds successfully. However, many commercial operations have been able to shorten rotation lengths due to genetic improvements in forest stands, site fertilization, and production technology changes that allow smaller diameter trees to be processed. These technological advances cause concern related to the effects of forest harvesting (particularly clearcutting) on steep slopes. Modeling studies have shown that decreasing rotation lengths will cumulatively increase the probability of shallow landslides if root systems do not fully recover in each successively shortened rotation [22, 25-27] (Figure 5). About 1.5 and 1.3 times more landslide volume was simulated in partially and clearcut Canadian catchments, respectively, subjected to a series of decreasing rotation lengths (ranging from 50 to 20 years over a 200 year period) compared to the same period with fixed rotations of 50 yr [26].

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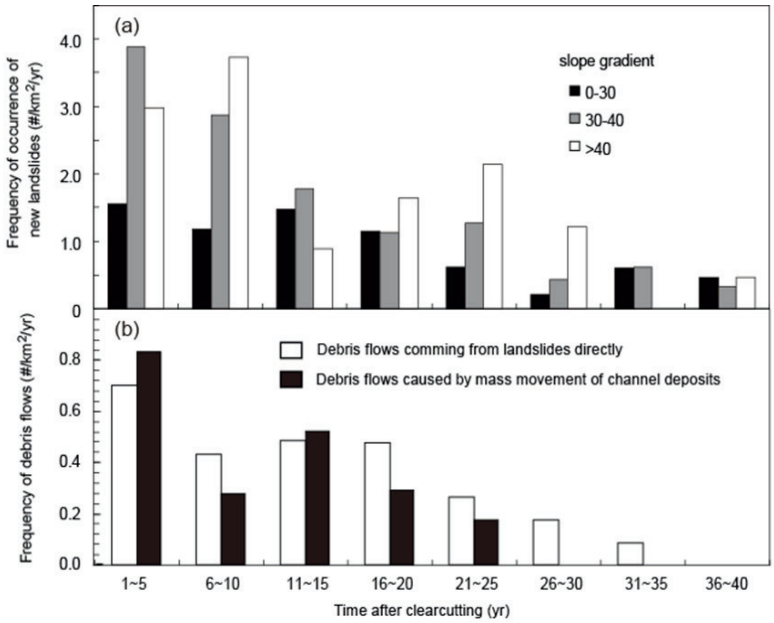

Figure 4. Temporal distribution of landslides (a) and debris flows (b) from the time of original clearcutting, Sanko catchment, Japan. Landslide frequency is grouped by slope gradient (after Imaizumi et al. 2008).

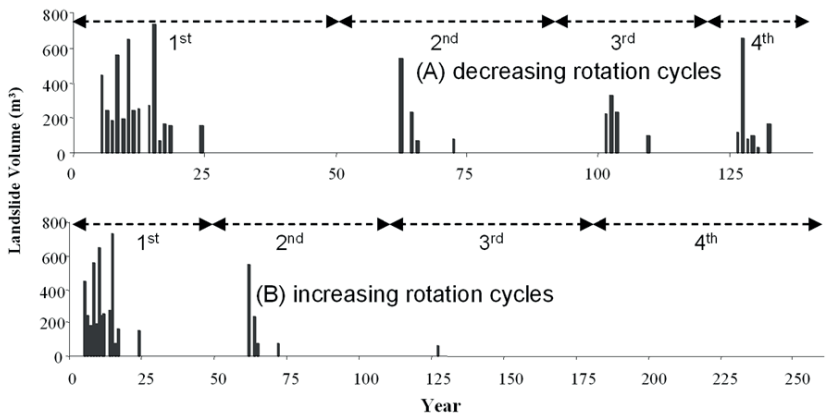

Figure 5. Temporal distribution of landslide volume in a Douglas-fir forest, British Columbia, Canada, over four clearcut rotation cycles: (A) decreasing from 50 to 20 yr; and (B) increasing from 50 to 80 yr (after [26]).

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Modeling has also confirmed the benefits of uncut 'leave areas' in unstable portions of catchments – particularly geomorphic hollows and very steep slopes [25]. In the British Columbia example [26], leave areas implemented on slopes > 40º and in geomorphic hollows resulted a reduction in landslide volume of 1.8 to 2.9-fold compared to the same catchment that was totally clearcut. Partial cutting simulations with both leave areas and increasing rotation lengths over time produced the fewest landslides. Modern logging practices, such as skyline logging, can reduce or even eliminate the destruction of understory vegetation during harvesting. Using a previously assessed value for understory root reinforcement in a Sitka spruce forest (2 kPa) [28], simulations showed that landslide probability in steep terrain increase by 2-fold and more than 3-fold when one-half and all of this understory root cohesion was destroyed by ground-based logging methods [22]. Similarly, in harvested forests in British Columbia, reduction in the volume of landslides during the management cycles when a small understory root cohesion (1 kPa) was retained ranges from 3.8 to 4.8 fold, greater than the benefits achieved by leave areas and lengthening stand rotation [26]. Thus, excluding timber harvest from small, but highly unstable, portions of catchments, together with maintaining understory vegetation and longer rotation cuttings, can significantly reduce logging-related landslide potential.

Vegetation conversion

Forest conversion to a different cover type (e.g., cultivated agriculture, exotic plantations, pasture) is more severe in terms of landslide implications because the site does not recover to its original level of root reinforcement [2, 4]. Forest conversion to agriculture and exotic plantations on steep sites in the tropics lends the landscape particularly susceptible to landslides because crops and trees are typically sparsely distributed, vegetation has shallow root systems compared to native forests, and evapotranspiration benefits of native forest cover are far greater than converted vegetation [2]. Traditional swidden agriculture (so-called slash-and-burn) involves clearing of forest patches during the dry season, subsequent burning prior to the rainy season to release nutrients, cultivation of the cleared patch for a number of years, fallowing, and secondary regrowth through various stages of succession [29]. During the cultivated and cleared periods, steep sites are at greater risk of landslides due to the reduced rooting strength and loss of evaporation benefits [2, 4].

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While swidden cultivation has been implicated in numerous reports for increasing landslides, recent practices of more widespread conversion of forested hillslopes in the tropics to commercial agriculture with low rooting strength pose an even greater risk.

Although limited studies have been conducted on the effects of forest conversion in the tropics related to landslide erosion, evidence to date suggests that such magnitudes are similar to surface erosion increases. In a small catchment in Sumber Jaya, Sumatra, which was converted from rain forest cover to coffee plantations in 1986, landslide erosion due to root strength reduction, generated 27 t $ha^{-1}yr^{-1}$ of sediment loss during a 4-yr monitoring period (beginning of 2000 to end of 2003); a loss similar to surface erosion from coffee plantations with no ground cover [2]. Areas of increased landslide erosion after forest conversion to agriculture or exotic plantations have also been documented in India [30], Tanzania [31], Japan [32], Honduras [33], and Thailand [2, 34]. Widespread conversion of indigenous forests to pasture in New Zealand during the late 1800's has left a legacy of landslide problems. Total increases in erosion, much of which was likely contributed by landslides, were 8- to 17-fold compared to indigenous forests [35]. More recent conversion of indigenous forest to radiata pine plantations in New Zealand also increased landslide erosion, but to a lesser extent because tree root reinforcement was retained, although at a lower level [36].

A practical issue in the tropics is that most soil and water conservation practices in converted catchments have focused on short-term, surface erosion problems, and have not adequately addressed the longer-term issue of the stability of steeper hillslopes [2]. Recent land cover changes in developing regions of Asia, Latin America, and Africa have been driven by incentives from government and international donors that promote high cash value crop production together with poorly coordinated conservation programs, transmigration schemes, rising market prices for certain crops, and the apparent needs of subsistence farmers to generate additional income from the land [2, 37-40]. Greater attention needs to be paid to the interactions between forest conversion to agriculture or plantations and landslide initiation. While agroforestry has been successfully applied on more gentle slopes, it is not a panacea for protection against landslides. The unexpected landslides that occurred on surface erosion plots in Honduras during

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Hurricane Mitch [33] are stark examples of this need to refocus research and management efforts.

Landslide – debris flow connectivity

In steep terrain, many landslides directly enter stream channels; however, routing of this sediment depends strongly on the connectivity of hillslope sources with the channel. Hillslopes that are uniformly steep, with no breaks in topography, facilitate the transport of landslide sediment directly into channels. Forest vegetation downslope of landslide initiation zones typically buffer landslide movement to streams, but in cases of large landslides that drag trees, the landslide mass may grow and move greater distances. Studies in two steep forested basins in Japan show that 14.6 – 19.3% of landslides mobilize directly into debris flows in steep channels, 39.9 – 51.6% terminate in the stream channel, and 29.1 – 45.5% terminate on hillslopes [41-42]. Landslide sediment stored on hillslopes may later be dragged by surface erosion or small-scale mass movements and make its way into steams. Storage of sediment in these headwater channels is highly variable and depends on channel gradient, roughness elements (woody debris, boulders), tributary junctions, and channel configuration. As sediment accumulates in steep gradient channels, the probability of a debris flow increases [43]. As such, sediment delivery (both suspended and bedload sediment) measured throughout the stream system may not accurately reflect current landslide activity. In systems susceptible to landslides and debris flows, the connectivity of headwaters to downstream reaches affects both the cumulative and dispersed nature of material transport within branched watershed systems [44].

Because the timing and amount of sediment delivered to headwater streams is affected by forest management, these impacts can also alter channel structure and biological habitat [4, 44]. Forest harvesting typically causes a short-term increase in small wood in channels; however, the supply of large wood is greatly reduced for many years unless mature forest buffers are left along stream corridors. If partial cutting only removes large trees in riparian zones, the later recruitment of large wood into headwater channels will be reduced for up to 100-150 years [45]. Accelerated rates of landslides and particularly debris flows following harvesting will have the greatest impact on headwater channels where timber is clearfelled down to the stream (i.e., no riparian leave area).

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Conclusions

Forest harvesting in steep terrain exerts a significant, although delayed effect on landslide occurrence. The increase in shallow landslides following timber harvesting is primarily related to deterioration in rooting strength and, in some cases, but to a lesser extent, increases in soil moisture after vegetation removal. The loss of root cohesion after clearcutting and prior to substantial forest regeneration lends unstable hillslopes vulnerable to landslides for a period of approximately 3 to 15-20 yrs, depending on the site conditions and regrowth and decay characteristics of tree roots. Modeling studies have shown that leaving as little as 10% of the forest stand interspersed on hillslopes can significantly reduce landslide probability compared to clearcutting. Stability benefits also generate from leaving woody understory species intact during logging, lengthening rotation cycles, and implementing leave areas in hollows and steep slopes (> 40º). The lesser slope stability benefits related to the higher evapotranspiration associated with mature forest cover may occur for the following conditions: (1) temperate conifer forest areas with significant snow packs, where evaporation is enhanced via canopy interception of snow; (2) tropical forests, where significant evapotranspiration occurs year-round; and (3) landslide-triggering storms that occur near the beginning of a rainy season (or during a dry period), when transpiration significantly modifies soil moisture.

Conversion of forests to vegetation with more sparse, shallower, and weaker root systems creates a long-term susceptibility for shallow landslides and debris flows. While forest conversion is widespread in the tropics, legacies of forest conversion and subsequent landslide initiation greatly influenced sediment budgets in more developed areas such as New Zealand, Australia and Europe. Linkages between hillslope landslides and debris flows in headwater channels depend on the dominant hydrogeomorphic processes – these can be instantaneous or span decades. Thus, the timing of sediment delivery to channels is not always directly linked to the occurrence of landslides. While this paper focuses on the effects of forest management practices on slope stability, other associated management practices like fire (used in forest conversion or site preparation) and particularly roads and trails can also contribute to landslides and debris flows [2, 4].

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Chapter 2

Progress and set backs in soil conservation research: challenges for the future

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Abstract. Soil is fundamental to the needs of man life, and plays a central role in determining the quality of our environment. Increased human influences on soils frequently results in widespread processes of land and soil degradation. Associated to land and soil degradation there is a decrease in available good quality water for agriculture, urban and industrial needs, and decreased biodiversity. The processes of soil and water degradation are closely linked through unfavorable alterations of 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 concentration 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. As a consequence and most probably related to these changes, there has been a change in the foci of studies and research on soil and water conservation. With the increasing evidence of the growing global problems of land, soil and water degradation and their effects on food production and the environment, there was increasing interest, especially since the late 1960s, 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. These efforts led to the development of models and evaluation systems mainly using empirical approaches. Further studies demonstrated the limitations of the generalized universal use of these empirical approaches. Concurrently with the renewed interest associated with soil and water conservation, there was an

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increase in related organizations, conventions, congresses and conferences. A global assessment of human-induced soil degradation (GLASOD) demonstrated the scarcity, difficult accessibility and poor quality of basic information required for the adequate planning and effective application of practices to prevent soil and water degradation. The more recent conventions and programs at international and regional levels are generally based on re-interpretations and different processing or representation of old information, using some times "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, and 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 any strong scientific basis. 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 very limited accuracy and are insufficient for developing adequate land use and management policies. "C sequestration" and "zero tillage" have become dominant paradigms, without due consideration and research of both their beneficial and detrimental effects in relation to various environmental and productive soil functions. It is concluded that like weather, soil and socio-economic conditions differ greatly from one location to another, and because they 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 these sustainable practices must be based on research with a broader vision on soil conservation, where all system components and their interaction 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 the better understanding of 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 the complexity of problems is recognized by adequately trained researchers in soil science and hydrology, who then develop appropriate strategies.

Keywords: Soil conservation, hydrological processes, clichés in soil research, integrated approaches, empirical models

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Introduction

Soil is a vast reservoir for life, and controls global geochemical cycles. The biophysical functions of soil are fundamental for the maintenance of the integrity and health of the environment. Therefore, soil is fundamental to the needs of man life, and plays a central role in determining the quality of our environment. In the future, the role of soils and soil cover in some crucial aspects for human life, such as food production, hydrological cycles and air composition will progressively increase. To protect those functions we must evaluate and predict the behavior 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 (Fig. 1).

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

Soils play a crucial role in the hydrological cycle. Soils 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 waters. 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) highlights the importance of water conservation.

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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.

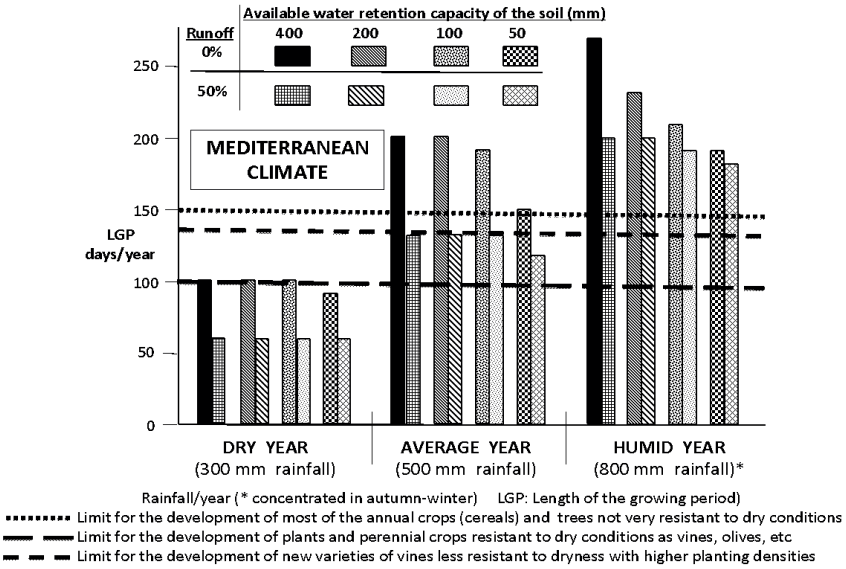

Figure 1. Potential length of the growing period in days/year (LGP) under semiarid Mediterranean climate conditions, as affected by the main critical factors derived of climate changes, land use&management and soil degradation (Pla, 2010)

The processes of soil and water degradation are closely linked through unfavorable alterations in the hydrological processes determining soil water regimes. They are also influenced both by weather conditions and the use and management of soil and water resources. Although the close interaction between the conservation of soil and water resources is increasingly accepted, they are still usually evaluated separately, and 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 weather changes, which will mainly affect hydrological processes on the land surface, mostly related to the field water balance (Fig. 2).

There is clear evidence that the degradation of soil and water resources at global, regional and local scales has been steadily increasing in recent decades,

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especially since the 1950s. This degradation is mainly due to the increased world population and socio-economic and technological developments, with 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 concentration 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. As a consequence and most probably related to these changes, there has been a change in the foci of studies and research on soil and water conservation.

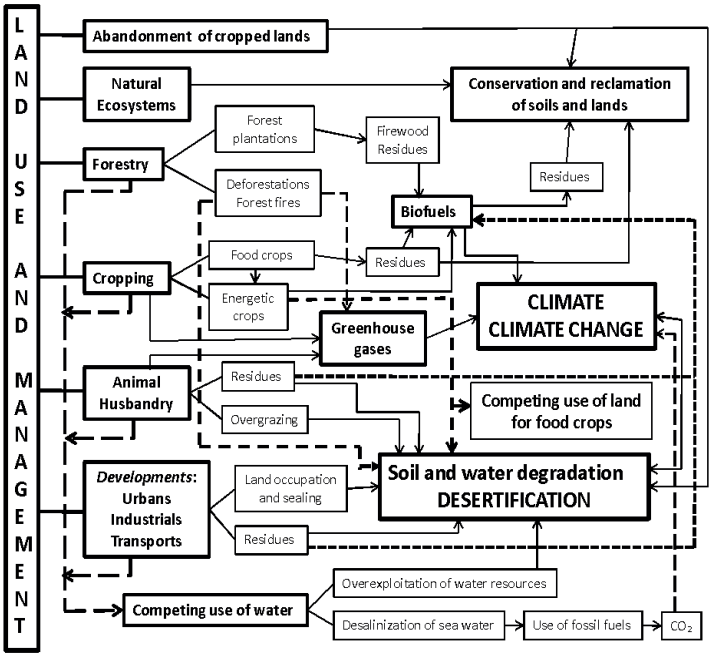

Figure 2. Relations between land use and management, climate and climate change, and soil and water degradation

Evolution of soil conservation research

With the increasing evidence of the growing global problems of land, soil and water degradation and their effects on food production and the environ-

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ment, there has been increasing interest, especially since the late 1960s, 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 the USLE (USDA-ARS 1965; Wischmeier and Smith, 1978) to predict soil erosion and to systems for evaluating and predicting risks of soil and water salinization (USSL, 1954). Such models and evaluation systems mainly used empirical approaches, based on statistical relations between accumulated information of the contributory factors (climate, soils and 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 similar conditions (climate, soils, topography and management) as their provenance (Fig. 3, 4).

Although these approaches were a crucial initial contribution to the understanding of soil and water degradation processes, and to the application of some standardized conservation measures. Further studies and research investigated the dynamic processes involved in soil and water degradation under different conditions. These studies 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, such as EUROSEM (Morgan et al, 1998) and WEPP (Nearing et al, 1989), which have tried to include very detailed descriptions of most of the factors involved in the surface erosion processes, generally do not adequately consider the involved hydrological processes, or are using 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, not adequately considering their spatial and

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temporal variability, leads to great uncertainty in the results. Furthermore, the requirement of a very detailed and accurate data base, which is usually not available, limits their application.

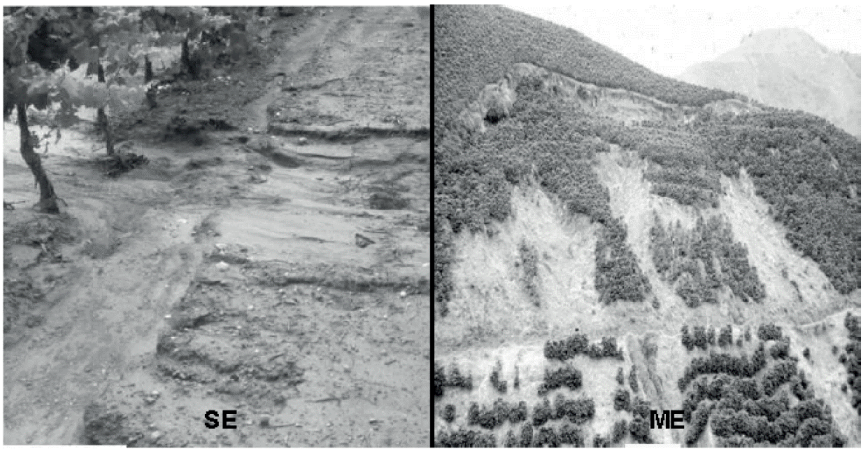

Figure 3. Surface erosion (SE: Vineyard-Spain) and mass erosion (ME: Coffee plantation-Colombia)

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

At the same time, with the renewed interest associated to soil and water conservation, there was an increase in related congresses and conferences. In addition, several international scientific organizations were initiated (SWCS:

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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 Science). Simultaneously, under the direction of UNEP-ISRIC there was a Global Assessment of Human-Induced Soil Degradation (GLASOD) prior to the United Nations Conference on Environment and Development (UNCED) in 1992. This elaborated Agenda 21, a global program for sustainable development. Several international conventions and programs were created in association with GLASOD. These include 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 the consequence of the need to evaluate the actual and potential problems of soil degradation on a global scale to provide international organizations with general overviews of the importance, extent and nature of the problems. The hope was that it would lead to increasing support in research and development activities focusing on prevention and control. This has not been the case, at least not at the required level, and therefore, even today these assessments are often used as a basis for environmental policies related with soil degradation problems at global, national and rgional 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 was 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 in 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 on re-interpretations and different processing or representation of old information, using some times “new” terminology. In other cases, new information has been mostly generated through indirect or

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remote sensing deductions, usually without adequate ground-truthing. Many past international assistance projects addressed to soil conservation in developing countries have failed to reach their objectives, mainly due to the lack of appropriate information at 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 laboratory equipment or field measurements for processing such information. Therefore, it is common that such programs have no continuity and the equipment becomes dysfunctional once the temporary economical and technical assistance ceases.

In recent decades, with the increasing evidence of the central role of soils in our environment and realizing that the welfare and survival of our species in the coming centuries is intimately connected to soils (Janzen et al, 2010), there has been an increasing interest in soil conservation across multiple disciplines. 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. In relation, 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 weather changes, when usually the main cause is associated with previous changes in land use and management leading to soil degradation processes.

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 very empirical approaches without a strong scientific basis. Some of them like "soil quality", "soil health" and "desertification" lack precise quantifiable meaning.

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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 focused on 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. In relation, there has been an increased tendency to increasingly rely on qualitative data and concepts based on expert judgments like soil quality indices. These have very limited accuracy and are insufficient for developing adequate policies for land use and management.

Many of the proposed concepts of soil quality are based on the original contributions of Larson and Pierce (1991), aroused with the purpose to protect the environment and sustaining the soil resource. But afterwards, this approach has led to developments of subjective soil quality indices, promoting oversimplification 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.

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 due to climate factors, and what it is human-induced trough 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 (Fig. 5)

The introduced "new" processes of soil erosion like "tillage erosion" (Lindstrom et al, 1992; Govers et al, 1994; Van Oost et al, 2003), and "land leveling erosion", which are simply mechanical soil displacements controlled by human actions, have nothing in common with the traditional water erosion (surface or mass erosion) related to hydrological processes, and wind erosion processes, derived of mainly uncontrolled natural phenomena. Tillage operations in sloping lands and land levelling 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

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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" (Fig. 6).

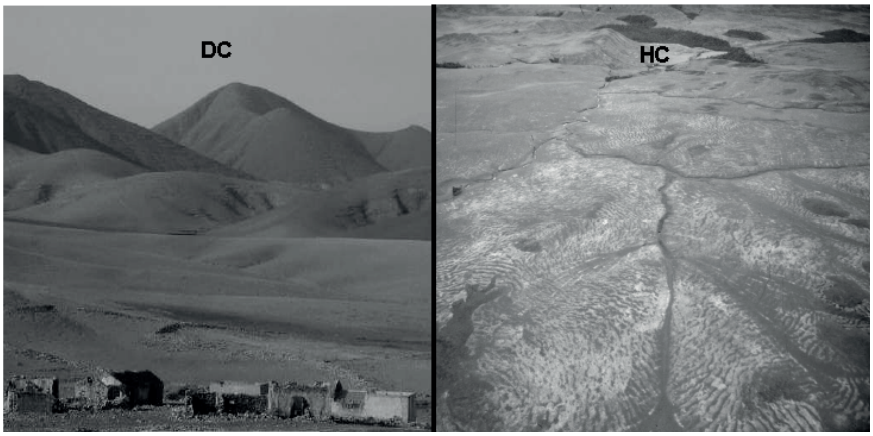

Figure 5. "Desertification" under dry climate conditions (DC: Fuerteventura Island-Spain) and under humid climate conditions (HC: Caroni river watershed-Venezuela)

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 of them in relation to various environmental and productive soil functions.

The term "C sequestration" has been generally used to describe the increase in soil organic matter and C content caused by a change in land use and management (Fig. 7). It has been suggested and accepted that a method to reduce atmospheric CO2, capable of offsetting a substantial portion of anthropogenic CO2 emissions, 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 unbalanced research in the area of soil conservation and degradation in relation to climate change, with very different and sometimes contradictory approaches.

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In general, misconceptions often lead to overestimation of benefits and of potential emission reduction of CO2 in soils (CAST, 2011). Still sequestering C in soils is largely an uncertain process, with difficulties in measuring impacts on a large scale (Baker et al, 2007).

Figure 6. Soil displacement (tillage erosion?, levelling erosion?) by land levelling in vineyards (NE Spain)(Pla&Nacci, 2011)

It is important to understand the sources and sinks of CO2 in a particular ecosystem to deduce if it will sequester C. 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 N2O and CH4, with more warming potential than CO2 (Li et al, 2005). There are also contradictions between the objective to increase "C sequestration" 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 to influence climate change through decreasing net CO2 emissions to the atmosphere (Fargione et al, 2008; Lal, 2009). Adverse impacts of residue removal on soil properties must be considered prior to use them for cellulosic ethanol. The over-emphasis centered on research about the benefits of soil C sequestration, decrease the required attention to studies directed to the over-all assessments

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of other measures aimed at maximizing the different ecosystems services supported by the soil (i.e. crop production, environmental protection) which may be more effective in combating climate change.

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

The term "zero tillage", also called "no-till" or "direct seeding" is used referring to a technique of planting crops directly into the previous crop´s residues without removing 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

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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 N2O emissions 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 (especially in C3 plant types), and in hydrological processes, due to increased CO2 levels in the atmosphere, we have to include increased photosynthesis and reduced respiration, increasing 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, such as 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 or not be 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 most 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 (Fig. 8).

It may be concluded that as climate, soil and socio-economic conditions differ greatly from one location to another, and as them are changing continuously, there cannot be simple universal prescriptions regarding practices for a

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sustainable soil management for crop production and environmental protection, and to help mitigate the greenhouse effect by C sequestration in soils.

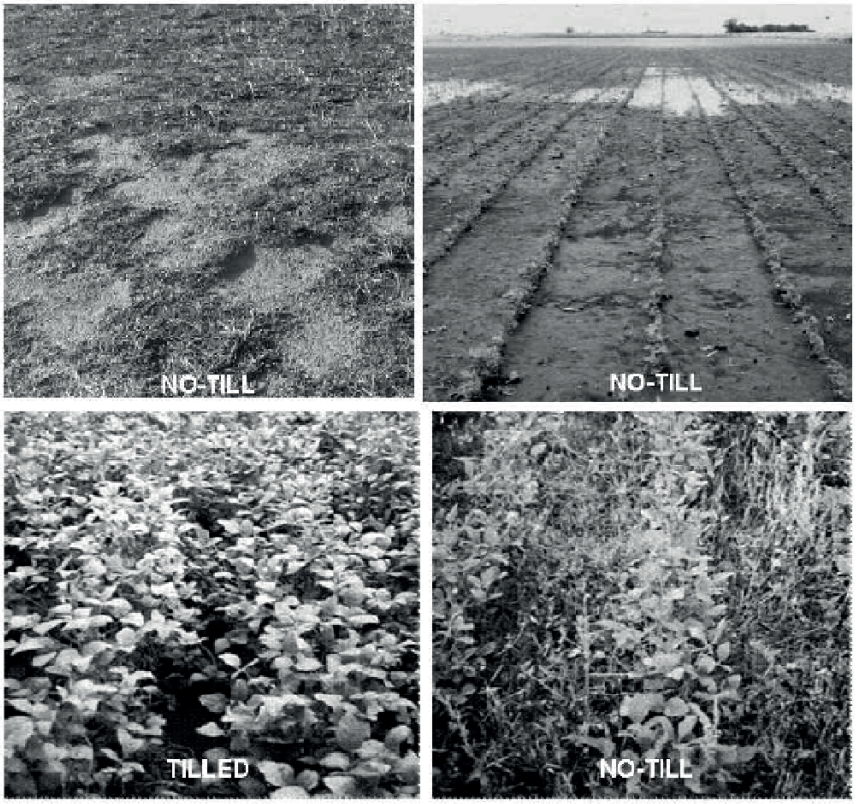

Figure 8. Long-term effects (20 years) of "no-tillage" on surface soil degradation (compaction, sealing) and in the appearance of herbicide-resistant weeds in fields continuously cropped with soybeans without rotations, in Argentina

The adequate selection of these sustainable practices must be based on research with a broader vision on soil conservation, where all 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).

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 modelling soil erosion in many places,

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sometimes complemented with locally specific also 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, compared with USLE, include the influence of rock fragments on infiltration and soil loss, based mainly on empirical relations, sometimes deduced of studies in soil columns with glass spheres simulating rock fragments. This results in the reduction of saturated hydraulic conductivity and water infiltration in soils with increasing rock fragments, while in most the cases, under field conditions, the reverse is true (Pla and Nacci, 2003).

Figure 9. Bench terracing in vineyards (Priorat-NE Spain), promoted and subsidized with EC funds for the pretended control of surface erosion, based on wrong generalized evaluations and predictions using empirical models, not taking into consideration the real hydrological conditions of this very permeable stony soils, but increasing at the same time the risks of mass movements (Pla, 2010; Pla et al, 2011)

Other more recent models like SWAT (soil and water assessment tool model), more based on hydrological processes, have been also extensively used in USA and Europe, in projects supported by various European

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Comission (EC) 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 the related applications and deductions of soil erosion and flooding processes. The existing information from previously made 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, frequently the dynamic soil properties, mainly hydrological, are 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 (Fig. 9).

The same stagnation happens with the evaluation and prediction of salinization in irrigated and dryland areas, where in many cases there are still used the diagrams and indices proposed by the USSL in 1954, because some of the more recently proposed models (Rhoades, 1992; Oosterbaan, 1997; Suárez, 1997) require information 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, under changing physical, social and economic conditions, especially considering the increasing concern about environmental issues, climate change, direct competition of water of good quality for urban areas, industries and recreation, and the increased use of residual waters for irrigation. More flexible approaches are required (Pla, 1989, 1997a, 2006) taking into consideration the changing physical and chemical processes leading to soil salinization and sodification under the different natural and management imposed conditions.

Concurrently, during recent decades there have been considerable changes in land use and management. Agriculture, urban development, industry and

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mining have continued degrading soil and water resources. Much of the present research in soil and water conservation related to those changes in land use and management is dedicated to isolated aspects and fail 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) consist 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 to the evaluation of soil and water degradation processes, and to the use of mainly empirical approaches for such evaluations.

There has been more emphasis on the identification, description and mapping of actual soil degradation and erosion, generally using geomorphologic approaches, remote sensing and GIS, than in identifying 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 a confusion in the identification of processes leading to surface or mass erosion (Pla,1997b; Sidle et al, 2006). Recommended practices (i.e. contour tillage, strip cropping, reduced tillage, ground-cover, terracing) effective in controlling or reducing surface erosion, may actually increase risks of landslides and mass erosion in general. In the evaluation and mapping of risks of landslides 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 weather conditions.

With a decline ln 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 unable to identify and apply effective re-

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sponses. Adequate training in soil science and hydrology is required to provide the knowledge and analytical skills to solve the current soil problems.

Conclusions and recommendations for the future

Future research in soil conservation needs to be more integrated with research on water conservation. Research needs to be directed to better understanding 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 (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 practices (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, on sustainable agricultural production, on the supply of water in adequate quantity and quality for potential uses and 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 modelling 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, and climate (Fig. 10). These models must enable detailed quantification of hydrological processes for both actual and potential conditions, answering major

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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).

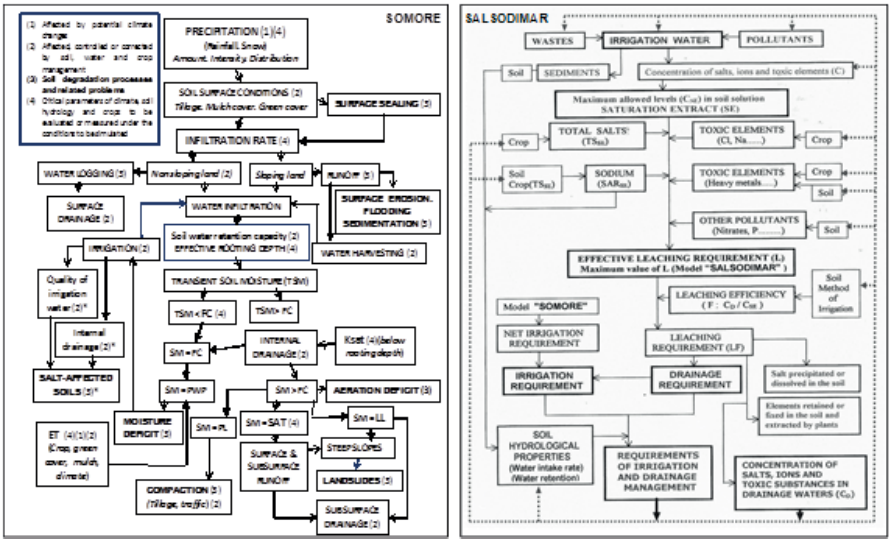

Figure 10. Flow diagrams of conceptual hydrology-based models which were the basis for the SOMORE (Pla, 1997, 2002, 2006, 2010) and SALSODIMAR (Pla, 1989, 1997, 2006) models, used to simulate and predict processes and problems of soil and water degradation by erosion, salinity-sodicity and related effects (SM: Soil moisture at root depth; SAT: Saturation; FC: Field Capacity; PWP: Permannet Wilting Point; PL: Plastic Limit; LL: Liquid Limit; ET: Evapo-Transpiration)

Although modern indirect techniques like remote sensing, computerized data processing, GIS and simulation models may assist 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).

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Soil degradation processes invariably have geological, chemical, physical, hydrological and biological dimensions. Lasting solutions will only be found if the complexity of problems is recognized by adequately trained researchers, who then develop appropriate strategies. More soil scientists are required with advanced training in fundamental sciences (physics, chemistry, biology, geology, and hydrology) and 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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Chapter 3

Quantification and simulation of evapotranspiration in a Mediterranean forest catchment

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Abstract. Current evapotranspiration in a typical Mediterranean catchment has been assessed in the Ribera Salada catchment in the Spanish pre-Pyrenees, using two equations, as an alternative to direct measurements. Evapotranspiration rates from the soil column (including root water uptake) and evaporation rates from the canopy interception were estimated. A soil-water balance model was also applied. These approaches have been used to estimate the evapotranspiration rate for Mediterranean vegetation, Quercus ilex, Pinus sylvestris, Pinus uncinata, pasture and tillage in seven experimental plots. Observations of precipitation, infiltration, surface runoff, soil moisture contents and deep soil percolation are used for this purpose. The calculated evapotranspiration rates are coincident with the established values by other authors on Mediterranean zones, which indicate that the estimation of the different

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parts of the overall plot scale evapotranspiration rates is a promising and relatively cheap technique for applications in disciplines such as hydrology, ecology, and forest management. Finally, the estimated evapotranspiration from the soil-water balance model "TOPLATS" has been compared with assessed values. The model has some uncertainties associated with the water flux into the soil, which entails either an overestimation or underestimation of the evapotranspiration values. This response is associated with soil moisture and canopy interception model formulation. A more detailed characterization of the different hydrologic balance components could be used for model improvement.

Keywords. Water balance, Runoff, Evapotranspiration, TOPLATS, Mediterranean Forest

Introduction

The regulation of water resources is an urgent priority in the management of ecosystems, particularly in semiarid environments. The Mediterranean climate is characterized by intra-annual rainfall variability, with conditions of water deficit in summer and a very strong impact of human activity (Rius et al., 2001; Ceballos et al., 2002). During the last five decades, land use in the Pyrenees has seen a big change, with forests replacing pastures and tillage (Ubalde et al., 1999). It is well known that land use has a strong impact on the hydrologic dynamics of Mediterranean basins (Gallart et al., 2005; Orozco et al., 2006). Short period evapotranspiration (ET) data for specific types of vegetation or individual trees in relation to soil and atmospheric conditions are scarce compared with watershed studies in Mediterranean environments. Preliminary studies by Piñol et al. (1991) for Quercus ilex forest in two Mediterranean mountain watersheds used a 79-month hydrological record, and the actual ET was calculated as the difference between annual values of precipitation and discharge. Many studies of Mediterranean watersheds have been conducted to calculate the actual evapotranspiration taxes using surface energy balance and soil water balance models, and remotely sensed data or standard formulas to estimate reference evapotranspiration (Rana et al., 2000; Detto et al., 2006; Minacapilli et al., 2009). The reference ET in the Central Pyrenees has been calculated using the Penman-Monteith method and the Hargreaves model, the results indicate that the former offers a more accurate estimation than Hargreaves' formula (López-Moreno et al., 2009). The actual evapotranspiration rate (ET) in a Mediterranean catchment was calculated from TDR (Time Domain Reflectrometry) under shrubs at a temporary interval of 15 days

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and it was compared with calculated ET by means of Thornthwaite's method (Belmonte and Romero, 2006). Cristóbal et al. (2007) modelled the actual ET in Pinus sylvestris forest stands, in a Mediterranean mountain region of Catalonia, using remote sensing data and compared it with stand-scale sap flow measurements. In the Mediterranean area with Pyrenean influence, Ibáñez and Castellví (2000) estimated daily ET using remotely sensed surface temperature and meteorological data in grass, wheat and alfalfa. In this case, validation was conducted using Bowen ratio equipment and water content reflectometers.

Evapotranspiration rates at the point scale are an important part of the water balance, because of their impact on soil water availability. This in turn has a stronger impact on vegetation growth and crop development. For this reason, a number of micrometeorological methods have been developed for the measurement of point scale evapotranspiration rates. The most commonly used methods are the Bowen Ratio Energy Balance (BREB) and the Eddy Covariance (EC) methods. Both methods are known to have various drawbacks. Even though BREB-based evapotranspiration rates can be obtained independently of the weather conditions, any inaccuracy in one of the instruments will have direct influence on all measured fluxes (Barr et al., 1994; Unland et al., 1996; Pauwels and Samson, 2006). The EC method disadvantages are dew formation on the instruments during daybreak, which renders the instruments unreliable, as well as the fact that instruments do not work properly under precipitation and the lack of energy balance closure, which under certain circumstances can be relatively large (Stannard et al., 1994; Pauwels and Wood, 1999; Twine et al., 2000; Todd et al., 2000; Foken, 2008). Even though the above mentioned micrometeorological methods have been extensively used in hydrological and ecological studies, a partitioning of the measured evapotranspiration into its components (transpiration, evaporation from the soil, evaporation from the interception storage) cannot be performed with any of these methods. A number of studies have already shown that, for example in forests, evaporation from the forest floor is an important part of the overall water balance (Silberstein et al., 2001; Deguchi et al., 2008). However, the technique that is usually applied for the measurement of forest floor evaporation, microlysimeters, tends to be prone to a non-negligible degree of error (Silberstein et al., 2001). Another appealing option to estimate plot scale evapotranspiration rates is the analysis of soil water content fluctuations.

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Schwaerzel et al. (2009) demonstrated that Time Domain Reflectometry-based soil moisture observations are in general consistent with observed evapotranspiration rates. One could thus, in theory, use a combination of soil moisture observations, estimates of soil hydraulic parameters, and a soil water movement model to inversely calculate the evapotranspiration rate. The problem with this approach is the need for a numerical model, which is always prone to errors and uncertainties. The results from this approach will, thus to a certain extent, be dependent on the model used.

In this paper, a different method to estimate plot scale evapotranspiration rates and some of its components are proposed. The methodology is based on detailed observations of precipitation, infiltration and percolation rates and surface runoff. A mass balance of only the soil column and a second mass balance of the combined soil-vegetation column are calculated, which lead to estimates of the plot scale evapotranspiration rates, the interception storage evaporation and the behavior of the soil water balance components. The methodology is applied to seven different combinations of land use and soil type in a Mediterranean catchment. Using the simple equations and TOPLATS simulation model, an assessment can be made of the importance of canopy interception processes on the overall evapotranspiration behavior of different land use and soil texture combinations.

Methods

Site description and data acquisition

The Ribera Salada basin is located in the Pre-Pyrenean mountainous area, in the Northeast of Spain, and it belongs to the Ebro basin. Within this area, seven experimental plots of 5 m x 5 m were selected based on representative soil types and land uses of the catchment (Table1). The location of the study area and the observation sites are shown in Figure 1. A description of the complete soil survey can be found in Orozco et al. (2006). For detailed basin covers we refer Ubalde et al. (1999) and complete analysis of spatial variability of soil physical parameters in the catchment we refer to Acuña and Poch (2001). The climate is mainly Mediterranean climate and varies to subalpine in the highest parts of the basin. The average temperature is 20 °C during the summer and 5.1 °C during the winter. The annual precipitation ranges from

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624 mm in the low lying areas to 874 mm in the higher areas. For all test sites in the study area snowfall occurs only very rarely.

The analyzed data in this study was collected from April 28, 2004, through December 19, 2008. The meteorological information was obtained from the Xarxa Agrometeorologica de Catalunya meteorological station. This station is named Lladurs and is located at the same site as the Montpol station. Air temperature and relative humidity were measured using a Vaisala HMP45 sensor (Vaisala Helsinki, Finland). Soil temperature was measured at a depth of 5 and 50 cm using a 107-L sensor (Campbell Scientific, Leicestershire, UK). Wind speed was measured using a Young 05103 sensor (RM Young, Traverse, Michigan, USA). Rainfall was measured using an ARG 100 rain gauge (Campbell Scientific, Leicestershire, UK). All these measurements were taken with an interval of one second and stored with an interval of one minute. All instruments were controlled by a CR10X datalogger (Campbell Scientific, Leicestershire, UK). Further, data from the Cal Ramonet rainfall station of the Forestry and Technology Center of Catalonia were available. These observations were obtained using a RGB1 rain gauge (Campbell Scientific, Leicestershire, UK). Rainfall information is measured with a five minute interval and stored using a CR10X datalogger (Campbell Scientific, Leicestershire, UK).

Table 1. Land use and soil type of the study plots. The fractional coverage of the land and soil types in the catchment are indicated in brackets (units are percentages).

Station	**Land use**	**Soil Type** (SSS 2010)
Montpol oak wood	*Quercus Ilex* (18)	Lithic/Typic Calciustepts (4)
Cogulers shady	*Pinus Sylvestris* (25)	Lithic/Typic Ustorthents (75)
Cogulers sunny		Lithic/Typic Calciustepts
El Prat pasture	Pasture (8)	Lithic/Typic Haplustepts (12)
Cal Ramonet tillage	Culture rotation (15)	Lithic/Typic Calciudolls (7)
Cal Ramonet pasture	Mountain Pasture (6)	
Cal Ramonet pine forest	*Pinus uncinata* (18)	
	Mixed rocks outcrops (10)	Miscellaneous (2)

In the study site, soil moisture was measured from 1998 to present. Each location was equipped with four ECH2O Decagon Devices Inc., Pullman, Washington, USA) sensors in the soil moisture content section (SSS, 2010)

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at 5 to 30 cms depth. Measurements were taken and stored with an interval of one hour, using an Em5 datalogger (Decagon Devices, USA). In order to ensure good contact, the soil was previously sieved and placed around the sensor in the field, avoiding direct contact with stones. The sensors were calibrated for each site during the period 2003–2004. The calibration was performed following the guidelines of the manufacturer. Volumetric soil moisture values were determined using in-situ obtained soil samples. These results were compared to the volumetric soil moisture values registered by the sensors. Linear calibration equations for the different soil types were obtained, with R2 values ranging from 0.74 to 0.92; we refer Loaiza and Pauwels (2008a).

A number of other hydrologic variables were monitored between April 21, 2004, and June 28, 2005. A weekly interval was used during rainy periods and a bi-weekly interval during dry periods. Deep soil percolation was measured using two tension zero lysimeters which were installed per site at depths ranging from 40 to 50 cms, depending on the soil type. A lysimeter is a rectangular metal plate measuring 20 x 30 cm and constructed to collect soil infiltrated water. Surface runoff was measured at all sites except Cogulers Sunny. A runoff area ranging between 10 and 45 m2 was selected and delimited by galvanized plates. Slopes ranged between 22% and 45%. The quantity of non-infiltrated water was collected at the outlet of the runoff area. For each site two such boxes were installed. Interception is higher in forest than pasture and agricultural lands. For this reason, each runoff plot was measured, and the infiltration was calculated as the throughfall plus stemflow minus the surface runoff. Canopy interception was measured for oak wood, Pinus sylvestris and P. uncinata forest in interception plots during the period. It consisted of 12 pluviometers under the canopy to measure throughflow, measured each 5 minutes. Stemflow was measured by means of 4 to 5 stem rings under each canopy type, which was collected in containers and measured after each rainfall period. Regression equations between rainfall and measured interception were obtained in Montpol, Cogulers and Can Ramonet stations by Solsona (2005).

Evapotranspiration

The methodology applied in this paper consists of observing all variables of the water balance, except for the evapotranspiration. The first water balance that is analyzed is the water balance of the soil column. The water that infiltrates into the soil will partly be portioned as evapotranspiration, percola-

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tion to deeper soil layers, and partly changes the storage of water in the soil column. This can be written as:

$$I = ETs + D + \Delta Ss \quad (1)$$

I is the infiltration rate, D the deep percolation, ETs the evapotranspiration from the soil column, and ΔSs the change in storage in the soil column, all in mm. It should be noted that the term ETs includes the uptake of soil water through the vegetation roots, since this process will reduce the amount of water stored in the soil column. A second water balance that was analyzed is the water balance of the vegetation column above the soil. The precipitation reaches this vegetation layer, and a part of this amount of water will be intercepted by the vegetation, while the remainder will reach the ground. The amount of water intercepted by the vegetation will evaporate, while a part of the water reaching the ground will infiltrate, and another part will be removed as surface runoff. Thus, the amount of evaporation from the canopy is equal to the precipitation minus the infiltration and the surface runoff:

$$Ev = P - I - Qs \quad (2)$$

P is the precipitation, Qs the surface runoff, and Ev the evaporation from the interception storage. If observations of the infiltration, deep soil drainage, and soil water content are available, ETs can thus be calculated using Equation 1. Analogously, if the surface runoff is measured, Ev can be calculated from Equation 2. The evapotranspiration from the plot is then simply the sum of ETs and Ev. For the seven stations, the precipitation, surface runoff, deep soil percolation, infiltration, and soil water content were observed for the entire study period. These observations will thus allow an assessment of the evapotranspiration rates of the different vegetation types, and its partitioning into interception storage evaporation and soil column evapotranspiration.

Hydrological model

The TOPMODEL-based land-atmosphere transfer scheme, TOPLATS (Famiglietti and Wood, 1994 Peters-Lidard et al., 1997) is a Soil-Vegetation-Atmosphere Transfer Scheme (SVATS) developed to be used as a land surface parameterisation in atmospheric models, based on a TOPMODEL framework (Beven and Kirkby, 1979). This model differs from other SVATS due to the

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representation of topographic effects on water availability resulting from down slope flows. According to Famiglietti and Wood (1994) the land surface is partitioned into bare-soil and vegetation components. The vegetated component is assumed to be distributed evenly over the surface.

The canopy water storage capacity is calculated according to Dickinson (1984) as a function of the leaf area index LAI. Evaporation and transpiration are computed for the wet and dry canopy, as well as for the bare soil component of the surface. The sensible and ground heat fluxes are also computed for the wet canopy, the dry canopy and the bare soil. Infiltration and surface runoff are computed for the bare soil and vegetation components of the land surface. In the model, runoff is generated by both: infiltration excess and saturation excess mechanisms.

The surface runoff and heat fluxes depend strongly on surface soil moisture. A detailed description of the original model is given by Famiglietti and Wood (1994), and modifications are described by Peters-Lidard et al. (1997) and Pauwels and Wood (1999). The water and energy balances are solved for each test site at the point scale. The required model input data consists of climate, soil type, land use and vegetation, as well as standard meteorological data. The land cover parameters were determined following Peters-Lidard et al. (1997). The soil and vegetation parameters are explained in Famiglietti and Wood (1994). To calculate the thermal conductivity of the soil parameters we refer to Pauwels and Wood (1999). The soil and vegetation parameters used in the simulations are shown in Table 2.

The TOPLATS model has been calibrated using the equations of the Extended Kalman Filter. The equations are applied recursively throughout an iteration process, based on which, the methodology can be referred to as weight-adaptive recursive parameter estimation. For a full description we refer to Goegebeur and Pauwels (2007). Model simulation with TOPLATS at each site was performed for a period of one year. The specific year depended on the availability of observations from each site. Simulated and measured soil moisture was compared at an hourly time step. The obtained parameters are shown in Table 2 and 3. Model validation was conducted using the data collected from April 28, 2004, through December 19, 2008; we refer Loaiza and Pauwels (2008b). The quantitative procedure for model evaluation consisted of the use of the statistical analysis to calculate the root mean square error (RMSE).

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This RMSE is calculated as:

$$\text{RMSE} = \sqrt{\frac{\sum_{n=1}^{N} [\theta o\,(n) - \theta o\,(s)]}{N}}$$

N is the number of observations, and Ɵo and Ɵs are the observed and simulated soil moisture (%), respectively.

Table 2. Soil and vegetation parameters used for the plot simulations at the Ribera Salada Catchment.

Parameters	Montpol oak wood	Cogulers shady	Cogulers sunny	El Prat pasture	Cal Ramonet		
					Tillage	pasture	forest
Bubbling pressure (m)	30.2	40.12	30.2	40.12	56.43	56.43	56.43
Saturated soil moisture (%)	39	38	46	40	57	57	57
Residual soil moisture (%)	12	13	21	2.4	14	14	14
Sand content (%)	53	31	52	55	45	45	45
Clay content (%)	15	10	13	13	33	33	33
Root fraction in top layer (%)	30	30	30	40	40	40	40
Root fraction in second layer (%)	20	20	20	30	30	30	40
Root fraction in third layer (%)	20	20	20	10	20	10	20
Stoniness (%)	39	32	35	37	56	51	45
Leaf area index	4.3	2.25	2.25	0.6	1	0.6	6.6
Albedo for dry surface	0.11	0.11	0.11	0.13	0.13	0.13	0.19
Albedo for wet surface	0.10	0.10	0.10	0.24	0.24	0.24	0.16
Momentum roughness length (m)	1	1	1	0.15	0.05	0.15	1.20
Heat roughness length (m)	0.10	0.10	0.10	0.02	0.01	0.02	0.12

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Zero plane displacement height (m)	6.7	6.7	6.7	1	0.3	1	8
Critical soil moisture (%)	27	25	25	38	43	43	43
Wilting soil moisture (%)	11	13	13	16	19	19	19

Table 3. Calibrated model parameters

Station	Ks * (mm/h)	β (-)	Ψ_e (m)	Qo (m^3/s)	f (-)	RMSE (-)
Montpol oak wood	24. 4	1.556	0.3836	$2.782e^{-8}$	0.7014	0.0189
Cogulers shady	0.39	0.633	1.0043	$7.083e^{-7}$	0.7178	0.0395
Cogulers sunny	20.38	1.162	0.3698	$2.928e^{-7}$	1.1792	0.0218
El Prat pasture	9.99	0.829	0.4129	$8.805e^{-8}$	1.1857	0.0546
Cal Ramonet tillage	5.97	0.208	0.4578	$5.129e^{-7}$	0.5548	0.0359
Cal Ramonet pasture	5.97	0.224	1.8859	$5.646e^{-7}$	0.5743	0.0344
Cal Ramonet pine forest	0.31	0.968	0.4407	$5.471e^{-7}$	0.4522	0.0634

(*) Parameter measured, RMSE: root mean square error.

The soil parameters were determined from the actual soil texture class following the parameters: Ks (saturated hydraulic conductivity), β (Brooks - Corey pore size distribution index), Ψe (air pressure entry), Qo (base flow saturated) and f (change Ks in depth), being calibrated for the studied sites according to Rawls et al. (1982) criteria. The relationships between these parameters allow us to predict water retention volumes for particular tensions and saturated hydraulic conductivities based on soil properties. The Brook and Corey equation provides a reasonably accurate representation of the water retention. Soil moisture and hydraulic conductivity in unsaturated soils can be described in terms of matric head (Famiglietti & Wood, 1994).

Results and discussion

The in-situ observations

The results presented here are valid for the plot scale. Figure 2 shows, for all stations, the cumulative water balance components over the entire study period. Table 4 shows the totals for each of these components. A number of remarks can be made from this plot and this table. First, for all stations, very low surface runoff values have been obtained, fluctuating between 0.24 % and 1.01 % of the total rainfall. This can be explained by the fact that the runoff

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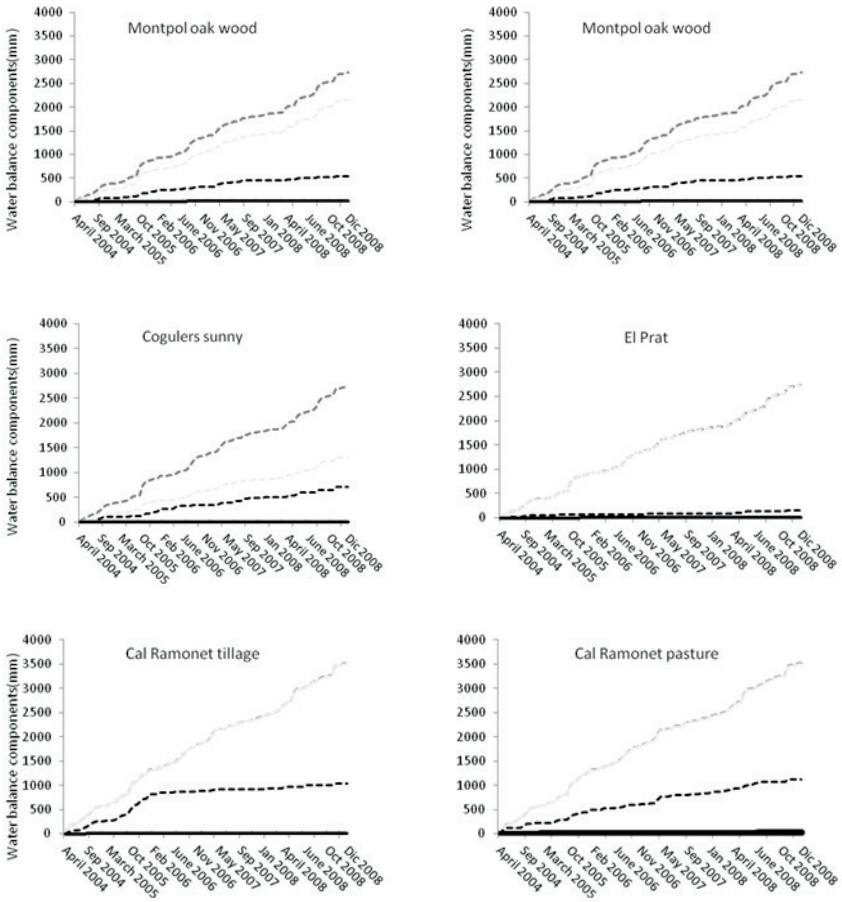
response in the catchment is driven by preferential flow such as bypass flow through macropores, root channels and cracks, and infiltration associated with presence of rocks in the soil (Verdú et al., 2000). Furthermore, for stations with forest as vegetation cover, the infiltration rates are much lower than the precipitation rates, which can be explained by the interception of precipitation water by the vegetation. The infiltration values fluctuate between 48.2 % and 99.7 % of the total rainfall.

The highest infiltration values explain the low runoff taxes in the catchment.

Figure 2. Observed cumulative water balance components for each station.



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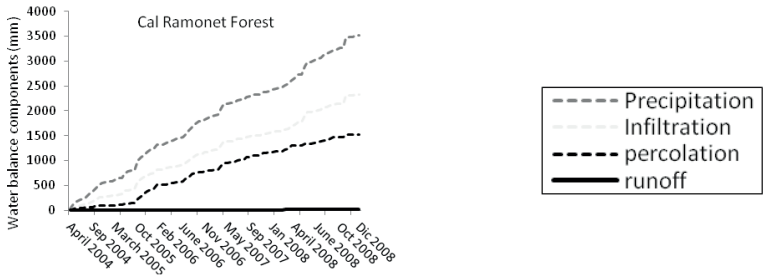

Figure 2. Observed cumulative water balance components for each station.

During the analyzed period, the interception percentage (with respect to the total precipitation) according to the studied covers varies between 15.6 % and 90.4 % for Quercus ilex, 32.4% to 95.7 % for Pinus uncinata, and 8.6% to 96.2 % for Pinus sylvestris. Also, the fraction of the infiltration that percolates to the deeper soil layers strongly differs between sites, ranging from 5.8 % to 43.3 % of the total rainfall. The lowest fraction of percolation was observed at the El Prat site. At the El Prat station, the soil water is used to supply the high evaporation demand (Table 4); therefore the soil moisture store is exhausted quickly. The water storage in the soil column is replenished sufficiently after rainfall episodes, but it is very low and is quickly emptied by transpiration (Figure 3).

Table 4. Observed water balance of the entire study period (2004-2008).
The numbers are cumulative fluxes (mm). Annual average values are shown in brackets (mm). F_{IP} stands for the fraction of the infiltration that percolates, ETs evapotranspiration from soil column, Ev interception storage.

Station	Precipitation	Surface Runoff	Infiltration	Percolation	$F_{IP\,(\%)}$	ETs	Ev
Montpol oak Wood	2733.3 (580.1)	28.2 (5.9)	2121.9 (450.6)	548.8 (116.5)	25.8	1653.5	546.2
Cogulers shady	2733.3 (580.1)	6.5 (1.4)	1644.1 (348.9)	747.1 (158.5)	45.4	906.5	1076.9
Cogulers sunny	2733.3 (580.1)	8.1 (1.7)	1316.3 (279.3)	708.7 (150.4)	53.8	607.6	1407.4
El Prat pasture	2733.3 (580.1)	6.9 (1.5)	2726.4 (578.6)	160.7 (34.1)	5.9	2526.7	0
Cal Ramonet tillage	3519.5 (746.8)	8.9 (1.8)	3510.6 (744.9)	1030.0 (218.6)	29.3	2512.7	0

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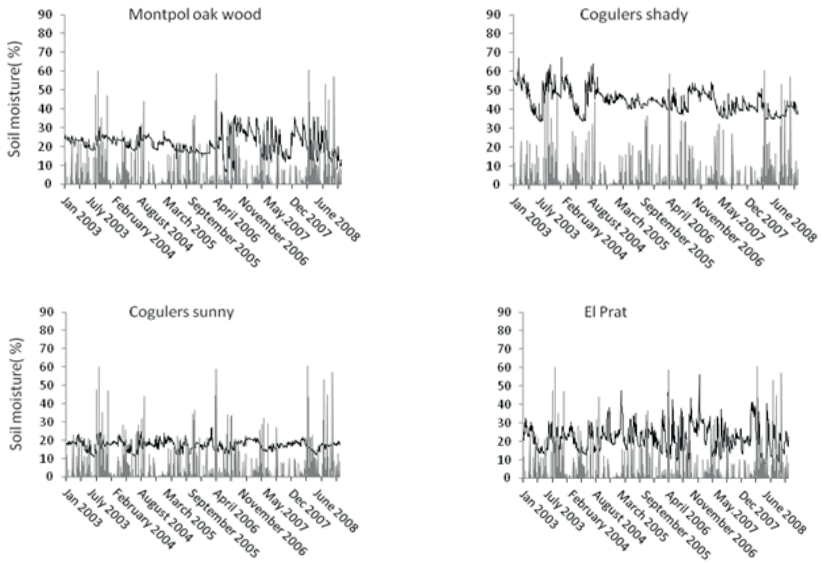
Cal Ramonet pasture	3519.5 (746.8)	20.2 (4.3)	3499.3 (742.6)	1128.3 (239.4)	32.3	2313.5	0
Cal Ramonet pine forest	3519.5 (746.8)	10.3 (2.2)	2332.5 (495.2)	1523.6 (323.3)	65.3	854.4	1145.9

We can see that for the sites at Cogulers, the station located in the shade shows higher soil water content than the station in the direct sun. This can be explained by the specific location of the stations. More specifically, the shady station is located close to water source (Cogulers stream). The sunny station has a higher tree density and less soil moisture content than the shady station, where the pine forest is less dense and soil water content is always saturated. Even though the amount of deep soil percolation is relatively similar, the amount of infiltration is approximately 25% higher in the shady station than in the sunny station. This difference can be explained by plot spatial variability.



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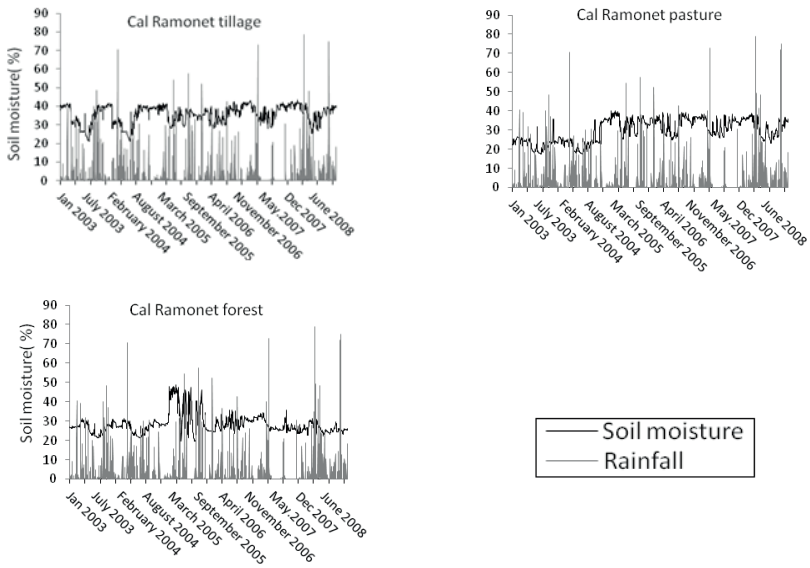

Figure 3. Soil moisture content and precipitation during the study period.

The sites at Cal Ramonet show some remarkable differences as well. The comparison between sites, the amount of infiltration at the tillage site is approximately 50% higher than the pine forest site, the amount of percolation under tillage is approximately 50% lower (Figure 2). On the other hand, the amount of infiltration and deep soil percolation is relatively similar for the tillage and pasture sites. The soil moisture content at the pine forest site is clearly lower than at the other two sites, which explains the deep soil percolation response. The lower infiltration rate at the forest station can be explained by canopy interception processes. The soil moisture contents are relatively similar for the pasture and tillage sites which, combined with the results in Figure 2, show rather similar water balances. In Cal Ramonet the presence of old agriculture terraces and soils with clay content is 30 % to 45% higher than on other sites; favored soil water retention, however soil water content was not saturated during the studied period, this response might be related to the presence of loam soils with higher stoniness (Table 2 and 3).

Estimated and simulated evapotranspiration

The cumulative calculated total evapotranspiration rates from the stations and the evapotranspiration rates from the soil column and the results of the

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TOPLATS simulations are shown in Figure 4. The difference between soil column and plot evapotranspiration is thus evaporation of intercepted water by the canopy. The resulting total evapotranspiration amounts, recalculated to daily averages, are shown in Table 5. This table shows that the locations with agriculture and pasture as land use tend to have higher soil column evapotranspiration rates than the forest sites. This study comes to the same conclusion as drawn by Gallart et al. (2005) for a Mediterranean mountainous site in the Southeastern Pyrenees (Vallcebre), where it was shown that pasture consistently has higher evapotranspiration rates than forests. Table 5 also shows that the amount of evapotranspiration from the soil column is rather low for all the sites with pine trees (Pinus) as land cover, but the amount for the site with Oak Wood (Quercus ilex) is about twice as high as for the other forest sites. The differences between Cogulers shady and sunny can be explained by the effect of the soil moisture content. Gallart et al. (2005) demonstrated that the actual evapotranspiration rates in a nearby area are strongly dependent on the soil moisture contents. The higher soil moisture content for the Cogulers shady site as compared to the Cogulers sunny site (Figure 3) can thus explain the higher soil column evapotranspiration at the Cogulers shady site than for the Cogulers sunny site. Referring the differences between Wood station and pine forest evapotranspiration rates from the soil column, soil survey results show that Oak Wood has deeper roots than pine trees (Olarieta et al., 2001). One major reason for the high soil column evapotranspiration at the Montpol site could be the low interception at the tree canopy. In addition deeper roots, dry and windy conditions at Montpol site favored the evapotranspiration demand. A final remark that can be made is that evaporation of intercepted water by the canopy is negligible for the pasture and agriculture sites.

The obtained values of plot and soil column evapotransporation during the measured period ranged between from 57 % – 93 % and 23% - 92% of the total rainfall, respectively. Lowest plot and soil column evapotranspiration values have been obtained at Cal Ramonet forest. This difference is due to a higher volume of percolation water losses and rainfall dynamics. Studies realized by Piñol et al. (1991), during a period of 8 years in a catchment in Prades (Spain), report evapotranspiration data ranging between 82 to 97 % of the total rainfall. Castañeda and García-Vera (2008) on the Monegros zone (north-east Spain) found that the evapotranspiration corresponds to 92% of the total rainfall. Belmonte & Romero (2006) under Mediterranean shrubs cover found that

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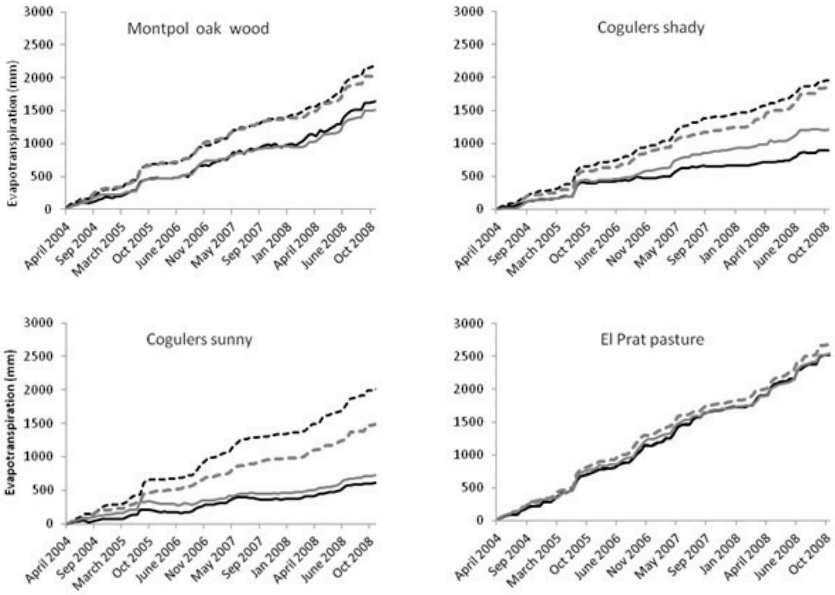
the soil column ETP fluctuates between 0.29 and 0.41 mm/day, being these values lower than the values found on this study (Table 5).

Measurements with sap flow technique in Pinus sylvestris show mean, minimum and maximum values of actual evapotranspiration 2.2, 0.6 and 3.6 mm/day respectively, for Q. pubescens the evapotranspiration varies between 0.25 to 1.4 mm/day (Poyatos et al. 2005). The values found in the present study of pine forests in Cogulers and Cal Ramonet, and on oak wood in Montpol are included within the rank reported by Poyatos et al. (2005) in Vallcebre catchment (Eastern Pyrenees). Studies performed by Minacapilli et al. (2009) in Mediterranean crops demonstrate that the evapotranspiration fluctuates between 0.61 to 3.23 mm/day. Thus the results obtained in Cal Ramonet crops are within this range. The overall results from the analysis of the water balance at the different stations indicate that a high percentage of rainfall goes to evapotranspiration. These results are consistent with Piñol et al. (1991), Gallart et al. (2005) and Castañeda and García-Vera (2008). With regard to the accuracy of the TOPLATS model, the RMSE (root mean square error) values in plots and soil column varied in range of 1.22 – 9.99 to 1.38 – 7.91, respectively. Figure 5 compares the modelled evapotranspiration with the calculated evapotranspiration on the sites with monitored plots.



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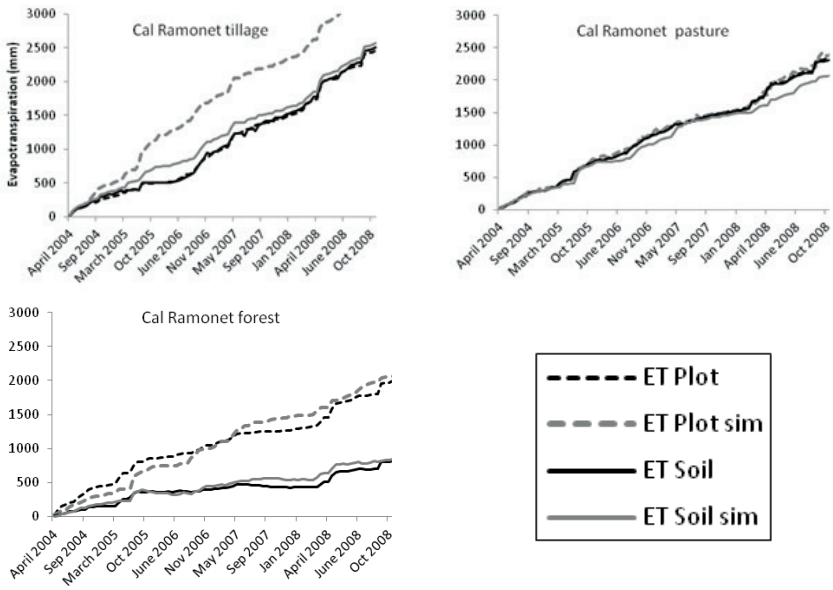

Figure 4. The calculated cumulative plot evapotranspiration, soil column evapotranspiration and TOPLATS simulations for each station.

Table 5. Calculated plot and simulation plot (ETs+Ev), soil column and simulation soil column (ETs) evapotranspiration rates over the entire study period. The numbers are averages (mm/day).

Station	Plot	Simulation plot	RMSE	Soil column	Simulation soil column	RMSE
Montpol oak wood	1.28	1.19	3.18	0.96	0.88	3.72
Cogulers shady	1.15	1.09	1.65	0.53	0.71	3.70
Cogulers sunny	1.17	0.87	9.99	0.35	0.42	7.91
El Prat pasture	1.47	1.56	1.22	1.47	1.49	2.26
Cal Ramonet tillage	1.46	1.99	5.32	1.46	1.50	1.88
Cal Ramonet pasture	1.36	1.40	1.67	1.35	1.21	1.38
Cal Ramonet pine forest	1.16	1.21	1.74	0.48	0.50	5.33

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It can be observed that for all sites (Table 5), practically all evapotranspiration rates are quite similar. In Cal Ramonet (forest, tillage and pasture) and Prat station the model slightly overestimates evapotranspiration plot loses. The discrepancies between observed and simulated data in the study sites can be associated to the relative simplicity for modelling the radioactive interactions for the two layer canopy representation (Pauwels and Wood, 1999). Simulated soil column evapotranspiration in Montpol and Cal Ramonet pasture are underestimated whereas in the others sites are overestimated. According to Crow et al. (2005) under and over estimation of soil column predictions are related to field-scale soil heterogeneity and spatially heterogeneous rainfall distribution that renders proper model calibration and parameter identification more difficult.

The difference between total measured and total simulated plot and soil column evapotranspiration values ranged between 1.4 % - 25.6 % and 0.5% – 25.4 % (over the entire study period), respectively. The differences between simulated and measured data can be attributed to the model structure, which considers the infiltration capacity in terms of cumulative infiltration and soil moisture recharge which start at each storm event (Famiglietti and Wood, 1994). The best results for soil plot evapotranspiration were obtained in El Prat, Cogulers Shady, Cal Ramonet pasture and forest, Montpol.

For soil column the best results were Cal Ramonet pasture and tillage, El Prat, Cogulers Shady and Montpol. However, it would be necessary to carry out more detailed studies of evapotranspiration by means of scintillometer implementation, sap flow meter and studies of waterflow (at minute scale and rainfall event scale) on the different studied plots, to know which of the listed variables has the strongest effect on the evapotranspiration behavior. These results would allow the generation of specific algorithms for each studied soil use, reaching a higher adjustment implementing these kinds of models.

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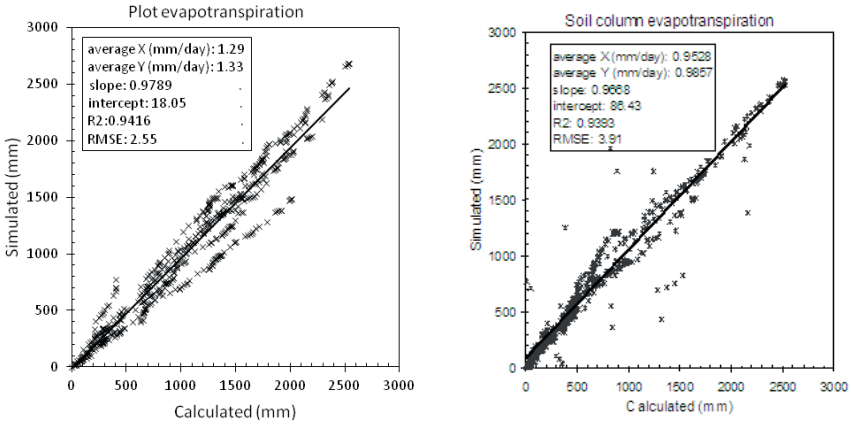

Figure 5. Comparison between modelled and calculated soil column evapotranspiration at all stations and according to observation intervals.

Conclusions

Runoff behavior and water percolation has been controlled by infiltration, which is directly related to soil moisture storage and evapotranspiration demand. Water content in the soil is very low (below the wilting point) and the soil water storage variability is higher during intermediate wet conditions. The soil water content decreases rapidly due to a higher evapotranspiration demand, which increases in summer. Simulation of plot and soil column evapotranspiration by the TOPLATS model under and over predicted the amount of evapotranspiration on the studied sites. The model high performance was under pasture, oak wood and shady conditions. The discrepancy between observed data and simulated results may be influenced by space/time scale patterns and simplicity modelling for canopy and soil moisture interactions. The simulated evapotranspiration values can be considered as an approximation and shows the usefulness of the calibrated model. The calculated RMSE indicates an acceptable model performance. This approximation can be useful to improve the model. Overall, the results in this paper indicate that the estimation of the partitioning of the total plot scale evapotranspiration into its different components through an analysis of the soil water balance is a promising and relatively cheap approximation to calculate evapotranspiration for hydrological and ecological studies.

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Chapter 4

The Streampower concept for assessing the sediment concentration and runoff under simulated rainfall

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Abstract. In erosion and overland flow, research is focused on a threshold driven detachment and transport equation in which the most determining parameters are: the critical momentum flux, the mean runoff velocity, the unit stream power or the critical shear strength. However, parameters such as critical momentum flux and critical shear strength are difficult to measure and good relationships with soil physical parameters are lacking. Moreover it is shown that the Manning equation is not suitable to calculate the velocity of overland flow during the interrill erosion process. Therefore it is preferred to apply relationships using the discharges (amount of runoff) measured at stream (or rill) outlet instead of the velocity parameters. For the erosion process in rills and gullies the streampower concept can be used in the transport function based on the slope and the discharge per unit width of the rill, and/or with addition of a rainfall intensity parameter. Laboratory rainfall simulation tests were performed on a large number of inclined soil pans packed with sandy, loamy and silty soils of loess origin and subject to different rainfall intensities. This resulted in several hundreds of observations of discharge (runoff) and soil loss in the runoff water. It was found that the streampower ω (g s^{-3}) was the best predictor of the unit sediment load q_s (g s^{-1} cm^{-1}). A power function fitted the data best. The relationship was also function of the clay content. The higher the clay content, the lower the unit sediment load.

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Keywords. streampower, sediment transport, rainfall simulation, loess soils, overland flow.

El concepto streampower para evaluar la concentración de sedimentos y el escurrimiento bajo lluvia simulada

Resumen: La investigación sobre erosión y flujo superficial se centra en un umbral de desprendimiento y ecuación de transporte en que los parámetros más determinantes son: el momento crítico de flujo, la velocidad media de escorrentía, la unidad de la energía de flujo o de la resistencia al corte crítico. Sin embargo, los parámetros como el momento crítico de flujo y la resistencia al esfuerzo cortante crítico son difíciles de medir y las buenas relaciones con los parámetros físicos del suelo son escasas. Además, se demuestra que la ecuación de Manning no es adecuada para calcular la velocidad de flujo superficial durante el proceso de erosión laminar. Por lo tanto, se prefiere aplicar relaciones usando las descargas (cantidad de escorrentía) medidas en la salida del flujo (o surco), en lugar de los parámetros de velocidad.

Para el proceso de erosión en surcos y cárcavas el concepto streampower se puede utilizar en la función de transporte con base en la pendiente y la descarga por unidad de anchura del surco, y / o con adición de un parámetro de intensidad de la lluvia.

Pruebas de simulación de lluvia en laboratorio se realizaron en un gran número de suelos en bandejas inclinadas llenas de suelos arenosos, francos, limosos de origen de loess y sometidos a diferentes intensidades de lluvia. Esto dio lugar a varios cientos de observaciones de descarga (escorrentía) y pérdida de suelo en el agua de escorrentía. Se encontró que el streampower ω (g s^{-3}) es el mejor predictor de la unidad de carga de sedimentos q_s (g s^{-1} cm^{-1}). Los datos se ajustaron a una función potencial. La relación estuvo también en función del contenido de arcilla. Cuanto mayor sea el contenido de arcilla, menor será la carga de sedimentos unidad.

Palabras clave: streampower, transporte de sedimentos, simulación de lluvia, suelos de loess, flujo superficial

Introduction

Numerous experiments have been carried out on laboratory and on field plot scale to assess the different sub-processes and factors involved with soil erosion. In view of this, some assumptions are made that experimentally obtained equations and/or relationships can be used to simulate the complex erosion process at the hillslope and/or (micro) watershed level.

Erosion occurs when the erosive forces, represented by the momentum flux of the raindrop impact and the momentum flux of the overland flow,

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exceed the cohesive forces between the soil particles and the downward component of the turbulent overland flow. Under field conditions the sediment transport is limited by the transport capacity of the flow. The factors which influence the transport capacity are the settling velocity of the soil particles and the vertical component of the turbulent overland flow. On very cohesive surfaces, sediment transport is also limited by the erodibility of the substrate. Fox and Bryan [1] found that the interrill process is detachment-limited, since soil losses are decreasing after having obtained an initial peak even though the runoff rate and subsequently its transport capacity is increasing. The factors controlling the detachment processes are the shear forces induced by the surface runoff and the raindrop impact, and the reciprocal shear forces due to the cohesion of the soil particles and gravity. Given the fundamental principle that rainfall erosion occurs when the acting forces (raindrop impact and runoff) exceed the cohesion of the soil particles and the fact that different soil types erode at different rates, many authors searched for threshold driven detachment and transport equations. The most determining parameters in the equations are: the critical momentum flux [2], the mean runoff velocity, the unit stream power [3, 4, 5,] or the critical shear strength [6, 7]. However, parameters such as critical momentum flux and critical shear strength are difficult to measure [8] and good relationships with the measured soil physical properties are lacking. This imposes problems when applying the detachment and transport equations in erosion modeling studies on a regional scale. Even though most velocity measurements are carried out using the same colored dye method, large variations are observed in the conversion factors used. Values from 0.7 and 0.8 [9] to 0.36 [1] have been used in literature and because this factor is not standardized and comparisons cannot be made easily. Fox and Bryan [1] also indicated that the Manning equation is not suitable to calculate the velocity of overland flow during the interrill erosion process. Therefore it is better to apply relationships using the discharge instead of the velocity parameter. Since discharges are easily measured at stream outlets, this parameter can also be used to perform inverse modeling and calibration, increasing the accuracy of the erosion model equipped with such equations.

For the erosion process in rills and gullies, Nearing et al. [6] reported a simple but very accurate transport function using the stream power (ω) concept

$$\omega = \rho \, g \, S \, q \tag{1}$$

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Where ρ is the density of the water (g cm^{-3}), g the gravitational constant (cm s^{-2}), S the slope (m m^{-1}) and q the discharge per unit width (cm^2 s^{-1}).

Based on laboratory V-shaped flume experiments, using silt loam and sandy loam soils, these researchers found a single logistic relationship between the unit sediment load (q_s) and the stream power of the overland flow.

$$\log_{10}(q_s) = a + b \quad \frac{e^{c + d \log_{10}(\omega)}}{1 + e^{c + d \log_{10}(\omega)}} \tag{2}$$

with a=-34.47, b=38.61, c=0.845 and d=0.412

This kind of relationship between the unit sediment load and stream power was also found by Elliot and Laflen [10].

In our study, a sediment transport model is developed based on small scale laboratory rainfall simulations for the sheet erosion process in which the sediment is delivered towards a rilling system in an agricultural field. The objective of this study is therefore to find a relationship between runoff discharge and sediment concentration under interrill conditions.

Materials and methods

Since the early 1970's laboratory rainfall simulations were carried out at the International Center for Eremology, Department of Soil Management, Ghent University, Belgium, to assess the parameter values of the USLE [11] topographic factor, the soil erodibility and to evaluate the effect of chemical soil conditioners on aggregate stability and on soil susceptibility to runoff and erosion. This resulted in 133 experiments carried out between 1973 and 1998 by Pauwels [12], Gabriels [13], Verdegem [14], De Beus [15], Goossens [16] and Gabriels et al. [17]. All these experiments were done on sandy, loamy and silty soils, mainly of loess origin. Biesemans [18] carried out 7 additional rainfall simulator experiments on an alluvial clay soil (42% clay).

All laboratory experiments were performed on a smoothed (aggregate fractioned) soil surface to avoid possible rill formation and to ensure a broad sheet flow during the simulated rain. The intensities of the simulated rain were held constant during the experiments and ranged from 20 to 128 mm h^{-1}. The width of the soil pan was 20 to 30 cm and the length was 30 to 90 cm.

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The slope of the soil pan was set between 4% and 33%. The experiments lasted between 60 and 120 minutes, and the discharge Q together with the soil loss Qs was measured at 5 to 10 minutes intervals, depending on the intensity of the simulated rain. Having a broad sheet flow form during the rain simulations; the width of the flow equals the sample width and the volumetric water flux q per unit of surface width could be derived directly. This resulted in 672 observations of discharge (runoff) and soil loss (in the runoff water).

Results and discussion

The laboratory experiments resulted in unit discharges in the range 0.01 to 0.27 $cm^2\ s^{-1}$. It was found that the stream power ω (kg s^{-3}) was the best predictor of the unit sediment load q_s (kg $s^{-1}\ m^{-1}$).

If the measured unit sediment load q_s is log-log plotted against the stream power ω of the overland flow, a linear relationship can be identified in the data. A power function fitted the data best (Equation 3).

$$q_s = 0.00015\ \omega^{1.33} \qquad r^2 = 0.86 \qquad [3]$$

It can be seen that the unit sediment load is between 1 and 3 log cycles higher for the laboratory rainfall experiments than for the flume experiments of Nearing et al. [6].

Many other authors have posted that stream power (g s^{-3}) is the best predictor for soil detachment (D_c) and transport in either rills or by shallow flow. And hence the power function is most commonly applied. Zhang et al. [19] found values of 4.29 10^{-2} for a, and 1.62 for b as parameters for the power function between stream power and soil detachment by shallow flow. The set-up consisted of flume experiments with disturbed soil samples from a silt loam soil. A Pearson correlation coefficient (r^2) of 0.89 was observed.

This kind of relationship between stream power and the unit sediment load was also found by Zhang et al. [9] using an identical set-up with undisturbed soil samples. The reported parameter values are 8.8 10^{-3} for a, and 1.07 for b, with $r^2 = 0.95$, indicating that undisturbed soil is much more resistant to soil erosion than would be assumed using disturbed soil samples. Nevertheless, Schiettecatte et al. [19] observed similar erosion rates during high intensity laboratory rainfall simulations using disturbed and undis-

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turbed samples at the same time. This can be explained by the effect of the raindrop impact influencing both the detachment and the sediment transport process during interrill erosion [21]. Because sheet flow is broader (widespread) and more shallow than rill flow, the momentum of a raindrop impact can act directly upon the soil surface. Consequently, the raindrop impact can be considered as the most important soil detachment process in interrill areas. The rain drop impact is also responsible for the increase of sediment transport capacity, due to increased turbulence.

The relationship between the unit sediment load and the stream power is also function of the clay content (Fig. 1). The higher the clay content, the lower the unit sediment load. The parameters of the regression power equations, with the corresponding correlation coefficient are given in Table 1.

Remark that the exponents b of the regression equations are all (except one) around 1.3. The intercept of the regression equations is a measure of the erodibility of the soil. In general, the higher the clay content, the higher the cohesion and the lower the erodibility. In comparison with the values reported by Zhang et al. [9, 19], even lower intercepts are found.

Without the data set for the soil with 24% clay, the overall correlation increases significantly.

$$q_s = 0.000018\ \omega^{1.29} \qquad r^2 = 0.89 \qquad [6]$$

This relationship can be used to describe the erosion process in interrill areas.

Table 1. Parameters of power functions between stream power (g s^{-3}) and unit sediment load (g s^{-1} cm^{-1}) for laboratory rainfall simulations

% clay	a (10^{-4})	b	r^2
6.9	2.61	1.30	0.49
12.5	1.64	1.29	0.89
17.9	2.06	1.28	0.87
24.0	6.03	1.70	0.97
41.0	3.30	1.31	0.98

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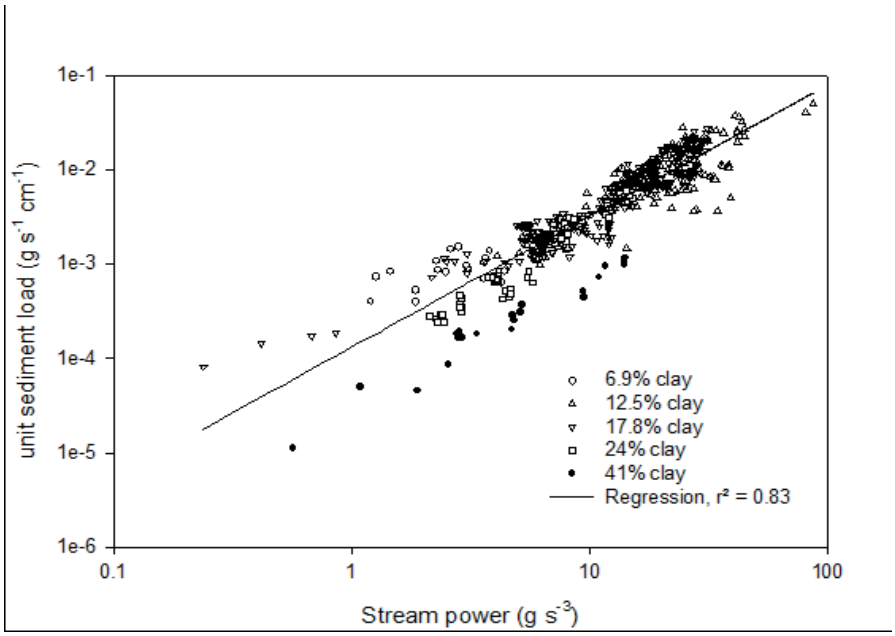

Figure 1. Relationship between stream power (g s^{-3}) and unit sediment load (g s^{-1} cm^{-1}) for soils with different clay content.

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Chapter 5

Conservation practices are essential land management strategies for climate change mitigation and adaptation

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Abstract. Recently, several scientific organizations have reported on the challenges that climate change will pose for food security in the 21st century. One organization that reported on this topic is the Soil and Water Conservation Society, which invited a group of scientists to review the science on climate change and conservation practices. Delgado et al. (2011) reviewed the potential impacts associated with climate change and its interactions with other environmental challenges such as desertification, deforestation, and the depletion of sources of irrigation water. This presentation will cover the Delgado et al. (2011) report, which concluded that without the implementation of conservation programs and/or conservation practices, the potential to achieve food security will significantly be reduced, since erosion rates are expected to increase as the climate changes, especially due to extreme weather events, and this higher erosion rate can significantly reduce soil productivity. The report shows that conservation practices will be key to land management strategies that will help us achieve maximum sustainable levels of food production. Without the implementation of these land management strategies, we will not achieve a sustainable food production system for the world's growing population. Without good conservation practices and policies, there will be negative effects on air, soil, and water quality; soil productivity; and efforts to achieve and/or maintain food security. Applying the principles for education, research, and conservation practices outlined in the Delgado et al. (2011) report will contribute to good land management strategies for climate change mitigation and adaptation by contributing to the conservation of air, soil, and water; positive impacts on the quality of natural resources; soil productivity; and efforts to achieve and/or maintain food security.

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This presentation will cover the Delgado et al. (2011) principles of using conservation practices as land management strategies for climate change mitigation and adaptation (http://www.jswconline.org/content/66/4/118A.full.pdf+html).

Climate Change and Adaptation

Climate change adaptation is an important topic that has been highlighted in recent reports from scientific societies and government agencies. For example, the USDA just released a report about climate change and adaptation that included several key messages (Walthall et al. 2012). The report assessed the degree of impact that climate change will have on major crops and livestock systems, and reported that during the next 25 years the effects will be mixed, but that in the long term (2050 and beyond) there will be overall detrimental effects to most systems. Getting ready to adapt to climate change will clearly require new tools.

Major challenges lie ahead of us that will impact soil productivity, and we will need to develop adaptive practices that take into account: i) climate change; ii) extreme weather events; iii) population growth; iv) depletion of some water resources; v) other environmental challenges such as deforestation, erosion, and crop disease outbreaks; and vi) how these challenges interact with each other. These challenges highlight the need for adaptation, and soil and water conservation will be at the center of adaptation efforts.

One key component of climate change adaptation will be the use of conservation practices, which are essential land management strategies. The Soil and Water Conservation Society (SWCS) invited Delgado et al. (2011) to conduct a review of the science of conservation practices and climate change. Delgado et al. (2011) concluded that as time goes on, the impact of climate change and other challenges will generate tremendous pressure to achieve and/or maintain food security. Implementation of good policies and/or practices for climate change mitigation and adaptation will be critical for the potential to increase productivity and food security; without good policies and/or practices, there will be negative impacts on soil, water, and air quality, diminishing the potential to achieve and/or maintain food security (Figure 1).

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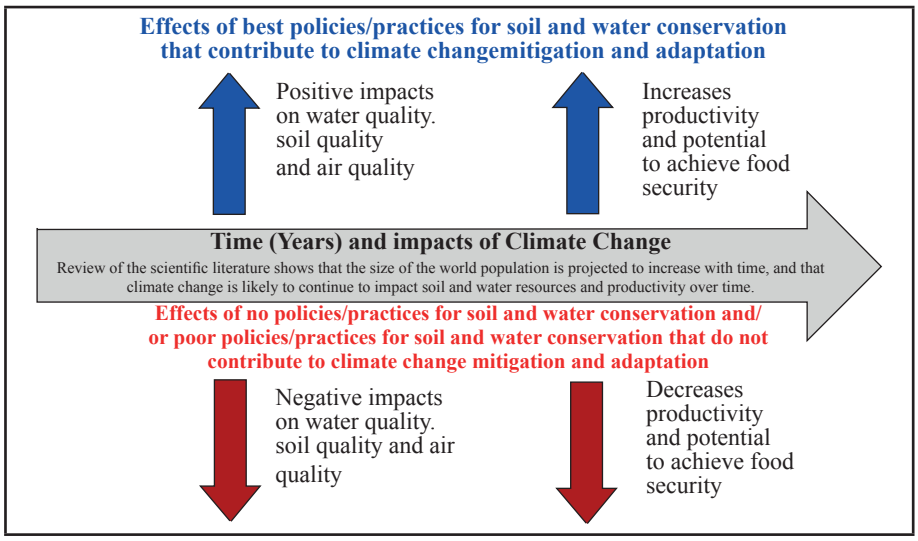

Figure 1. There is a dose relationship between climate change, limited global water and soil resources population growth and food security. As climate change impacts the world's soil and water resources, it threatens to negatively impact food production (i.e., decrease food production and/or food production potential). As the climate changes, conservation practices have the potential to help us achieve maximum sustainable levels of food production, which will be essential to efforts to feed the world's growing population. Good policies/practices for soil and water conservation will contribute to positive impacts on soil and water quality, soil productivity, and efforts towards achieving and/or maintaining food security. These good policies/practices will contribute to climate change mitigation and adaptation. Poor policies/practices for soil and water conservation (or a lack of policies/ practices) will contribute to negative impacts on soil and water quality, soil productivity, and efforts toward achieving and/or maintaining food security (From Delgado et al. 2011- Journal of Soil and Water Conservation).

Potential Negative Impacts from Climate Change

With climate change comes great challenges associated with soil productivity due to the increased potential for erosion, and conservation practices are the main mechanism for efforts to adapt to climate change and address the negative effects of erosion (Delgado et al. 2011, 2013). It has been reported that climate change is increasing and/or will increase the potential for soil erosion due to increased precipitation and extreme events (Groisman et al., 2005), and this was discussed in detail by Delgado et al. (2011; 2013). Pruski and Nearing (2002) reported that for every one percent increase in precipitation, an average increase of 1.7% in the erosion rate for cropland in the U.S.

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could be expected. This will have significant negative effects on productivity, since it is well established that with higher erosion rates soil productivity is reduced (Bakker et al. 2004). Bakker et al. (2004) reported that on average, a realistic number would be a productivity loss of 4% per every loss of 10 cm of top soil due to erosion. However, it is important to note that the relationship between soil erosion and productivity is not always linear, and so the loss of the next 10 cm of soils could potentially result in a much higher loss of productivity. Delgado et al. (2013) reviewed the data presented by Bakker et al. (2004) and found that over half of the studies showed a loss of 20% of productivity independent of the amount of soil lost, showing that erosion is a global threat to food security, and a problem that could be exacerbated in the face of a changing climate (Delgado et al. 2013). Conservation practices can help minimize the negative effects of climate change (Delgado et al. 2011). Delgado et al. (2011) reviewed the literature on conservation practices and climate change, and outlined some key principles related to climate change mitigation and adaptation. The SWCS consulted the Delgado et al. (2011) review of literature as a scientific reference and developed a position statement on conservation and climate change (see SWCS press release:

http://www.swcs.org/documents/filelibrary/climate/SWCS_Climate_Press_Release_C7A5421A213D7.pdf).

Principles Needed for Adaptation

Delgado et al. (2011) proposed some key principles regarding climate change mitigation and adaptation. The principles were established in three areas: *I*) communication; *II*) soil and water conservation practices; and *III*) new science and technologies. The principles for communication reported by Delgado et al. (2011) were: *i*) Develop Communication that Connects Science to Land Managers; *ii*) Develop Communication that Connects Science to the Public; *iii*) Teach the Value of Soil Carbon; *iv*) Embrace Technology; *v*) Improve Historical Context; *vi*) Ongoing Training Essential; and *vii*) Enhance Exchange. Principles *i* and *ii* underline the importance of communication between the scientific community, farmers and farmers' groups, and the general public. Communication is essential so that stakeholders understand the importance of conservation programs and policies in achieving and/or maintaining food security in the 21st century. The quick exchange of information (e.g., information on best management practices, weather patterns,

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and new technologies) is important for effective adaptation. Simply put, if climate change adaptation efforts are to be successful, communication will need to have a key part in these efforts. Principle *iii* is important because the public not only needs to understand the importance of removing atmospheric carbon by the process of carbon sequestration in soils, but that this process is beneficial to the environment, and that it contributes to soil and water quality, even reducing the potential for erosion when combined with the use of minimum tillage and keeping the surface covered. We need to teach the value of soil carbon early on, at K-12 level, and also ensure that the general public (conservationists, farmers, policy advisors, university students, etc.) understand its value as well. Communication principles *iv* and *v* stress the role that technology and databases will need to have in climate change adaptation. Databases from studies on various conservation practices will be needed to determine the potential response options in the face of more extreme weather events and a changing climate, so that resilient systems can be developed. Communication principle *vi* is related to the importance of developing and maintaining a workforce trained in the most advanced technologies with the areas of expertise needed to implement conservation practices for adaptation. Such a workforce will need ongoing training and continuing education, so there will be a need to attend trainings and scientific society meetings to maintain continued exchange of information on the most recent advances in the science of conservation at a national and international level (principle *vii*).

Delgado et al. (2011) also reported on a second set of principles important for climate change adaptation in the area of conservation practices. These basic principles included: *i*) Surface Residue Protects; *ii*) Soil Function Improves with Soil Carbon; *iii*) Cover the Surface; *iv*) Value Perennial Crops; *v*) Embrace Technology; *vi*) Off-Field Remediation Practices Are Helpful; *vii*) Improve Landscape Diversity with Agroforestry; *viii*) Synergism Achieved through Multiple Conservation Practices; *ix*) Build on Within-Field Tried and True Practices; *x*) Effectiveness Enhanced with Landscape-Targeting Precision Conservation; *xi*) Promote Energy Efficiency; *xii*) Value Water More; *xiii*) Greater Diversity Needed; *xiv*) Minimize Gas Losses; and *xv*) "Tighter" Nutrient Cycles. Principles *i* and *iii* are important since they emphasize the need to cover the soil surface, reducing the impact of greater erosion from wind and water due to climate change. Principle *ii* is about the importance of soil carbon and soil carbon sequestration. Principles *xiv* and *xv* are about exist-

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ing practices for soil and water conservation, and the importance of reducing emissions of trace gases such as N_2O and CH_4, which will also help conserve water quality (e.g., decrease losses of reactive nitrogen), respectively. Principles *v* and *x* are related to the use of new technologies that have the potential to help us increase conservation efficiency by accounting for temporal and spatial variability, helping us placing the conservation practices in the right place at the right time, and contributing to climate change adaptation efforts. Principles *iv, vi*, *vii,* and *xiii* are related to the use of perennial crops such as grasses used for biofuels, off-site practices, agroforestry, and the use of new crop rotations and/or new varieties that are more resistant to drought or flooding. Growing seasons for cropping systems may have to be adjusted and planting may have to occur earlier or later, depending on the local and regional impacts of climate change, and these key principles bring opportunities for farmers to adapt and establish buffers or other conservation practices off site to help reduce off-site of transport of nutrients, and potentially gain additional income (Table 1). Principles *viii* and *ix* are related to how the synergistic effects of implementation of multiple conservation practices can increase the potential for adaptation, especially if the practices are implemented within the cropping systems. Principles *xi* and *xii* are about the importance of energy and water efficiency.

Another key principle for climate change adaptation is Research Pays Dividends Long Term (Delgado et al. 2011). Research activities will significantly contribute to the development of cropping systems that will help us mitigate/adapt to climate change and increase the potential to achieve and/or maintain food security in the 21st century. Research and conservation practices and policies are related to national and global security, and long-term research programs will be important in climate change adaptation (Delgado 2010; Delgado et al., 2011; 2013). All these key principles for using conservation practices for climate change adaptation proposed by Delgado et al. (2011) are in agreement with the principles of conservation agriculture, which include minimal disturbance of soils, providing continuous plant residue cover, and using diverse rotations and/or cover crops (FAO 2009). For additional details on examples of conservation practices that contribute to climate change adaptation, see Table 1.

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Table 1. The majority of this table is adapted from Eagle et al. (2010). Other results from Adler et al. (2007) life cycle analysis of bioenergy systems, and from a matrix of conservation practices developed by USDA NRCS, West Technology Center were also incorporated, as well as additional comments from the authors of this document. The effect[¥¶§] of management practices on soil carbon sequestration (CS); the net flux of nitrous oxide and methane greenhouse gas (GHG) emissions; and on the change in upstream and process emissions (UPE, fuel, fertilizer, other) are estimated. All estimated values[¥¶] were expressed as equivalents of CO_2. A positive, high, and very high sequestration potential are represented by +, ++, and +++, respectively, while net equivalent emissions are represented by -. The net carbon sequestration impact (NCSI) is the sum of CS, GHG and UPE (From Delgado et al. 2011)

Management Practice[£]	CS	GHG	Additional Benefits to the Producer and Environment	UPE	NCSI
Agroforestry					
Windbreaks for crops and livestock	++	+	Improves crop and livestock protection and wildlife habitat. Provides alternative income source. Has potential to contribute to adaptation (e.g., minimize impacts of extreme wind storms).	+	+++
Silvopasture with rotational grazing	++	+	Provides annual income from grazing; long-term income from wood products. Has potential to contribute to adaptation (e.g., provide a viable income and serve as a tool against a changing climate).	+	++
Riparian forest buffer	++	+	Improves water quality and wildlife habitat. Provides alternative income source (specialty crops, hunting fees). Has potential to contribute to adaptation (e.g., potential to use targeted, strategically located riparian forests to reduce impacts of extreme events due to higher water flow).	+	+++
Livestock					
Organic soil amendments (especially manure)	+	+	Provides nutrients for crops; improves water quality when nutrient management plans are followed and manure is not over applied. Has potential to contribute to adaptation (e.g., potential to result in higher nutrient cycling capacity and soils with improved soil quality that may be able to adapt better and maintain productivity in a changing climate).	+	++
Rotational grazing	++	+	Reduces water requirements. Helps withstand drought. Increases long-term grassland productivity. Has potential to contribute to adaptation (e.g., potential to provide economic alternative due to higher-quality forage).	+	++
Improve grazing management rangeland	++	+	Potentially increases carbon sequestration on land, depending on previous crop(s) grown. Has potential to contribute to adaptation (e.g., potential to provide economic alternative due to improved grasslands and soils with improved soil quality that may be able to adapt better and maintain productivity in a changing climate).	NA	+

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Cropland					
Change from conventional to conservation tillage	+	+	Improves soil, water, and air quality. Reduces soil erosion and fuel use; saves expenses, time, and labor. Has potential to contribute to adaptation (e.g., potential to provide economic alternative due to savings in energy).	+	+
Change from conventional to no-till	+	-	Improves soil, water, and air quality. Reduces soil erosion and fuel use; saves expenses, time, and labor. Has potential to contribute to adaptation (e.g., potential to provide economic alternative due to savings in energy).	+	+
Improved irrigation management	+	+	Improves air quality, reduces water quantity usage. Has potential to contribute to adaptation, since saving water (reduced usage) will be crucial in the coming decades to deal with a changing climate in drier regions and to respond to droughts.	+	+
Crop diversity crop rotation	+	+	Reduces erosion and water requirements. Improves soil and water quality, reduces nitrogen and other fossil-fuel-intensive inputs. Has potential to contribute to adaptation (e.g., potential to provide economic alternative that may be able to adapt better and maintain productivity in a changing climate that could bring new pests and diseases due to warmer weather).	+	+
Crop conversion to pasture	++	+	Reduces erosion and increases carbon sequestration. Has potential to contribute to adaptation (e.g., potential to provide economic alternative that may be able to adapt better and maintain economic productivity in a changing climate).	+	+++
Effective nitrogen management (use of slow-release fertilizer, nitrification inhibitors, higher use efficiency, lower rates)	NA	+	Reducing losses of reactive nitrogen can contribute to improved water quality; saves expenses, time, and labor. Can reduce losses via ammonia volatilization.	+	+
Cover crops	+	+	Reduces erosion and contributes to soil and water quality. In some cases can contribute to increased economic returns from the following crop. Can be used as biocontrol and reduce chemical inputs. Has potential to contribute to adaptation (e.g., potential to provide economic alternative that may be able to improve yields of subsequent crops and help in weed and pest management).	+	+
Crop conversion to natural	++	+	Reduces erosion and contributes to soil and water quality.	+	+++
Improved grazing management	++	+	Reduces erosion and increases carbon sequestration.	NA	++

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Change from annual to perennial crop	++	+	Reduces erosion and contributes to soil and water quality.	+	++
Biochar application	++	+	Increases carbon sequestration.	+	+++
Wetland restoration	++	-	Wildlife and other ecological benefits derived from easement (water quality, flood retention). Has potential to contribute to adaptation (e.g., potential to use targeted, strategically located riparian forest that can be used to reduce impacts of extreme events due to higher water flow).	+	++
Change from annual to switchgrass bioenergy system	+	+	Can serve as a net sink for carbon sequestration across life cycle analysis. Has potential to contribute to adaptation (e.g., potential to provide economic alternative, with improved soil quality that may be able to adapt better and maintain productivity in a changing climate).	+	+
Change from annual to hybrid poplar bioenergy system	+	+	Can serve as a net sink for carbon sequestration across a life cycle analysis. Has potential to contribute to adaptation (e.g., potential to provide economic alternative, with improved soil quality that may be able to adapt better and maintain productivity in a changing climate).	+	+

¥ +, ++, and +++ indicates that the mean CO_2 sequestration is 0 to 2; > 2 to 4; and > 4 t $ha^{-1}y^{-1}$, respectively.

¶ - indicates that there are net emissions of CO_2 at a rate of 0 to 2 t $ha^{-1}y^{-1}$.

§ NA indicates that no data was available.

£ This table presents and compares select conservation practices. We acknowledge that many other conservation practices exist that are not covered in this table, which was presented to show examples of how conservation practices can contribute to climate change mitigation and adaptation.

Summary

A key message of the recent USDA report on adaptation was that by the middle of the 21st century, major livestock and crop systems will face great challenges related to productivity (Walthall et al. 2012). Conservation practices will be critical in order to maintain productivity (Delgado et al. 2011; 2013; Walthall et al. 2012). Serious challenges lie ahead such as climate change, population growth, and depletion of water resources, among others. Depletion of water resources is an important issue because irrigated systems have much higher yields than non-irrigated systems. With population growth, agricultural production will need to increase, and we cannot afford to lose produc-

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tivity from our agricultural systems. Delgado et al. (2011) reported that with conservation practices to mitigate and/or adapt to a changing climate, we will have a potential opportunity to protect our natural resources, protect soil, water, and air quality, and achieve and/or maintain food security (Figure 1). Another factor that we need to consider when implementing conservation practices and policies for climate change adaptation is the spatial variability in temperatures and precipitation; for example, in some regions such as the Pacific Northwest in the USA, it is expected to be wetter in the future, whereas the Southwest is expected to become drier (Delgado et al. 2011, 2013 Walthall et al. 2012). Precision conservation and other conservation practices could be used to manage this spatial variability (Delgado et al. 2011, 2013 Walthall et al. 2012).

We need to keep in mind that adaptation will be more complex in the future (Lal et al 2012; Walthall et al. 2012). This complexity needs to be considered when developing and implementing conservation practices and policies, and we need to account for regional variability to improve our potential for adaptation (Delgado et al. 2011, 2013; Lal et al. 2012; Walthall et al. 2012). Lal et al. (2012) reported that the drought of 2012 in the USA was a window providing a glimpse into the future challenges associated with climate change. Lal et al. (2012) reported that winter wheat under minimum tillage in Akron, Colorado resulted in much higher yields than winter wheat under conventional tillage, showing that conservation practices could potentially contribute to adaptation. However for corn, the 2012 drought had a catastrophic impact and the crop system did not produce any grain, showing that under extreme weather events, we may not be able to adapt, even with conservation practices. Climate change will present great challenges in the 21st century, and it is imperative that good soil and water conservation practices and policies be implemented to adapt to climate change and increase the potential for food security; without such practices and policies, we will not have the highly productive soils we need, and the survival of the human species will be at risk (Delgado et al. 2011, 2013; Walthall et al. 2012).

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Chapter 6

New method for quantifying hydraulic properties of shrinking soils

Uwe Schindler

Abstract. In general, soils and their pore size systems are assumed to be rigid during loss of water on drying. This is different from reality for many soils, especially for soils with high quantities of clay or organic matter. As the result of shrinking, the bulk density, the porosity and the pore size distribution of these soils change. The aim of this study was to develop a practicable method for determining the water retention curve and the unsaturated hydraulic conductivity function under consideration of shrinkage. The extended evaporation method (EEM) was combined with a circumference meter. Preliminary investigation confirmed the linear decrease of the sample diameter during evaporation from the bottom to the top. Concluding, recording the perimeter change during drying-out in the middle position of the sample together with the corresponding tension and water content were sufficient to determine (i) the increasing dry bulk density and (ii) the hydraulic functions under consideration of shrinkage in the range between saturation and close to the permanent wilting point. Measurements are presented for a clay loam sample. The soil water retention function was clearly affected by the shrinkage process. The unsaturated hydraulic conductivity function, however, was only slightly influenced by shrinkage. Advantages of the presented method are: (i) the simultaneous determination of the water retention curve and the hydraulic conductivity function under consideration of shrinkage with high resolution over the whole range from wet to dry, (ii) the simple and robust handling of method and device (HYPROP®), (iii) the low measurement time between 3 and maximum 10 days, (iv) the functions are described over the whole tension range by many user-defined data points, (v) improved evaluation of soil water content measurement at shrinking soils and (vi) common data models can be fitted to the hydraulic data as well as to the shrinkage data.

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Keywords: Extended evaporation method/ HYPROP/ soil hydraulic properties/ water retention function/ unsaturated hydraulic conductivity/ shrinkage

Introduction

Numerous methods for determining volumetric shrinkage have been presented previously (Bronswijk 1988, Braudeau et al., 1999, Boivin et al., 2004, Boivin et al., 2006, Sander and Gerke, 2007, Gregory et al., 2010, Garnier et al., 1997, Garnier and Rieu, 1999, Reeve and Hall, 1978, Peng and Horn, 2005, Dörner et al., 2010). Direct measurement of the shrinkage volume was first applied on soil samples by Lauritzen and Stewart (1941). They coated soil samples with paraffin and measured the displacement of water according to Archimedes' principle. Reeve and Hall (1978) and Bronswijk (1988) used saran resin for coating the sample. Other authors measured the displacement of petroleum for small samples (Monnier et al., 1973). Tariq and Dumford (1993) enwrapped soil clods with a flexible rubber membrane. All these direct methods, however, only allow the volume to be measured at a single water content. Optical methods and triaxial measurements can be used to measure shrinkage dynamics of cylindrical soil samples, clods or aggregates (Garnier et al., 1997, Braudeau et al.,1999, Boivin et al., 2006, Sander and Gerke, 2007, Gregory et al., 2010, Seyfarth et al., 2012.

Currently, only a few methods enable the simultaneous determination of the shrinkage behaviour of soil samples in combination with the quantification of the corresponding soil hydraulic properties. Either the methods need proprietary software for data processing, the used equipment is expensive or the calculation of the hydraulic properties is executed by inverse modelling (Stewart et al., 2011). The objective of this study was to develop an alternative, simplified method for the simultaneous and automatic determination of the (i) shrinkage behaviour (ii) the water retention curve (pF) and (iii) the unsaturated hydraulic conductivity function (K). The measurement should be executed continually in the same sample and in the entire water content range between saturation and the permanent wilting point (pWP). The method should be easy to handle with results that are significant and good enough for soil water simulations and to improve the accuracy of soil water content measurements in the field.

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Material and Methods

Basic method and instrument. The extended evaporation method (EEM, Schindler et al., 2010a and Schindler et al., 2010b) and the HYPROP® (**HY**draulic **PROP**erty analyzer, UMS, 2012) provides measurements of the water retention curve and the hydraulic conductivity function in the tension range between saturation and close to the wilting point. For the measurements, undisturbed soil cores are taken in stainless steel cylinders ---- 8 cm in diameter and 5 cm in height. Tensions and sample mass are recorded at selected time intervals. Single points of the water retention curve are calculated on the basis of the water loss per volume of the sample at time ti and are related to the mean tension in the sample at this time. The unsaturated hydraulic conductivity (K) is calculated according to the Darcy-Buckingham law (Equation 1).

$$K(\Psi_{mean}) = \frac{\Delta m}{aA\,\Delta t i_m \rho} \qquad (1)$$

where: Ψ_{mean} is the mean tension over the upper tensiometer at position z_1 (3.75 cm above bottom) of the sample and the lower tensiometer at position z_2 (1.25 cm above bottom) geometric averaged over a time interval $Dt_j = t_{i+1} - t_i$, with i =1…n, j = 1…n-1; Dm is the sample mass difference in the time interval (assumed to be equal to the total evaporated water volume $DV_{H2O} = Dm/r$ of the whole sample in the interval); r is the density of water; a is the flux factor, in case of rigid soils is a = 2; A is the cross sectional area of the sample and i_m is the hydraulic gradient averaged over the time interval.

Model concept for quantifying of shrinkage. Soil samples in steel cylinders do not allow for observing geometrical changes. Therefore the cylinder was removed and the sample was coated with a rubber membrane. To do this, the sample was first saturated and afterwards air-dried for approximately 2 hours. The drying ---- was continued as long as the sample had shrunken only slightly (between 0.2% and 0.3 % by vol.), and could be easily removed from the cylinder. After coating, the sample was saturated again, connected with the HYPROP device and the soil hydraulic properties were determined as described above. The rubber membrane was made from a rubber glove (size 9), which was impermeable to water and vapor, simple to handle and economical.

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Preliminary investigations showed that shrinkage occurred linearly across the sample height (Schindler and Mueller, 2013). It was sufficient to measure the temporal change of the diameter or the circumference in the middle of the soil sample (2.5 cm below sample surface) for quantifying shrinkage dynamics. Measuring the sample circumference (c) instead of the diameter reduces uncertainties and increases the sensitivity at factor p (c= pd).

In case of isotropy, the change of the sample volume due to shrinkage can be calculated based on the perimeter change alone (Eq. 3, 4 and 5).

$$\Delta V_{s,i} = \frac{p}{4} d^2 h \Delta \frac{p}{4} d_{s,i}{}^2 h_{s,i} \quad \text{with} \tag{2}$$

$$d_{s,i} = \frac{c_{s,i}}{p} \quad \text{and} \tag{3}$$

$$h_{s,i} = d_{s,i} \frac{h_{s,i}}{d_{s,i}} \tag{4}$$

V_s is the shrunken volume at time t_i for i=1…n, c_s, d_s, h_s are the circumference, diameter and height of the shrunken sample at time t_i. In case of isotropic conditions the ratio $\frac{d_{s,i}}{h_{s,i}}$ is 1.6. For non-isotropic conditions, the ratio between h_s and d_s has to be adapted in Eq. 4. This should be done by measuring the sample diameter in the middle position and the height when the evaporation experiment is finished. Because of measurement uncertainties, this change should be done only in case when non-isotropy is clearly diagnosed.

Perimeter measurement.-For recording shrinkage dynamics, a circumference meter was constructed by the UMS GmbH Munich. The device consists of a thin, flexible, non-distensible cord connected to a spiral spring and a flexible bow with an affixed strain gauge. Circumference changes can be determined with an accuracy of 0.01mm.

Calculation of the soil hydraulic functions under consideration of shrinkage.- The total water loss during evaporation (presumption Dm/r = DV_{H2O}, Eq. 1) consists of two parts, (i) the change of water volume in the soil

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matrix ($DV_{H2O,m}$) and (ii) the volume change of the soil sample. In shrinking soils this part (ii) corresponds with the increase in soil density and the decrease in the sample volume (DV_s).

For calculating the hydraulic conductivity (Eq. 5), the flux factor a_s and the changing cross sectional area A_s are adapted to the changed geometry of the sample (Eq. 6 and 7).

$$K(\theta_{i,mean}) = \frac{\Delta m_i}{a_{s,i} A_{s.i} \Delta t_i i_{i,m} \rho} \quad with \tag{5}$$

$$a_{s,i} = \frac{2h_{s,i}}{h} \quad and \tag{6}$$

$$A_{s.i} = \frac{\pi}{4} d_{s.i}^{\ 2} \tag{7}$$

For calculating the soil water content in the time steps t_i, the changing sample volume (Eq. 2) or dry bulk density (dry soil mass per sample volume at time t_i), respectively was considered.

Results and Discussion

Figures and illustrations are presented for a clay loam (FAO, 2006) sample of the Seelow site (Oder Valley, Germany). The basic HYPROP measurements – tensions of the upper and lower tensiometer and sample mass – and the measurements extension using the air entry values of the tensiometer's ceramic (Schindler et al., 2010b) are illustrated in Fig.1 (left). Additionally the change of perimeter was recorded for quantifying of shrinkage (Fig. 1, right). At the upper tensiometer maximum tension of 1532 hPa was achieved. The tension recordings at the lower tensiometer end at 1088 hPa. The air entry and tension collapse at the upper tensiometer (8900 hPa) was achieved after 2.19 days and at the lower tensiometer (9000 hPa) after 4.03 days. Generally that is the end of the EEM measurement for quantifying soil hydraulic functions. The decrease of circumference during drying out was used for quantifying the sample volume alteration. However, if required the recording of sample mass and perimeter changes could be continued.

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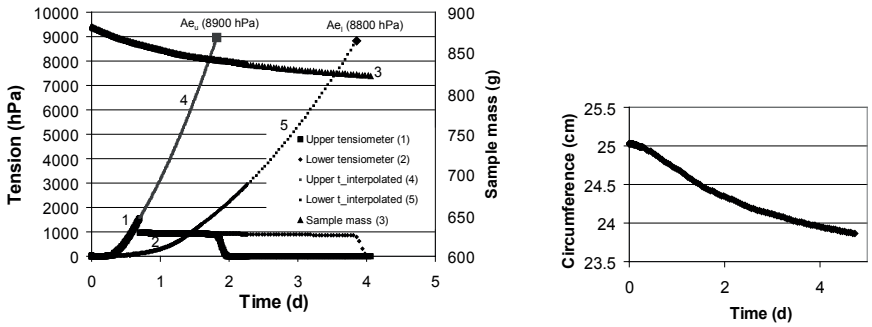

Figure 1. Basic HYPROP recordings with tension extension using the air entry value (Ae) of the tensiometer's ceramic cup (left) and perimeter dynamics (right).

Each line is described by more than 100 data points. Line 1 in Fig. 2 pictures the water retention curve when the soil is assumed to be rigid. This function is sufficient for soil water simulation as well as for calculating the amount of plant available water also in shrinking soils. Correct evaluations of soil water content measurements in the field for instance for the validation of soil water modeling results or for the calculation of soil water content differences, however, needs considering the shrinkage process. Soil shrinkage corresponds with the soil volume decrease (line 3) and the increase of bulk density (line 4), respectively. Data pairs of the shrinkage (line 3) were calculated from the saturated water content minus the shrinkage soil volume (V_s, acc. to Eq. 2). Taking the dry bulk density change into account gives line 2, the water retention function of the dynamic or shrunken soil, respectively. The dry bulk density was calculated based on the oven dry sample mass and the soil volume at the measurement times (initial sample volume minus shrunken soil volume V_s). The total water loss at the end of EEM measurements was 17.3 % by vol. (water content 27.6 % by vol. – line 1). The shrinkage volume was 22.0 cm^3 or 8.8 % by vol., respectively. Due to this fact, the dry bulk density increased from the start to the end of EEM recordings from 1.46 g cm^{-3} to 1.60 g cm^{-3}. Consequently, the volumetric water content in the soil matrix was 30.1 % by vol. instead of 27.6 % by vol. as calculated when the soil was assumed to be rigid. The van Genuchten Eq. (van Genuchten, 1980) could be easily fitted to the data (Schindler and Mueller, 2013). The effect of shrinkage on the unsaturated hydraulic conductivity was negligible small as can be recognized in Fig. 2, right. Only at the dry end the dynamic hydraulic conductivity values were

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slightly increased compared with the rigid ones. This statement was valid for all soils we have analyzed within this study.

The water retention curves (rigid and dynamic) together with the shrinkage volume and the increasing dry bulk density are illustrated in Fig. 2 (left) together with the unsaturated hydraulic conductivity (Fig. 2 (right).

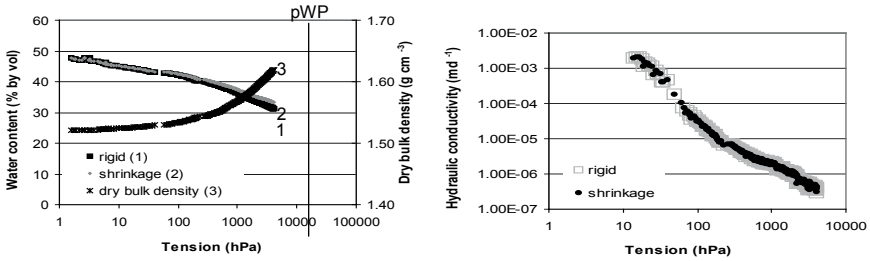

Figure 2. Water retention function of a clay loam sample of the Seelow site (Oder valley, Germany) under consideration of shrinkage, left and unsaturated hydraulic conductivity, right.

Conclusion

The extended evaporation method (EEM) and the HYPROP® device were combined with a soil sample circumference meter. Recording of the decreasing perimeter in the middle position of the soil sample (2.5 cm below sample surface) facilitates the simple determination of the soil hydraulic properties under consideration of shrinkage of the cylindrical soil samples. Soil hydraulic function can be determined in the range between saturation and close to the wilting point. On conclusion, sample mass and circumference recordings allow quantifying the shrinkage process in all distinct phases from the wet to the very dry end. The soil hydraulic and shrinkage functions, as well as the increase of dry bulk density as the result of shrinking, can be described with plenty user-defined data points in the whole range. Further advantages of this method are (i) the simple and robust handling of method and device, (ii) the low measurement time, (iii) common models can be fitted to the hydraulic data as well as to the shrinkage data.

The results agreed with findings by Dec et al., (2008) and Horn et al., (2013) that soil water content measurements at shrinking soils in the field can lead to an underestimation of soil water content differences in case of not considering the changing dry bulk density.

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However, the degree of misinterpretation depends strongly on the soil and its shrinkage activity. It ranged from negligible to strong.

Acknowledgement

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Chapter 7

Water flow evaluations in watersheds with native evergreen forests and eucalyptus plantations by means of stable isotopes in the south of Chile

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Abstract. The isotopic composition changes of water in a hydrological cycle derive from a recognized sign, related to the different cycle phases, which serve to characterize the different water sources that flow in a watershed. The identification of the mechanisms that influence runoff generation is necessary for a better understanding of the interaction among vegetation, soil and water. The objective of the current study is to evaluate the water sources that feed runoffs and the water used by the trees in watersheds with different vegetation covers. Water samples of precipitation, direct precipitation, water from the soil at 30,60, 90 and 120 cms depth, estuary and xylem samples from trees in six small watersheds with native evergreen forest cover and *Eucalyptus nitens* plantations, located in the South Coast mountain range of Chile (40° S). The water samples were analyzed to determine ^{2}H and ^{18}O. Soil infiltration and moisture measurements were also taken at different soil depths. Preliminary results of the isotopic composition of the estuaries, soil and water from the xylem of the trees show that during the summer season, the water consumed by the native evergreen trees and the *Eucalyptus nitens* plantation have different origins than the water that supplies the estuaries and the water available in the soil.

Keywords: stable isotopes, evergreen forest, *Eucalyptus* plantation.

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Introduction

The circulation of water in forest ecosystems, it is vital to understand the effects caused by the change in soil cover. The Stable isotopes $\delta^{18}O$ and $\delta^{2}H$ have been widely used for the study and monitoring of water in these complex ecosystems [3]. When evaporation occurs from the horizontal soil surfaces, water suffers heavy isotope enrichment. This way, each water sample can be characterized in each compartment (for example, soil water, ground water, estuaries, in trees) within the watershed.

Even though water movement in soils has been described using the concept "piston flow" [4]. This assumes that the filtered water in the soil, replacing and pushing the water to deeper layers. Eventually, this water will emerge through the estuaries. However, recently [1-2], it has been seen that two compartments of water contain different isotopic signatures, similar to those present in (i) the vegetation and (ii) the estuaries.

Previously, [2] using the content of $\delta^{2}H$ in the soil water, estuaries and xylem water indicated that the oldest trees use water from the deepest soil layers. It has been currently concluded that the complete mixture of water in the soil cannot be proposed in Mediterranean regimens as it has been in the past [1].

These precedents allow for questions such as: (i) what is the water source for estuaries in watersheds with different vegetation covers?; (ii) from what soil compartments are are the trees getting their water?.

We state that the native evergreen trees are consuming water from the superficial soil compartments; whereas the trees from the *Eucalyptus nitens* plantation are consuming water from much deeper soil layers,eventually groundwater, during the periods of dry season. Therefore, the main objective of this study is: clarify the origen of the water sources used by the native species *Laureliopsis philippiana*, *Aetoxicon punctatum* and *Eucriphya cordifolia* and the exotic species *E. nitens* in the soil at levels: superficial (0.3m depth), subsurface (0.6 m depth) and underground (1.2 m depth), and the water that supplies the estuaries in small watersheds.

Materials and Methods

Study Area: six watersheds were selected, all of similar size, altitude, geology, climate and soil characteristics, located along the mountain range

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of the south-central coast of Chile (40° S). The vegetation covers were: three with old evergreen forest cover and three with *Eucalyptus nitens* plantation cover. The climate is temperate and rainy with mediterranean influence and an annual precipitation of around 2300 mm. The soils are silty clay-loam with a higher amount of clay of around 45,1 – 37,2 % in the *Eucalyptus* plantation soil and a 31,1 – 37,3 % in the native forest. According to its chemical characteristics, the Ph in the native forest profile is of around 5,3 and 5,5 whereas in the plantation varies between 5,0 and 5,4. The organic matter content fluctuates between 14,5 and 17,8% in the native forest and between 1,8 and 17,1 in the *Eucalyptus* plantation.

In the evergreen forest, the individuals that show more frequency (tree/ha) are *Laureliopsis philippiana* with 718 trees/ha (watershed 1), *Drimys winteri* with 1567 trees/ha (watershed 2) and *Laureliopsis philippiana* with 1178 trees/ha (watershed 3). The greatest basal area is shown by the *Laureliopsis philippiana* with 37,2 and 38,1 m^2/ha in watersheds 1 and 2, respectively, and *Eucryphia cordifolia* with 113,9 m^2/ha in watershed 3. In the case of the *Eucalyptus nitens* plantation, the highest density is found in the diametric classes of 20.25 and 25-30 cm. The total density is of 2911, 2733 ad 2911 trees/ha in watersheds 1,2 and 3, respectively. The basal area corresponds to 131,9, 138,1 and 144,4 trees/ha in watersheds 1, 2 and 3, respectively. The average height of the trees is of 26,4, 24,2, and 23,4 m, in watersheds 1, 2 and 3, respectively.

Methods: Pluviographs were set up in a meadow near both study sites, to continuously register precipitations, as well as sequential water samplers. Direct precipitation water samplers were installed in the watersheds to collect water from within the forest and plantation every 5mm of precipitation fall during the precipitation events. For soil water collection, suction lysimeters were installed on three depth levels (0,3, 0,6 and 1m) and additionally two lysimeters to collect water from a 2m depth. Both watersheds have a 90° V-shaped rain gauge (one with forest and other with plantation) and were provided with automatic water sampler collectors (ISCO sampler) and continuous water level monitors (DIVER). Additionally, the two main watersheds (native forest and plantation) have been equipped with 9 soil moisture monitoring tubes (Profile Probe type PR2) and two continuous soil moisture registers (DECAGON Devices EM-50).

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For the collection of xylem water from the trees, billets were extracted from the main species of the evergreen native forest (*Laureliopsis philippiana*, *Aextoxicon punctatum* y *Eucryphia cordifolia*) and from *Eucalyptus nitens*. A vacuum distillation pump was built in the laboratory to extract water from the soil and plant material for stable isotope analysis [5]. The samples collected during the summer of 2013 were sent to the Laboratory of Applied Physical Chemistry at Ghent University (Belgium) and analyzed to determine δ^2H and $\delta^{18}O$, with a Wavelength-Scanned Cavity Ring-Down Spectroscope Analyzer (Picarro).

Results and Discussion

Preliminary results show that estuary water, under-canopy precipitation and soil water at 0.3, 0.6, and 1.2 depth are different and have a lighter isotope signal than the water being consumed by the trees during the summer period. In both watersheds, the water being used by trees, originates from a compartment that has been subject to evaporation, therefore "heavier" (Fig. 1).

The isotopic composition in the xylem water of the trees is different to that of the precipitation water and estuary water, but particularly to that of the soil water that evaporated from the precipitation before being used by the trees. On the other hand, the isotopic signal of the estuary water is different, when compared to the water used by the trees (evaporated water from the soil), but fairly close to the precipitation values.

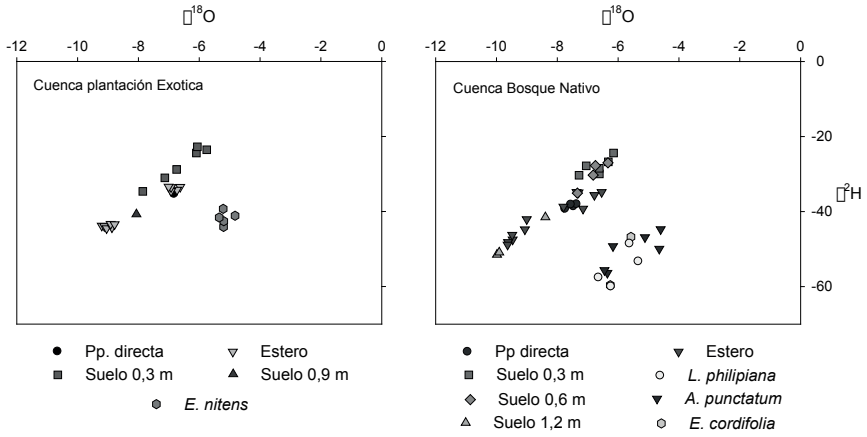

Figure 1. Isotopic composition of estuary water, under-canopy precipitation, available soil water at 30, 60 and 120 cm depths and xylme water from the native species (*L. philippiana*, *A. punctatum* and *E.cordifolia* and exotic *E. nitens)* during the summer of 2013.

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This behavior has been found by other authors [1-2-3], which concludes the existence of two distinct sources of water in the watersheds, a highly mobile source that originates from the precipitation that quickly filters through the highly porous and eventually contributes to the estuaries, and another source which is strongly trapped in the soil derived from the precipitation that is modified by evaporative processes and then used by plants. Based on this evidence, we expected the *Eucalyptus nitens* trees to use the "pool" water that supplies the estuaries or from much deeper sources. Nevertheless, this is not the case as both watersheds have similar behavioral patterns.

Conclusion

Preliminary results of the isotopic composition of the estuaries, soil and water from the xylem of the trees show that during the summer season, the water consumed by the native evergreen trees and the *Eucalyptus nitens* plantation have different origins than the water that supplies the estuaries and the water available in the soil. As suggested by literature, probably the water used by trees comes from the water strongly trapped in the soil profile and during this preliminary study has yet to be analyzed.

Acknowledgments

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Chapter 8

Natural resource conservation as a key element of land use planning

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Abstract. The increasingly intensive use of "highly productive lands" and the accelerating encroachment upon "marginal lands" to meet the ever-increasing needs of human populations have led to well-recognized global degradation of natural rand environmental resources. It is imperative, therefore, that land use policies and practices should realistically assure maintaining a balance between the ability to provide needed products and services, and the provisions necessary for ensuring land stability and sustainable management.

Fortunately, both the production and protection outcomes are determined by the very same fundamental factors, processes, and constraints. These include intrinsic site attributes (weather, topographic, and soil-based), and the consequences of selecting specific land use patterns and management practices. This commonality strongly argues for compatibility, rather than conflict, between production-driven and environmental objectives. Certain provisions are needed to implement this desired outcome, including:

- acquiring the necessary databases to allow systematic biophysical designs of resource management systems,
- maximizing the match between site attributes, planned land use, and selected

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management technologies,

- using realistic temporal (long term) and spatial (full landscape) scales to plan, implement and monitor land use systems,
- incorporating concepts and lessons learned from stable natural systems,
- utilizing emerging technological innovations in crop and soil improvement and post harvest processing, and
- easing the barriers to long term research for building meaningful databases and developing validated predictive models and decision-aid tools to minimize random errors toward meeting the desired goals.

These and other criteria can be used in multiobjective analyses to assist in defining a constructive path for decision making toward both productive and sustainable land-use and management.

Introduction

A very timely question facing policy and decision makers at every level is: "Can agriculture continue to cope with the expanding demand for food, fodder, fuel and fiber by the earth's ever increasing populations? The answer lies in the rigor of land use planning and implementation actions. Although human-managed agricultural enterprises have had a commendable historic track record for addressing the food needs of global populations, technological successes that provided farmers with "improved" production practices and profitable outcomes were often short lived or accompanied by long term instability and degradation of lands and subsequent declines in environmental quality. Deliberate provisions for protecting the natural resource base via protective or conservation practices are proving to be of ever-increasing importance. The criterion of ample farm output alone is not acceptable for assuring the welfare of future generations. Successful land use in the long term requires plans that incorporate physical, biological, ecological, economic, social, and/or political sustainability determinants.

Model for Reconciling Production and Sustainability Goals

Evidence shows that resource degradation is a major concern in both small and large enterprises, as well as for developing and developed countries. Much of the degradation and associated enterprise failures are predictable, and are often triggered by large mismatches between the site's attributes and

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applied land use and management. "Correcting" such mismatches to meet optimistic production goals or to restore the land's productive capacity is often expensive and unsustainable. In this paper, we will address obstacles to achieving sustainability goals and suggest management strategies that facilitate achieving them through holistic planning and enhanced harmony between opposing land use consequences. Our suggested model is based on the hypothesis that productive and environmental goals of land use are reconcilable, if steps are followed to provide maximum matching between site attributes and applied land use. The model also advocates recognizing and arresting or reversing the causes of agricultural "un-sustainability" at an early stage through monitoring and iterative improvements in resource management and conservation. It is briefly illustrated in Chart 1.

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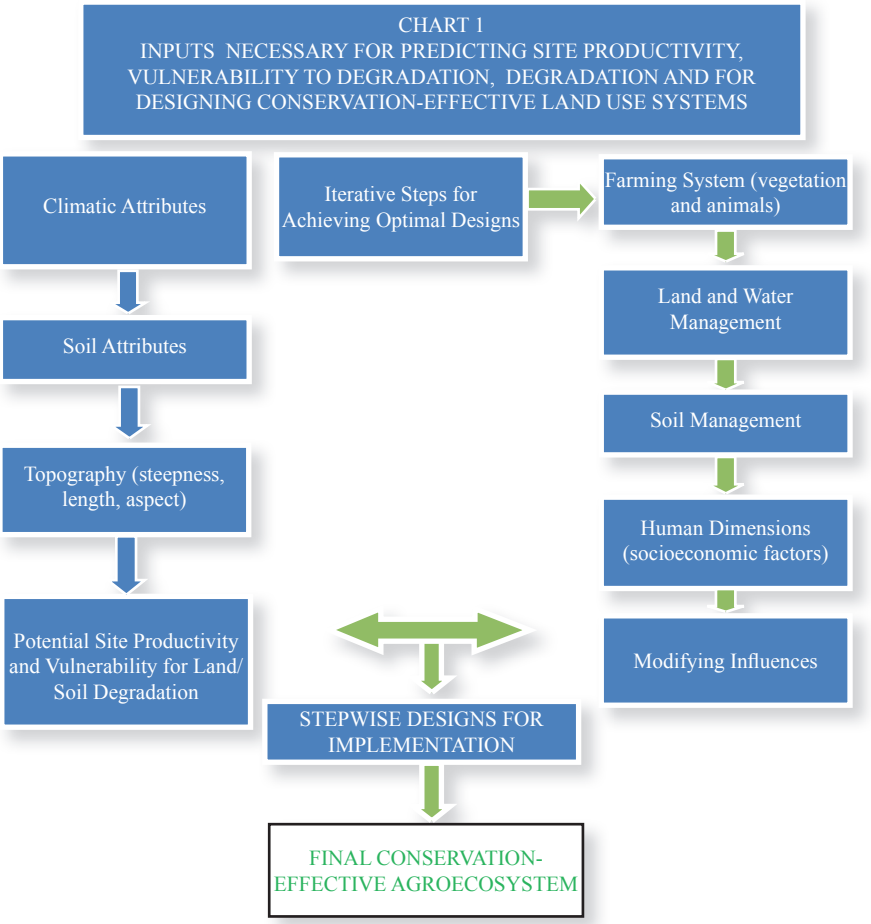

This chart represents a watershed-based ecosystem showing that a site's *potentials* for being *productive* or *degradable* are determined by the very same intrinsic attributes shown on the left-hand side (LHS). This recognition is fundamental to the selection of appropriate land uses (e.g. intensive or extensive farming, forestry, rangeland, grazing pastures, etc) as well as the best complementary management and conservation practices (on the right-hand side, RHS). Skillful integration and matching of the LHS with the RHS is the key to sustainable land use.

Roles of Intrinsic Natural Resource Attributes (LHS)

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The *quality* of a given site for useful and sustainable utilization may be *broadly* defined as its capability for productive use as well as its inherent capacity for resisting degradation. Both of these components are collectively determined by a host of intrinsic attributes that favor, limit, or completely inhibit agricultural activity. Basic attributes include weather, pedologic, and topographic/geomorphologic characteristics and so are not normally amenable to change by human manipulation. The next paragraphs present a brief discussion of each.

Macro and micro *Climatic* characteristics, on one hand clearly determine the adequacy of a site for productive and economically profitable uses, primarily by providing sufficient rainfall, solar radiation and thermal regimes that favor and promote plant growth. On the other hand, these very characteristics also determine the site's vulnerability to degradation by highly erosive rainfall, runoff, wind and/or not favoring sufficiently protective vegetation.

Macro and micro *soil* properties are crucial for supporting plant growth physically, chemically/nutritionally and biologically, and also determine its susceptibility to degradation (e.g. erodibility level). Broadly defined; the attributes that comprise soil quality include its:

- inherent productivity, i.e. ability to support optimum plant growth
- contribution to the quality of grown products,
- hydrologic partitioning function that promote adequate water storage and drainage,
- resistance and resilience against degradation,
- genetic pool content, especially of beneficial or harmful organisms
- ability to act as a sequestering medium and to regulate water and air quality.

Table 1 shows the key roles that the soil resource base play in controlling ecosystem functions.

Topography is a particularly critical determinant of site quality, especially as encroachment increases on steep hill and mountain lands. Slope characteristics, i.e. steepness, length and aspect, may favor or restrict land use; as they determine accessibility to target locations; trafficability to farm implements; sta-

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bility against surface erosion and mass movement, potential runoff and flooding; and exposure to weather influences such as rain, wind and solar radiation.

These intrinsic properties interact and together determine the site's overall potential for viable agricultural use and also its vulnerability to degradation processes. Capability classifications abound to assist decision makers in land use planning at regional and national levels (e.g. http://soils.usda.gov/technical/handbook/contents/part622.html).

Role of Decision Making in Selecting Land Use Patterns and Practices (RHS)

Assessment of the site's productivity potential and vulnerability to degradation is the first logical step in guiding land use choices and decision making. Unfortunately, production potential declines and the degradation hazard accelerates as human encroachment on marginal lands increases due to the scarcity of high quality lands. Statistics show that less than a quarter of the global land area is considered potentially productive, with only 9% possessing high or medium productivity (Buringh, 1982 and El-Swaify, 1991). It is safe to assume that all this area is now fully "developed" and that most remaining undeveloped lands are quite marginal, presently in grasslands or forests, and ideally should not be used for intensive development.

These facts present a special challenge to land use planners and decision makers. Table 2 shows an example of how selected land uses can profoundly affect soil erosion on such lands. Mimicking natural systems is a good rule of thumb! When deliberate matching of land characteristics with a realistic use is not done and intensive cultivation is implemented (even by necessity) on these degradation vulnerable lands; applying the RHS of our model judiciously becomes highly compelling.

Table 1. How Soil Attributes Influence Overall Ecosystem Functions

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Soil Quality Attributes	Relevance to Soil Performance and Contribution to Ecosystem Function*							
	Overall Productivity	Product Quality	Degradation Resistance/ Resilience	Genetic pool	Biogeo-chemical function	Hydrologic partitioning	Buffering/filtering for regulating water and air quality	Sink/ sequestering medium
Physical								
Soil depth and profile horizonation	xxxx	xx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
Water infiltration, storage, and availability	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
Erodibility	x		xxxx	xx	x	xxxx	xxxx	xxxx
Structural integrity, porosity,	xxxx	xx	xxxx	xx	xxxx	xxxx	xxxx	xxxx
compaction & bulk density	xxx	x	xx	xx		xx	xx	xxxx
Strength	xxx	x	xxxx	xxx	xxx	xxxx	xxxx	
Surface sealing and crusting	xxx	xx	xxxx	xxxx	xxxx	xxxx	xxxx	xxx
Aeration								
Chemical								
Nutrient storage & availability	xxxx	xxxx	xxx	xxxx	xxxx	x	xxxx	xxxx
Acidity and toxicity	xxxx	xxxx	xxxx	xxx	xx	x	xx	xxxx
Salinity/sodicity	xxx	xx	xxx	xxx	xxx	xxx	xxxx	xxxx
Mineralogy	xx	x	xxx	xx	xxxx	xxxx	xxxx	xxxx
Redox status	xx	x	xxx	xxxx	xxxx	xx	xxxx	xxxx
Biological								
Diversity of soil communities	xxx	x	xxx	xxxx	xxxx	xxxx	xx	xxxx
Microbial biomass	xx	x	xx	xxxx	xxxx		xx	xxxx
Organic carbon	xxxx	xx	xxxx	xxxx	xxxx		xxxx	xxxx
Beneficial micro-organisms	xxxx	xxxx	xx	xxxx	xx			xxxx
Beneficial macro-organisms	xx	xx	xx	xxxx	xx			xxxx
Pathogens	xxxx		xx	xxxx	xx			

* The relevance is judged on a relative scale with a minimum of 0 (left blank) and a maximum of xxxx

Although the data in Table 2 are quite broad, it is evident that applied management practices assume greater priority if marginal lands, such as those in natural forest are opened for intensive development. Selecting effective conservation practices will protect such fragile lands against irreversible degradation.

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Of course, preserving the quality of highly productive lands, already cultivated, is most important to ensure no further exacerbation of food scarcity problems.

Table 2. Estimated quantitative effects of land use conversion on surface erosion

Initial status	Type of disturbance	Magnitude of impact by specific disturbance
Forestland	Planting row crops	100-1,000
Grassland	Planting row crops	20-100
Forestland	Building logging roads	220
Forestland	Woodcutting and skidding	1.6
Forestland	Fire	7-1,500
Forestland	Mining	1,000
Row crops	Construction	10
Pastureland	Construction	200
Forestland	Construction	2,000

Source: Modified from McElroy, 1976 cited by El-Swaify, 1991.

Rangelands and pastures present a special challenges in this context. Overgrazing of such lands has resulted in well documented severe land degradation, especially in semiarid and arid regions. Dregne (1993, cited by El-Swaify, 1994) stated that desertification has degraded 3.3 billion hectares of global rangeland. Reasons for excessive damages inflicted upon grazed lands include:

- Overstocking with grazing animals,
- Replacement of native perennial grasses with others incapable of maintaining protective soil cover year around, followed by infestation with "weedy" and non-protective vegetation,
- Trampling by dense animal populations and subsequent soil compaction, surface sealing, and reduced infiltration or soil storage of rainwater,
- Increased water and soil losses as runoff and erosion,
- Excessive exploitation of groundwater to meet the consumption needs of large animal stocks, and
- Reduced organic matter and biological activity in the rhizosphere

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Additional Principles for Conserving the Natural Resource Base

Whether or not the site is highly fragile; predicting, recognizing and monitoring specific degradation events are essential follow-up steps before and during project implementation. For an overall ecosystem, degradation of the resource base affects ecosystem physical and biological features and components. Damages are typically manifested at watershed scale and trigger unwanted changes in land, water and atmospheric resources. Soil degradation lies at the core of ecosystem degradation because of soil's role as a buffer, filter, and sequestering medium. Soil changes are always associated with the wider ecosystem responses shown in Table 1.

A semi-quantitative picture on the extent of human-induced soil degradation was published in a generalized report titled "Global Assessment of Land Degradation" or "GLASOD" (ISRIC/UNEP 1991). It categorized the various degradation classes by severity and provided a geographic breakdown by continent (Figure 1).

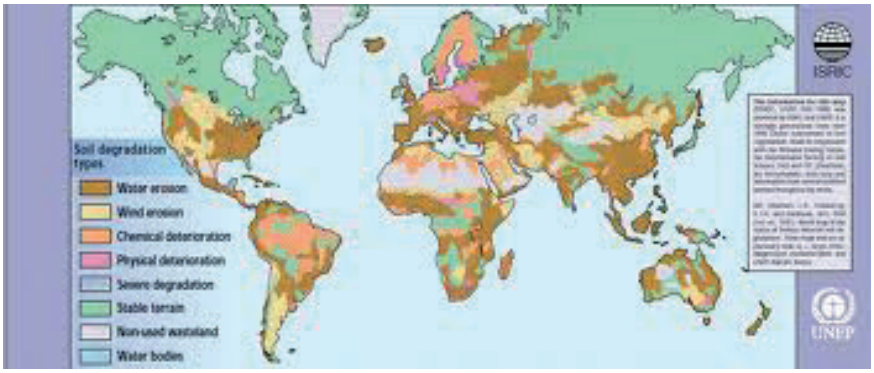

Figure 1. GLASOD Snapshot Map, 1991

Aside from the map's assessed categories, certain human activities (such as deforestation or introduced irrigation) are prone to bringing about degradation if practiced without the necessary conservation provisions. Also, the "depletion" of key renewable or non-renewable natural, resources is often a critical sustainability constraint. Examples include the declining availability and quality of water resources, increasing scarcity of affordable sources of energy, insufficient soil enriching organic material, and dwindling biological diversity. Historically, irrigation has been responsible for abundant and secure

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crop production under the "Green Revolution". Shortages of water available for irrigation have been further exacerbated by degradation in the quality of many water supplies (Postel, 1989). The decline in irrigation development requires that stronger emphasis be placed on sustainable land use in rainfed areas (El-Swaify, 1988).

Excessive exploitation and alteration of natural ecosystems, including sensitive tropical rain-forests is seriously impacting global biological diversity. Lack of diversity impacts agroecosystems by disturbing ecological balance and limiting the natural stocks available for genetic improvements of crops to better resist pest infestations, to gain the resilience and tolerance necessary to cope with environmental stresses, and reduce dependency on high external and management inputs.

The causes and potential for occurrence of most forms of degradation in different environments are well understood and largely predictable. So are their impacts on productivity and environmental quality. These include soil erosion and salinization. For other forms, such as structural breakdown, surface sealing and crusting, compaction, and restricted aeration, quantitative information on extent and impacts, and remediation management options may be scarce or lacking altogether. For still other forms, such as excessive exhaustion of the soils nutrient pool, diminishing water supplies and energy sources; the basic underlying causes may be neither physical nor biological, but rather economic, social, cultural, or policy-driven.

It may be concluded that strategies for avoiding the potential conflict between productive agricultural land use and detrimental environmental impacts should be "defensive" and based mainly on understanding and combating natural resource degradation. Actions based on this understanding will likely assure the maintenance of ecosystem "health" and maximize harmony between profitable land uses and benefits to the overall interlinked ecosystems. It is the author's contention that this task is easier to accomplish if points of commonality and departure between various management goals are well understood**.**

Certain authors (e.g. Soule and Piper, 1992) suggest that inherent conflicts may exist between "farming" (the actual farmbased production activity) and "agribusiness" (those support activities that are associated with selling farm inputs, processing of products, marketing them, etc.). It is hypothesized that the latter's profit motives may exert undue pressures on farming enterprises to

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intensify the use of external inputs and follow *production-maximization* strategies; with an increased risk to environmental quality. It is unclear whether the high demands of genetically "improved" crops, such as those used in the *Green Revolution*, were partly exaggerated by commercial peddlers of necessary agricultural chemicals and perhaps contributed to soil degradation and noted decline of quantity and quality of certain water resources. Capitalintensive dependence on farm machinery and agrichemical inputs which can cause "modern" forms of land and environmental degradation (e.g soil pollution and structural deterioration) no longer separate so called developed and developing nations.

Importance of Spatial and Temporal Dimensions of Land Use Planning

Ensuring the environmental integrity of "whole ecosystems" requires that comprehensive attention be placed on the productivity and environmental function of not only a single farm or even farm groups, but most importantly on the performance of all interdependent segments in the total landscape. This is best accomplished within delineated watershed boundaries. Therefore, meaningful indicators of sustainable land use require ensuring that a well-defined ***spatial*** scale is used for addressing the functions of all ecosystem components, while recognizing the needs and necessary cooperation among land users and occupants. Boundaries of the "watershed" may define a small catchment or extend to a whole river basin, thus moving beyond political boundaries when necessary (El-Swaify and Hurni, 1996). Whatever the scale, an integrated and comprehensive quantitative accounting of development impacts, degradation sources and conservation needs is necessary.

A similar argument may be made for necessary emphasis on ***temporal*** scale. In short term planning, production- and profit-driven goals prevail over environmental concerns particularly in developing, heavily populated and/or rapidly industrializing countries. Here, the urgency of meeting society's present material needs often overwhelms leaders and planners to such an extent that considering the long term changes in "ecosystem health" is considered a luxury. However, developing a meaningful picture of sustainability status, requires that plans, measurements or monitoring be made for a sufficiently long time to provide the physical, biological, and socio-economic data that are valid for ensuring the welfare of future generations.

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Need for Incorporating Scientific Knowledge

Natural resource scientists, educators and organizations do not always play the role expected of them in influencing land use policies. Sometimes, their important role is overlooked by planners and policy makers, or they may isolate themselves by choice. It is essential that they be actively involved in providing factual information and in heightening the awareness of decision makers at all levels as to how their knowledge and databases might contribute to sound natural resource policies, plans and management practices. They also have an obligation to sell the "holistic perspective" approach, which allows full accounting of impacts of environmental change in managed ecosystems. While scientists may not be responsible for rendering final decisions, they have the obligation and primary responsibility for identifying and quantifying sustainability indicators, formulating and diffusing conservation-effective ideas and practices, advocating meaningful monitoring, targeting intolerable rates of degradation, and facilitating the adoption of sound land use support practices. They must maintain excellent communication with policy makers and involve land users who take the major economic risks, in the decision making process. To do so effectively, they must have the support needed to obtain and share necessary scientific information.

Examples and Case Studies

Examples from the fields of soil erosion and conservation and nonpoint source pollution will be used to illustrate the influence of selected spatial scale on reconciling competing objectives of land use and management.

Small Tropical Volcanic Island Ecosystems

Small tropical islands of volcanic origin, such as the Hawaii Archipelago, are characterized by steep topography, aggressive rainfall, and a small proximity between sediment sources on land and ultimate sediment destinations in the surrounding estuaries. Potential erosion (LHS) and actually measured erosion are usually high. The temporal spans and spatial scales between onsite production and offsite impacts of sediment are highly compressed, resulting in high sediment yields and runoff pollution. The high frequency of rapid sediment movement to shoreline areas following significant rainstorms poses strong challenges to contaminant control and coastal zone management efforts

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(El-Swaify, 1992). In addition, opportunities for conflict between communities which pursue different means of livelihood (e.g. farming versus fishing), are many and frequent.

In this and similar settings, holistic conservation planning must incorporate the full continuum of landscape segments including contaminant sources, pathways, and destination areas. Considerable community and agency efforts have been dedicated to addressing these problems within an Interagency Water Quality Action Program. These efforts benefitted from what historians have documented about the "Ahupua'a" concept, which was embraced by early native Hawaiians as a framework for policy on land use, and was applied as a tool for land allocation and management. Land access and right of use for deriving food needs were granted by ruling monarchs as continuous land strips extending from the crests of uplands into the sea. It, therefore represents an extension of "watershed" use as a management unit by integrating landscapes, emphasizing good "husbandry" of all land segments, and sustaining benefits to all active occupants.

Large River Basins

While awareness of upland-lowland interactions is so readily attained for small landscapes, it can escape people's attention in areas such as complex large catchments and river-basins. In addition, such large areas, while intimately linked and hydrologically unified by "bonds" of flowing water, are nonetheless often divided by political boundaries. An instructive case study is that of the Nile River, where sediments borne by seasonal floods were historically considered favorable, some believe essential, for sustaining Egypt's early agriculture and indeed civilization (Hughes, 1992). Seasonal floods from the Ethiopian and Eritrean highlands and plateaus contribute approximately 86% of the total annual water supplies to the lower Nile and the vast majority of erosional sediments (Said, 1991). The Atbara and Blue Nile rivers are the primary conveyers of these seasonal waters. Watershed catchments of the two rivers belong to four countries, namely Eritrea, Ethiopia, Sudan, and Egypt.

Sediments no longer have the same value to agricultural productivity in the Nile's lower basin and, instead, both upland erosion and downstream sedimentation have severe detrimental impacts on co-basin states (El-Swaify and Hurni, 1996). Upstream, a 1-2% annual reduction in soil productivity was estimated for the Ethiopian highlands; actually observed declines reached up

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to 10% per yr in the Western parts of Ethiopia. Downstream, sediment deposition threatens the usefulness and longevity of several water storage structures, dams, and reservoirs designed to stabilize water resources and availability, and to generate hydroelectric power for use by the respective communities. For example, Egypt's population of over 80 million inhabitants is almost entirely dependent on the capacity and function of the Aswan High Dam. Sediment accumulates in the lake south of the High Dam at an average of nearly 120 Mm^3 / year (El-Dardir cited by ElSwaify and Hurni, 1996). The potential effect of siltation on the course of the Nile river itself is also a serious concern, should sediment buildup continue as at such a rate. It can be shown that all sister countries comprising the Nile basin are detrimentally impacted by erosion, sedimentation, or associated phenomena and thus can benefit from integrated measures of soil and water conservation and restored land quality and productivity in sediment source areas. Existing information shows high availability of well-suited soil and water conservation technologies. Implementing appropriate measures for control of erosion in the upper catchments will have several tangible benefits, including:

- arresting land degradation in these areas,
- reducing the need for further exploitation of the few remaining natural areas,
- enhancing watershed performance, base flows, and reliability of water supplies into the eastern tributaries of the Nile,
- reducing the frequency of catastrophic flood events,
- maintaining hydroelectric power capacity,
- enriching habitats for fish and wildlife,
- reducing the sediment loads of the region's rivers,
- enhancing alternative economic uses of water bodies,
- reducing siltation of waterways and storage dams, and
- preserving the present, natural, course of the Nile.

Technical actions and necessary steps can readily prescribed. However, it is recognized that implementing technical actions must follow political agreements endorsing the need for basinwide cooperation, and the blessing of

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communities and leaders of cobasin states, together with especially targeted funds to allow such implementation.

Conclusions and Recommendations

Policy makers, planners, and scientists can achieve sustainable agricultural land use and management, with maximum harmony between production-driven and environmentally sensitive objectives, by:

1. Using sound site-specific information (data bases, geographic information systems etc.) as a foundation for optimum land use planning and management.

2. Maximizing the match between site attributes, planned land use, and selected management technologies by use of scientifically valid models and decision aids.Where possible, comprehensive, ***ex-ante*** accounting of land use and management impacts on the ecosystem as a consequence of alternative development options should be performed.

3. Recognizing that substantial mismatches will often necessitate massive landscape modifications and the use of large quantities of external inputs to achieve unrealistic production targets with negative environmental consequences.

4. Keeping a holistic perspective of sustainability during the planning process.

5. Taking stock of relevant determinants of "success" (physical, biological, economic, and socioculturalpolitical) to quantify specific measurable criteria for monitoring and judging the outcome of land development. Casual inference is inadequate for rigorous decision making. Defining objective indicators and realistic thresholds for the agroecosystem's productive capacity and ecological integrity, and monitoring of these indicators for regular ***ex-post*** evaluations of project performance upon implementation.

6. Conducting the planning, implementation, and evaluation of land use systems at meaningful temporal and spatial scales. The first should provide a sufficient time frame for planning, implementation, and evaluation to allow detecting "steady state" consequences of development. The latter should be landscape-based, even if the required continuity crosses political boundaries.

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7. Emphasizing incorporation of concepts and lessons learned from natural systems, including maximization of biological diversity and recycling, and minimization of soil disturbance.

8. Employing protective rather than corrective strategies against natural resource degradation. Even if the degradation is reversible; the economics and length of time required for reclaiming or rehabilitating degraded lands are such that "Prevention is Better than Cure".

9. Planning of production ventures to maximize the *useefficiency* of added inputs rather than for maximizing *total output* (e.g. yield). Overprescribed agrichemicals pose both productivity and pollution hazards. Tools include integrated pest management, intercropping, crop residue management, and conservation tillage.

10. Engaging scientists in providing current scientific knowledge on sustainable land use and management and urging their active involvement in heightening the awareness of decision makers.

11. Benefiting from, rather than emotionally dismissing, emerging innovations such as biotechnology and irradiation which often displace agrichemical inputs.

While it is relatively easy to quantify the value of land products; economic accounting of environmental changes in managed ecosystems still lags behind. Multicriteria analyses in these situations will assist in defining critical bottlenecks to achieving sustainable land use and optimizing management objectives. Such decision aids need not be complex. Rather, systems of varying complexity are necessary for meeting the needs of various clientele and decision makers (El-Swaify, 1998).

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Chapter 9

Effect of changes in land use and management on water and sediment yields in the Paya River watershed, Venezuela

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Abstract. Comparisons were made of six scenarios of land use and management on water and sediment yields for a period of 31 years in the Paya River Basin. Scenarios 1 and 2: conditions of the basin for the year 1986 and 2003; scenario 3: a high intervention condition, scenario 4: an ideal cover, scenario 5: a prospective scenario with part of the forest with sparse grassland and scenario 6: a prospective scenario with part of the forest with subsistence agriculture. The SWAT model was applied for the simulation. Characterizations of physical and natural attributes and of land use and land cover were carried out by interpretation of satellite images. For the simulation, the watershed was divided into 5 sub-basins and 19 Hydrological Response Units (HRU). A comparison of cover and land use between 1986 and 2003, showed significant changes: for 1986 the evergreen and semi-deciduous forests occupied 62.8%, while for 2003, the predominant cover and land uses were wooded grassland (41.1%), semi-deciduous forest (20.8%) and sparse grassland (16.6%). The results indicate that the highest water yield was produced in 1986, 2003 and ideal cover (scenarios 1, 2 and 4), while the lowest water yield was produced with scenarios 5 and 6, with very large surfaces covered with sparse grassland and subsistence agriculture, respectively. The scenario 5 with sparse grassland produced the highest sediment yield followed by scenario 6. Scenario 4 with the perfect cover resulted in the lowest sediment yield.

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Keywords: SWAT, Paya River, hydrological response, erosion, land use, sediments.

Resumen. Se realizó la comparación de series de 31 años de la producción de agua y sedimentos, en la Cuenca del Río Paya, para seis escenarios de uso y manejo de la tierra, utilizando el modelo SWAT: escenarios 1 y 2: condiciones de la cuenca para los años 1986 y 2003, respectivamente; escenario 3: condición de alta intervención; escenario 4 de cobertura ideal; escenario 5: uno prospectivo donde parte del bosque se convierte en herbazal ralo, y escenario 6: uno prospectivo donde parte del bosque se convierte en agricultura de subsistencia. Se realizó la caracterización de los atributos físico-naturales, así como del uso y cobertura de la tierra a través de la interpretación de imágenes de satélite. La Cuenca fue dividida en 5 microcuencas y 19 Unidades de Respuesta Hidrológica (URH) utilizadas para la simulación. La comparación de la cobertura de uso y manejo de la tierra entre 1986 y 2003, permitió evidenciar cambios importantes: para el año 1986 los bosques siempre verde y semidecíduo ocupaban un 62,8 %; mientras que para el 2003, las coberturas y usos predominantes fueron el herbazal arbolado (41,1%), bosque semidecíduo (20,8%) y herbazal ralo (16,6%). Los resultados indican que los escenarios con mayor producción de agua fueron los de las coberturas del año 1986, cobertura ideal y la cobertura del año 2003 (escenarios 1, 2 y 4), mientras que los escenarios de menor producción de agua fueron los escenarios 5 y 6, con superficies muy extensas cubiertas de herbazal ralo y agricultura de subsistencia, respectivamente. El escenario con mayor producción de sedimentos fue el de herbazal ralo (escenario 5), luego el escenario 6. El escenario con menor producción de sedimentos fue el de cobertura ideal.

Palabras clave: SWAT, Río Paya, comportamiento hidrológico, erosión.

Introduction

In a watershed all the elements that make up an ecosystem are combined and the governing processes supplying water production occur as ecosystem service. Thus, the structure, operation and state of preservation of the watershed determine the welfare achieved in each of the activities that demand such service [1]. Changes in land use have had beneficial effects; however, allowed to undermine the capacity of ecosystems to sustain food production, maintain freshwater and forest resources, regulate climate and air quality, among other effects [2]. The hydrological model SWAT (Soil and Water Assessment Tool) is designed to predict the impact of use and land management practices on the production of water, sediment and chemicals in large, complex watersheds [3]. This kind of models are tools to support the analysis of the causes and consequences of changes in land use in order to better understand the

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functioning of land use and to support planning and policy on the use of land [4]. The majority of SWAT applications have been focused on the impact of land use and management change as well as climate change dynamics [5].

The aim of this study was to assess the effects of changes in land use and management on the hydrological behavior of the Paya River Basin, Venezuela

Materials and methods

Location and general characteristics of the Paya River Basin

The Paya River Basin is located in Santiago Mariño Municipality, at Northeast of Aragua State, between 1.130.000 - 1.148.000 N and 666.000 – 667.000 E, with an area of 7,608 ha and a perimeter of 42,380 m.

The altitude of the basin is between 500 - 2400 m asl from the Paya River valley to the mountains [6], with mean annual temperature ranging between 24 ° C in the lower part, up to 14 ° C in the higher part, and with mean annual rainfall between 800 and 900 mm.

The basin was divided into 5 sub-basins and 19 units of equal geomorphology and soil, getting preliminary Hydrological Response Units (HRU) whose characteristics are presented in Table 1. The length of the river and area for each HRU per sub-basin was determined. For each preliminary HRU, the predominant use and vegetation cover for 1986 and 2003 was calculated, using the ARC GIS Software 9.0, which allowed obtaining the data necessary to characterize HRU at the end of each year.

Scenarios of use and land cover

The water and sediment production in the Paya River Basin was evaluated for six scenarios of land use and management: Scenarios 1 and 2: conditions of the basin for the years 1986 and 2003, respectively; Scenario 3: a high intervention condition with all Hydrological Response Units (HRU) with sparse grassland), Scenario 4 with an ideal vegetation cover (all HRU with evergreen forest), Scenario 5: a prospective scenario with part of the forest which becomes sparse grassland, and Scenario 6: a prospective scenario with part of the forest becoming subsistence agriculture.

The conditions for the years 1986 and 2003 were derived from a series of two images corresponding to the orbit / point 004/053 TM/Landsat-5 Sensor (13/03/1986 passage), with spatial resolution 28.5 m, obtained from the

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NASA website (http://glcfapp.umiacs.umd.edu:8080), and the image 658/329 colorful HRVIR-XI/Spot-4 sensor (31/12/2003 passage), with a spatial resolution of 20 m and the image 657/329 HRG/Spot-5 panchromatic sensor (passage of 04/01/2003), with a spatial resolution of 5 m, ceded by the French company Spotimage.

Evaluation of water and sediments production

To estimate the water and sediment production, the SWAT model was run six times for a series of 31 years, for the six scenarios of land use and cover, keeping the values of the parameters of topography, hydrograph, soil and climate fixed and varying only the values of each scenario and its management values.

Table 1. Characteristics of the hydrological response units (HRU)

HRU	Subbasin	LU	Area (ha)	% area	River length (m)	Slope (average) (%)
1	A	4	747,8	14,8	10121,2	27,0
2	A	1	157,8	3,1	2158,8	40,5
3	B	4	845,4	16,7	8330,5	35,9
4	B	1	461,0	9,1	4568,8	29,2
5	B	3	126,8	2,5	1282,1	34,7
6	C	1	468,5	9,3	6938,5	39,0
7	C	2	384,9	7,6	5805,5	21,1
8	C	4	107,8	2,1	1731,1	27,5
9	C	3	48,9	1,0	713,3	33,3
10	C	5	38,7	0,8	590,2	6,3
11	D	3	312,8	6,2	4796,3	43,8
12	D	2	236,8	4,7	3629,7	39,0
13	D	5	100,2	2,0	1529,0	6,7
14	D	4	58,6	1,2	893,2	25,4
15	D	1	39,6	0,8	585,5	34,9
16	E	2	684,0	13,5	7826,1	24,9
17	E	5	127,1	2,5	1477,8	8,0
18	E	3	61,4	1,2	1206,6	22,9
19	E	3	58,3	1,2	198,4	34,6

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The climatic variables required by the SWAT model (rainfall, temperature, wind speed, relative humidity, standard deviation from the average temperature of the daily data, probability of a dry day following a wet day, and probability of a wet day after a humid day, monthly rainfall intensity 30 minutes and 6 hours, annual rainfall intensity with a 10-year return period, coefficient of variation of mean monthly temperature, mean monthly radiation) were taken from Guayabita and Santa Cruz stations (records 1967 - 2000), for the bottom of the basin (HRU 10, 11, 12, 13, 15, 17, 18, 19), while for the upper part (HRU 1, 2, 3, 4, 5 , 6, 7, 8, 9, 14, 16) records (1967-2000) from Rancho Grande and Colonia Tovar stations were used.

The soil information required (number of horizons, wet soil albedo, wet bulk density, thickness of each horizon, % sand, % silt, % clay, % organic carbon, % rock fragments, soil erodibility factor, saturated hydraulic conductivity and available water capacity) was obtained in each landscape unit, delineated on the fifth level of abstraction [7]. As no soil map is available studies of intermediate-scale geological information with scale between 1:500,000 and 1:100,000 were used.

LU: Landscape Unit: **1** MBr: Mountain System, Formation Las Brisas, landings; **2** MBl: Mountain System, Formation Las Brisas, hillsides; **3** MBE: Mountain System, Formation Las Brisas, ridges; **4** MMm: Mountain System, Formation Las Mercedes, mountains; **5** VMca: Valley system, Formation Las Mercedes, colluvial-alluvial

Results and discussion

Land use and vegetation cover of the Paya River Basin for 1986 and 2003.

For 1986, the vegetation cover was predominantly wooded grassland (41%), followed by semi-deciduous forest (35%) and evergreen forest (9%), with smaller amounts sparse grassland, agriculture and urban use. For 2003, the largest surface covers were occupied by semi-deciduous forest (35%), remaining the same surface in 1986, followed by wooded grassland (27%) and sparse grassland (12%). A decrease in cover: evergreen forest, wooded grassland and low dense urban use, as well as increases in cover: grassland sparse, subsistence agriculture, and medium dense urban use (Figure 1)

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Hydrological behavior of the Paya River Basin for different scenarios of land use and vegetation cover

With respect to water yield (Figure 2A), the behavior of the basin was similar for scenarios 1, 2 and 4, which indicates that in 2003the basin was sufficiently preserved and the water yield was not affected, corresponding to the 'ideal' cover scenario. However, if cover involves changes into sparse grassland or subsistence agriculture (scenarios 5 and 6, respectively) the water production decreases; with the lowest water yield for scenario 3.

In relation with surface runoff (Figure 2B), the vegetation cover of the scenarios 5, 6 and 3 negatively affects water infiltration into the soil and thus increases water loss by surface runoff. On the contrary, the scenarios 1986 and 2003 create better soil conditions for infiltration of rainwater; both having similar magnitudes as the 'ideal' scenario (scenario 4). The worst scenario was the sparse grassland, resulting in low stability and high surface runoff, expecting higher risk of torrential floods and erosion.

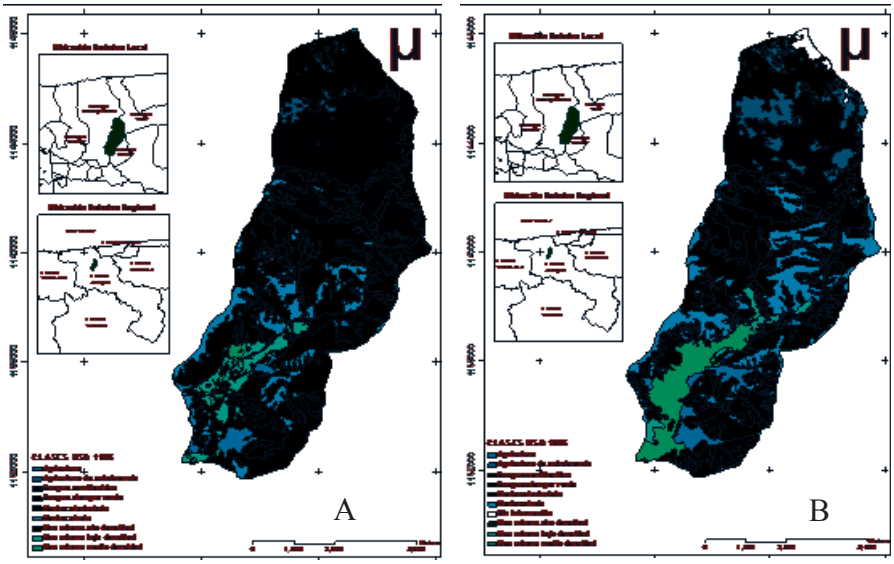

Figure 1. Land use and vegetation cover of the Paya River Basin for 1986 (A) and 2003 (B)

The scenario with the highest value of base flow was the vegetation cover in 1986 (Figure 2C), followed by the 'ideal' cover and the 2003 scenario (scenarios 4 and 2, respectively) there were significant differences in trend and

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magnitude observed, indicating that the cover of these scenarios allows much of rainwater to infiltrate into the soil to the groundwater and eventually becomes base flow. The decrease in area covered by forest and replaced with less protective cover such as sparse grassland and subsistence agriculture, reduces the potential of the basin to produce water in times of drought, which for the sparse grassland scenario, resulted in the lowest base flow.

There was a high similarity in the sediment production between the 'ideal' scenario, for 1986 and 2003 (scenarios 4, 1 and 2). Therefore, it could be assumed that with respect to the hydrologic conditions there were no major changes in the period 1986 – 2003. For scenarios 5 and 6 the sediment production increases more than double when compared to the 2003 scenario. The sediment production for scenario 3 (sparse grassland) proved to be much higher than for the other scenarios.

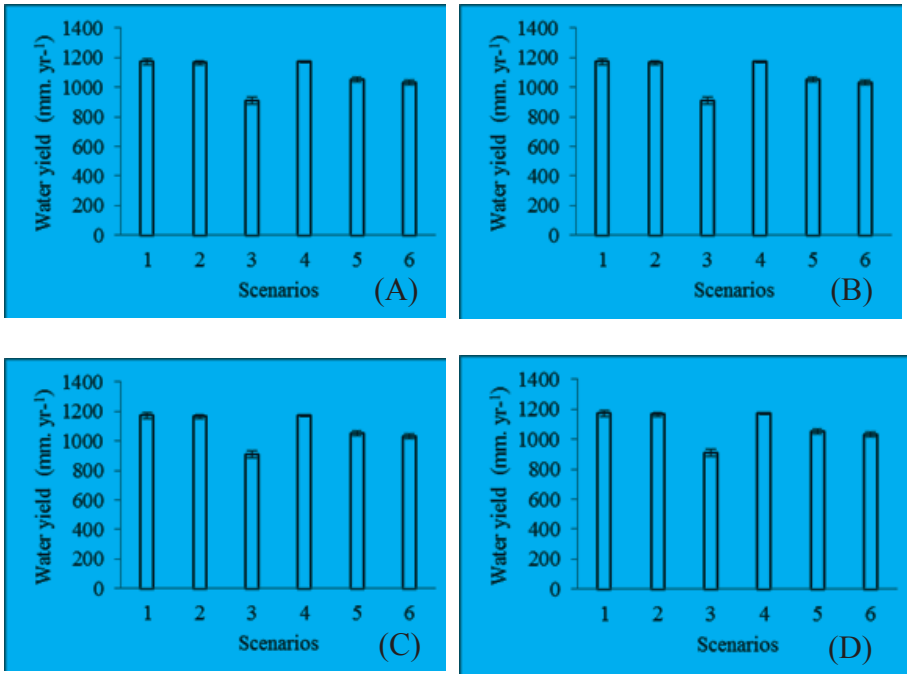

Figure 2. Hydrological behavior of the Paya River Basin for different scenarios of land use and cover

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Conclusions

The worst and most unstable scenario for land use and vegetation cover with respect to hydrological behavior of the Paya River basin was sparse grassland, since it presented the highest values of surface runoff and sediment yield, in addition to having the lowest values of water yield and base flow. The most stable scenario was the scenario with evergreen forest, with higher water production and base flow, and low sediment production and runoff. The highest water yield was produced in 1986, 2003 and 'ideal' cover (scenarios 1, 2 and 4), while the lowest water yield was produced with scenarios 5 and 6, with very large surfaces covered with sparse grassland and subsistence agriculture, respectively.

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Chapter 10

Water erosion mechanisms in andosoils and volcanic aridisols (Canary Islands, Spain)

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Abstract. In this paper the results for the monitoring of water erosion in Andosols and Aridisoles in two contrasting bioclimatic regions of the island of Tenerife (Canary Islands) are presented. In the North the study was conducted for nine years, three experimental plots on allophanic Andosols (Ultic Fulvudands) each with an area of 200 m2 (25 x 8 m). In the South the study was conducted on plots of the same features, but with Petric Calcisols (typical Petrocalcids). In andosols the percentage of runoff between 2 and 30% of the rainfall and erosion rates are highly variable with mean soil loss of 9.0 $tha^{-1}year^{-1}$. Petrocalcids in the runoff percentage was less than 5% in all cases and the total rainfall and erosion almost zero, regardless of the quantity and intensity of rainfall events. It is related rather to the conditions of the soil surface and antecedent moisture.

Introduction

Approximately 42% of the area of the Canary Islands is severely affected by water erosion accelerated processes, with losses exceeding 12 $tmha^{-1}year^{-1}$

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soil, equivalent to a thickness of 1-1.5 mm of soil per year (Rodríguez Rodríguez, 2001, Rodríguez Rodríguez et al., 1998).

On the islands two distinct bioclimatic regions, one located in the north, to windward and under the influence of the trade winds and the other in the south, downwind and subjected to sporadic torrential rains usually while the storms of the south are present.

In the rainier northern area, the floors are andic type and vegetation cover has a relatively high density, so that erosion occurs continuously, linked to changes of land use it causes sometimes drastic deforestation. In the southern arid zone, the dominant soils are saline and carbonated Aridisols, with scarce vegetation cover, where erosion processes occur in a timely manner during the rains in southern high intensity and are also linked to changes of use in its territory. But in this case as a result of land use for urban construction and various infrastructures, due to tourism, which in many cases could obstruct natural drainage channels runoff.

In this paper the results of nine years of measurement and evaluation of erosion in both situations from experimental plots of conventional type are presented.

Material and Methods

A) North Zone The study area is located at an altitude of 1000 m above sea level and is characterized by a humid bioclimate type of thermo-mesophytic (Rivas Martinez et al., 1993), with a potential vegetation that corresponds to the laurel forest (*Lauro azoricae-Perseeto indicae S.*), but mostly the original forest has been deforested and replaced by plantations of *Pinus radiata D. Don*. The soils in this area are developed on a complex geological material composed by Pleistocene basalt flows and ash with successive depositions of the same composition and variable grain size and characteristics lead to classify them as allophanic Andosols or andosols fulvic silica (WRB, 2007) (UlticFulvudands , Soil Survey Staff, 1999).

The study was conducted in three erosion plots installed in 2003 on this type of soil, with an area of 200 m2 (25 x 8 m) each and include pluviographs and deposit collectors equipped with capacitive sensors and ultrasonic device to quantify runoff.

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The soil erodibility calculated by the method of Wischmeier et al., 1971 is very low, obtaining values of K = 0.21 ±0.04 tañoMJ^{-1} mm^{-1} for the ground of the plots. In the first plot the soil is kept bare by manual removal of unwanted vegetation, the second plot has a vegetation of *Pinus radiata* with a density of 65% and the third is colonized by vegetation replacement is installed to eliminate plantations Pine (Rubio-periclymeni-Rubetum), with a density of 100% (Rodríguez Rodríguez et al., 2002a).

B) South Zone In this aspect the study area is located about 200 m a.s.l., characterized by a bioclimate of inframediterranean arid desert type (Rivas Martinez et al., 1993), where a potential climax vegetation corresponds to the domain of sweet spurge (Ceropegio fuscae- S. balsamiferae Euphorbieto), although at present because all these areas were cultivated until the early twentieth century they are colonized by a thicket of substitution forming a ruderal herbaceous steppe vegetation communities. The soil in these areas have been developed on Pleistocene basalts alterations and heterogeneous colluvium from erosion of soils located at higher elevations and are classified as Petric Calcisols (WRB, 2007) or typical Petrocalcids (Soil Survey Staff, 1999). The soils of the plots are slightly saline (CE_{es} = 2.7 dSm^{-1}) and the erodibility index (Wischmeier et al., 1971) provides values of 0.62 ± 0.08 tañoMJ^{-1}mm^{-1}.

The study was conducted in two erosion plots similar to those installed in the north and with the same equipment features. One of the plots devoid of vegetation is maintained by manually removing it and the annual steppe vegetation colonizes the other.

Results and Analysis

The annual and overall results of the entire study period of evaluation of the hydrological cycle and erosion are presented in Table 1.

In the northern region the annual average rainfall has been 625 mm (Figure 1), although with high interannual variability (Table 1), concentrating rains in the months of February-March and October-November. Although high intensity rainfall may occur (up to 240 mmh^{-1}), the maximum intensity of rainfall in this area are between 30 and 80 mmh^{-1}, with high homogeneity in the average intensity of rainfall (7-15 mmh^{-1}).

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In the southern area however the average annual rainfall is less than 100 mm (69 mm) with low variability between years and focusing on very temporary and spatially localized events in the months of October to April, when Southwest storms most frequently occur. The maximum intensity of rainfall in these conditions is low when considering the annual average, leading the mean values to not be indicative of the erosive potential, because sometimes all the annual rainfall occurs in a single event located. This is due to the type of rainfall regimes, with sporadic rainfall occurring at the time of penetration stormy fronts, but often leaving a significant amount of rain in a short amount of time.

With these conditions of differential rain in either zone, sediment yield and runoff generation in plots, must be different, taking into account the peculiarities of soils.

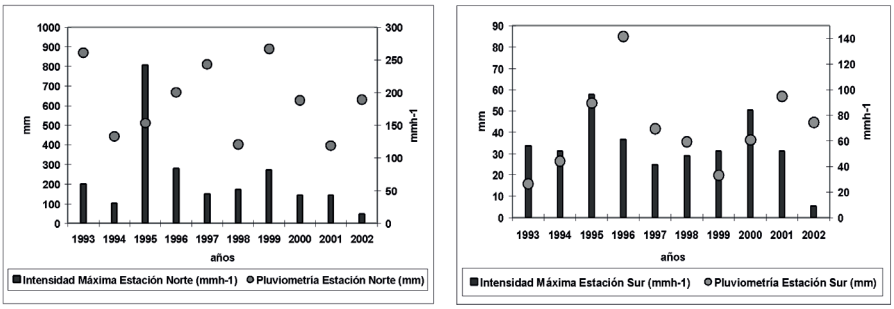

Figure 1. Maximum annual distribution and intensity of rainfall

In andosols runoff rates ranging from 2% to 30% of the rainfall in bare soil, indicating a high infiltration capacity in the surface horizons of these soils, which increase when there is a canopy on the ground where runoff percentages do not exceed 0.6% of total rainfall, regardless of the amount and intensity. Consequently erosion rates also have high interannual variability (Table 1), having a loss of middle ground in the plot without vegetation 9.0 $tha^{-1}\ yr^{-1}$, while in the plots with vegetation soil loss has been practically nil.

Under these conditions the highest rates of erosion have no clear relationship with the strongest rainfall, or the yield of runoff. The most increased production of sediments and runoff occurs with rain falling on dry ground.

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Table 1 Annual comprehensive assessment of rainfall and erosion

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Mean
North Zone Station											
Rainfall											
P (mm)	870	443	511	667	811	403	889	627	396	631	625
Imax (mmh^{-1})	60	31	242	84	45	52	82	43	43	14	242
R mean ($Mjha^{-1}mmh^{-1}$)	828	398	342	497	959	435	1220	886	218	383	617
Sediment yield ($tha^{-1}año^{-1}$)											
Bare Soil	28.9	8.7	5.6	17.4	14.9	3.0	9.5	0.8	0.4	0.4	9.0
Vegetation Replacement	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Runoff generation (mm)											
Bare Soil	94.4	80.9	156.3	155.9	105.6	77.4	70.4	5.5	5.0	3.3	75.4
Vegetation Replacement	5.5	1.3	0.7	2.3	1.4	0.8	1.2	0.6	0.4	0.6	1.5
Pine	3.2	0.7	0.7	1.5	1.3	0.5	1.8	0.9	0.8	1.2	1.3
South Zone Station											
Rainfall											
P (mm)	26.2	43.8	89.4	141.5	69.5	59.1	33.0	60.7	94.6	74.4	69
Imax (mmh^{-1})	33.6	31.2	57.6	36.6	24.7	28.8	31.2	50.4	31.2	5.4	58
R mean ($Mjha^{-1}mmh^{-1}$)	-	-	6.5	9.5	12.6	14.8	20.5	123.9	69.6	31.6	29
Sediment yield ($tha^{-1}año^{-1}$)											
Bare Soil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.01	0.04
Vegetation Replacement	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04	0.0	0.0	0.00
Runoff generation (mm)											
Bare Soil	0.14	0.11	2.6	4.5	3.3	0.14	0.80	1.6	0.64	2.9	1.7
Vegetation Replacement	0.03	0.03	2.6	3.8	3.5	0.71	0.27	1.3	0.27	2.6	1.5

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Given the known hydrophobicity of the andosols organic surface horizons, with dry soil a high runoff carries the aggregates of the bare soil, regardless of the intensity of the rainfall that is generated. After the slow wetting of the soil, high-speed infiltration and especially high water holding capacity of this soil, cause runoff generation to be very low, result in high volume water fall during rains (regardless of intensity). These drag laminar flow through the wet aggregates that have been fragmented by the impact of the previous drop of rainfall intensity (Rodríguez Rodríguez et al., 2002a). The hypothesis that has been suggested (Rodríguez Rodríguez et al., 2002b) is that sheet erosion in andosols occurs through a mechanism that in no case involves dispersing the particles prior to their mobilization by the flow, but on the contrary the particles mobilized into small aggregates (0.5 mm) to the highly stable dispersion.

In Petric Calcisols runoff rates are always lower than 5% of the total rainfall (average of 1.9% in a bare soil plot and 1.6% in a natural vegetation plot) and generate negligible sediment in both plots, regardless of the amount of rainfall and the intensity of the rain and even more so in relation to the state of the ground surface and previous moisture.

If, as we have said, the rains are sporadic and erratic but with strong intensity in this area, it is likely that erosion in these conditions is not a continuous process as it is in the case of andosols of the north. But on the other hand occur discontinuously in time, much like a pulse, having only certain quantitative importance in a number of years or certain stormy episodes when the conditions of humidity and state of the ground surface are present.

This type of soil, salt and lime have a high capacity of turning the surface into a crust of up to 1.5 cm thick, caused by the light rain that often precedes more intense rainfall. Sealing generated by these rains produce a drastic reduction in infiltration at the time of the heaviest rains and then generate a significant runoff, leading the laminar crust to flow on the sealing layer, which by presenting a high mechanical resistance at the cutoff does not have broken nor separated solid particles, which is why most rainfall events generate high runoff but don't produce erosion.

Only in the rare case that there are several consecutive high intensity rainy episodes is erosion found within the plots in which sediment is generated, due to the fact that the sealing layer loses its stability because of moistening which disintegrate the soil into individual particles that are carried by the laminar flow.

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However, in most of these soils intense erosive gully morphology and small gullies are observed that do not correspond to the sheet erosion detected in the plots shown. In these cases it occurs that by increasing the length of the slope (lengths much greater than the dimensions of the parcel) laminar flow is concentrated in gullies increasing turbulence and velocity, which are directed towards the open drainage channels or these slopes lead to new grooves and channels which are opened. Since the valley reaches the shear force sufficient to break the surface sealing the typical dynamics of gullies are continued after each following rainfall.

Conclusion

In Aridisols in the south of the island, unlike what happens in the forest of the andosols in the north where the predominant erosion is a concentrated flow generated in long slopes, the experimental plots do not seem to be the adequate facilities to assess soil losses by erosion, even if they can provide information on surface laminar flow dynamics and mechanisms of initiation of runoff in some areas where water resources are mainly from the exploitation of surface runoff. This is an important model for managing water resources on the areas with andosols where processes like infiltration and groundwater recharge should be favored, since in these cases water abstractions are always underground.

Also the design of measures to combat erosion must be different, since the North andosols should predominately have biological and agronomic measures to allow a permanent vegetable soil layer to decrease the kinetic energy of raindrops, triggering agent sheet erosion predominating these areas, and improving infiltration and aquifer recharge. While in the South Aridisols, measures to control erosion should be directed to mechanical methods to shorten the length of the slope, avoiding flow acceleration and concentration, the principal agent of the beginning of erosion rill and gully prevailing in these areas, and the channeling and use of concentrated surface runoff.

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Chapter 11

Soil conservation in a semi-arid basin, San Luis Potosí, México

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Abstract. Soil and water management programs with a watershed approach are considered essential for the sustainable management of resources. In this study, the resources that were characterized are from Monte Caldera-Portezuelo watershed (13 424 ha) located in a semi-arid zone of the Sierra de Alvarez, San Luis Potosi, Mexico. Water erosion risk was estimated using a GIS and the soil prediction model (USLE). Five categories were considered: no apparent erosion risk (soil loss less than 2.2 t ha^{-1} yr^{-1}), slight erosion risk (2.2-10 t ha^{-1}), moderate (10-50 t ha^{-1}), high (50-200 t ha^{-1}) and very high (> 200 t ha^{-1}). A database was created and the available technology for resource management was analyzed in order to identify the most appropriate management practices for land conservation and restoration. At the moment, with the collaborative efforts of several institutions, 240 ha have been restored by incorporating rangeland management actions as well as soil and water conservation works. After five years of implementation, impact assessment was carried out regarding the conservation measures. One of these assessments was carried out using rainfall simulation. It was seen that with an application rate of 14.7 cm hr^{-1} for 30 minutes, the sediment production was lower in the restored site (12.4 kg ha^{-1}) compared to the 19.9 kg ha^{-1} obtained in the unrestored site. The accumulated infiltrated water (cm) in the restored site was 10.8 cm and was higher ($\alpha \leq 0.05$) than in the unrestored site (4.03 cm). Bio-

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mass production was 3.9 t ha^{-1} in the restored site and 2.5 t ha^{-1} in the unrestored site and presented treatment differences (P>0.05). Restoration actions carried out have increased water infiltration, reduced soil erosion and increased biomass production.

Keywords: Erosion risk, watershed, sediment production.

Introduction

In Mexico, the ecosystem production capacity is being lost considerably due to the over-use of resources. The summer pasture ecosystems are the most deteriorated, as the overgrazing has damaged more than 60 million hectares [13]. As the second most damaged are the forest areas and in third seasonal farming, in which a total of 21 million hectares, 70% of which have been identified to have erosion and wind issues. The deterioration of resources due to erosion, creates loss of land, reduces productivity and the system's capacity to recover naturally in a reasonable amount of time.

In San Luis Potosí, the arid and semi-arid areas make up 77% of the state surface. Extensive livestock represents the main use of land and the production of forage in rangelands or grasslands is very limited. The over-use of plant coverage is generalized, which has caused the deterioration of resources, such as the reduction and loss of productive plant life, increase in non-usable plant life, loss of germplasm, reduction in the filtering capacity and the soils water bearing capacity, deteriorating the plant coverage and soil erosion [12].

The erosional processes are not local, but rather regional, according to water basin regulation principles. A water basin is a physical space limited by a watershed where factors of an ecological, climatic, hydrological, social, economic and cultural nature concur and interact with each other thus giving each basin its own dynamics. Because of their regional character, they may be used as planning units. The watershed is part of the water basin and due to its local character is considered the action programming unit, where with the active participation of the farmers, all the integrated services provided by the institutions can be developed and coordinated [3]. The basic procedure to controlling erosion on a regional level, consists in carrying out the classification and evaluation of lands, selecting an appropriate system, and if necessary, the design of conservation measures [11].

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The National Watershed Program provided by SAGARPA, describes the watershed as the basic unit regarding soil and water conservation projects as well as for community development. Its principles are to assist, comprehend and respect the issues, needs, demands, community objectives and decisions, seeking to develop co-responsibility and transfer means and functions to the community organizations. Previous to the rehabilitation, conservation, protection and use of natural resources, one of the fundamental objectives is to promote planning and participation processes, making the elaboration of the Production and Conservation Master Plan [2]. On that basis, the Watershed Program in San Luis Potosí, since 2002 defines a watershed as the planning unit for the integrated services of the institutions of the sector, emphasizing the development of actions tending to land use regulation.

The Portezuelo-Monte Caldera watershed between the following coordinates 22º 06' 44'' y 22° 16' 8'' L N y 100º 42' 12'' y 100° 54' 36'' LW, with an average of 2040 meters above sea level, has suffered strong changes in land-use since 1592 when the Potosí mines were discovered in the San Pedro Hills, S.L.P. Besides the historical background, the area is currently part of the San José-los Pilares watershed, which supplies water to the habitants of the Potosí capital. Extensive cattle grazing is the main land use; deforestation and overgrazing have been identified as the main deterioration causes. The weather is dry steppe with an average annual temperature of 17 degrees centigrade and an annual precipitation of 304.5 mm.

The objectives of the current research were:

1 Characterize the soil, plants and potential use of the Portezuelo-Monte Caldera watershed

2 Estimate the potential risks of water erosion.

3 Impact assessment of the soil conservation actions.

Materials and Methods

The process consisted of limiting the watershed and obtaining area maps of physiography, edaphology, current use and potential soil uses using INEGI as base cartography and the digital elevation model scale 1:50000 [6-10], using ARC/INFO™ workstation software and ARCVIEW™; creating the database of each subject.

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For erosion risk forecasting, the different layers were overlapped, producing a final map of potential erosion risk, with the support of Geographical Information Systems and the USLE [15] soil loss forecast model, according to five categories: no apparent erosion risk (soil loss less than 2.2 t ha^{-1} yr^{-1}), slight erosion risk (2.2-10 t ha^{-1}), moderate (10-50 t ha^{-1}), high (50-200 t ha^{-1}) and very high (> 200 t ha^{-1}). Rainfall erosivity was obtained through the corresponding equation of the Region IV: Y=2.89594x+0.002983x2, where "Y" corresponds to the erosion rate and "X" represents the average annual precipitation [5].

With the resources of the Secretary of Agricultural Development and Water Resources (SEDARH in Spanish), the National Commission of Arid Zones (CONAZA in Spanish), The National Forest Commission (CONAFOR in Spanish) and the participation of the farmers, 240 hectares of natural pastures were recovered, where levees were built to level at a 24 m (horizontal interval) distance between each other; all grazing was prohibited for a 2 year period to allow land recovery.

Five years later after works started, the infiltrations, runoffs and sediment productions are being estimated. Two sample sites were located: the first site, with soil recovery works and exclusions (with 4 repetitions), and site two, with continuous grazing, with animal load control (six repetitions) (Figure 1). For information analysis, a completely random design was used implementing different repetitions.

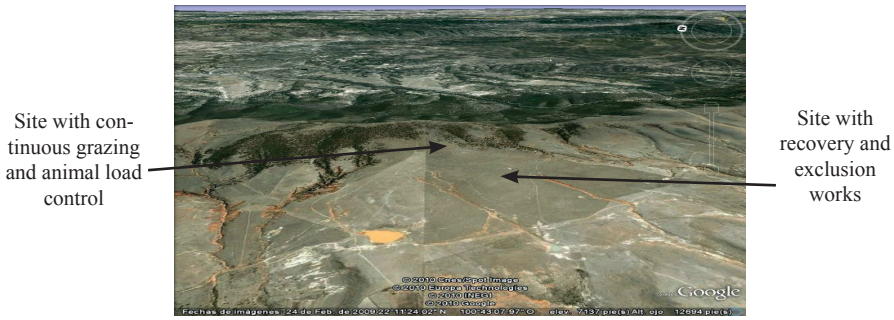

Figure 1. Sample sites

Biomass production was assessed using 35 x 35 cm plots and the existing plant life was removed; the apparent soil density was determined, for which a unaltered core sample extractor was implemented; the infiltration layer, the runoff layer and the total sediment production were evaluated; for this pro-

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cess, two sprinkler type rainfall simulators were used, which are provided by the natural resource department of the UAAAN [4] according to the proposed model [14] which simulates 36% of a natural rainfall, it is portable, with a 0.1225 m^2 assessment area, works well in strong slopes and plains; the rain is applied at a height of 1.55m, consists of two rain gauges and a square metallic infiltrometer of standard dimensions (35 x 35cm) with a runoff towards a collector pan to estimate the runoff volume once produced (Figure 2).

The structure is buried at a depth of five centimeters and the rain simulator is placed above, ensuring that the sprinkler nozzle is pointing to the center of the plot. The rain gauges are placed on opposite corners of the plot or quadrant. Before placing the rainfall simulator, an excavation was made to place a collector pan where initially the runoff was measured and afterwards measured every five minutes during a 30 minute period of simulation. Infiltration, runoff and sediment production estimates were carried out. The rainfall application rate was of 14.7 cm h^{-1}.

To determine the sites and treatments of the current study, both sites had to have the same physiographic position, similar soil and slope conditions to estimate the plant coverage alone in regards to the soil loss.

Figure 2. Rainfall Simulator used in study.

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Results and Discussion

In regards to the characterization of resources, it was observed that the dominant type of soil is lithosol (58%), phaeozem occupies 16%, xerolsol 17.5%, kastanozem: 0.5% and 7.5% corresponds to completely eroded soils. The current use of most of the surface is destined to livestock, which matches with the land classification by usage capacity, where 57% of the land is occupied by classes V - VII.

In regards to water erosion risk, 4,547 hectares present slight erosion risk below 10 t ha^{-1}, 4.869 hectares have moderate erosion risk(10-50 t ha^{-1}), 3,231.4 hectares high erosion risk (50-200 t ha $^{-1}$) and 724.5 high erosion risk (>200 t ha^{-1}). The current average of water erosion in the watershed at the moment of starting works was of 53.65 t ha^{-1} $year^{-1}$. The management proposals that have been implemented in 240 restored hectares include maintain and encourage the development of the plant coverage, regulating the use of summer pastures as well as the construction of levees.

Results from the rainfall simulation tests to assess soil loss, indicate that in the recovered site with mechanical practices and grazing exclusions, the sediment production was of 22.34 kg ha^{-1} compared to the 15.23 kg ha^{-1} of the eroded soil in the recovered area. The reduction in soil loss is due to the modification of the physical properties and the effect of the restoration works carried out on the plant life. The recovered site reduced its apparent density to 1.07 g cm^{-3}, compared to the 1.31 gr cm^{-3} of the unrecovered site. The dry material production also increased from 2.4 t ha^{-1} in the unrecovered site to 3.9 t ha^{-1} in the recovered site.

Conclusion

The restoration actions carried out have increased water infiltration, reduced soil erosion and increased biomass production.

Acknowledgments

Special thanks to the improvement program of the faculty for the resources provided to carry out the study under the agreement framework of PROMEP/103.5/10/7750 (UASLP-PTC-258).

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Chapter 12

Addressing soil erosion in the mattole watershed

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Abstract. This document describes erosion control efforts in the Mattole River watershed covering an area of 74,000 hectares in northern California. This landscape is comprised of steep terrain, poor soils, and high precipitation rates that lead to extreme natural susceptibility to erosion. Beginning in the 1950s, unregulated logging and road building drastically altered natural geomorphic processes causing gullies and landslides that are still affecting the watershed today. Forest and ranch lands have been degraded and fish populations have been devastated as creek and river channels were filled with sediment. With strong support from numerous government agencies and the local community, broad erosion control measures and other watershed restoration actions have been implemented. Between 2002 and 2012, work was implemented in nearly 75% of the watershed, treating approximately 1200 sediment sources and preventing nearly 900,000 cubic meters of soil erosion. Methodologies used to build consensus and funding for the projects are discussed followed by innovative and cost-effective erosion control techniques including sediment source assessments and bio-technical stream bank stabilization methods. Photos, maps, and figures are used to demonstrate key components of the work through project design, implementation, and monitoring phases. The document concludes with a discussion of results and limitations as well as lessons that can be applied to other regions.

Keywords: erosion, sedimentation, geomorphology

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Introduction

The Mattole River is located along the northern coast of California and drains an area of 74,000 hectares (286 square miles). The climate is characterized by high intensity rainfall in the winter with dry summers. Average annual rainfall in the watershed varies from 152 to 292 cm (60 to 115 inches). The Mattole watershed contains a mixture of dense Douglas-fir forests, deciduous forests and grasslands, with a sparse human population. The soil is highly susceptible to erosion due to the soft nature of the underlying Franciscan Coastal formation bedrock and rapid seismic uplift rates.

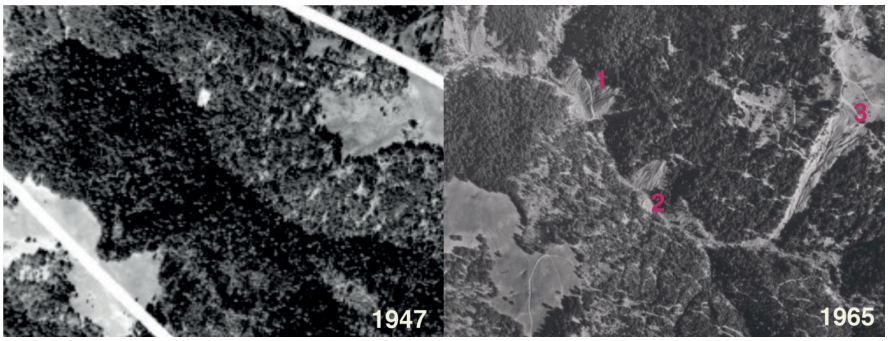

Figure 1. Aerial imagery of the Mattole watershed before and during the logging era; Location 1 – logging road built across active slide; Location 2 – logging road built in creek; Location 3 – large debris slide below new road network

The Mattole River watershed once hosted abundant runs of Chinook and coho salmon as well as steelhead trout. However, widespread logging and road building, followed by flood events in 1955 and 1964, triggered erosion throughout the watershed (Figure 1). Extensive upslope landslides filled lower channels with heavy sediment, causing further erosion and leading to a drastic decline in the local fish populations. In 1994, the US Environmental Protection Agency (EPA) listed the Mattole River as "impaired" with excess water temperature, turbidity, and sedimentation . In 2003, the EPA and the California Resources Agency respectively, published the Mattole Total Maximum Daily Load for Sediment and Temperature (TMDL)and North Coast Watershed Assessment Program (NCWAP). These scientific documents, as well as the Mattole Watershed Plan published by the Mattole Restoration Council (MRC) in 2005, laid out a

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general roadmap for watershed recovery. Among other findings, the Mattole TMDL estimated the rate of soil erosion throughout the watershed (Figure 2) distinguishing between natural and human induced erosion sources, and targeted a goal of achieving 125% of the natural rate.

	Estimated Sediment Delivery (tons/mi2/yr)			
Sediment Source	North	East	South	West
Natural Erosion	4500	1900	1800	2500
Human Induced Erosion	3700	7600	2600	5100
Total Erosion	8200	9500	4400	7800

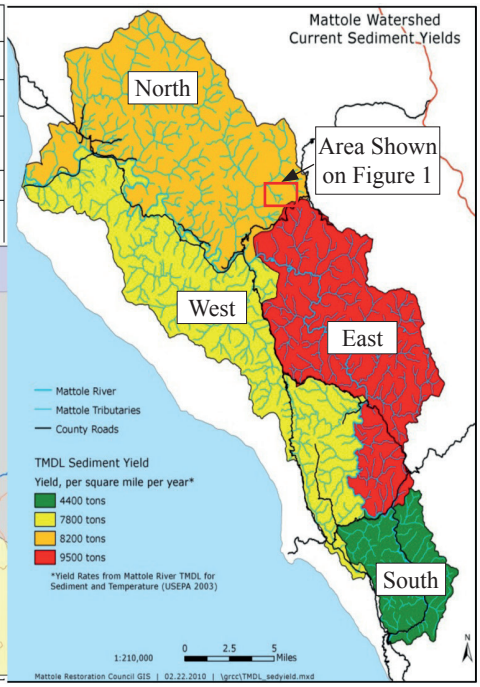

Figure 2. Mattole watershed location and estimated soil erosion volumes from Mattole TMDL

Following is a description of how the MRC, a local non-profit organization, partnering with government agencies and landowners, created a watershed-wide sediment reduction program that was successful in preventing an estimated 900,000 cubic meters of soil erosion between 2002 and 2012.

Methods

Successful erosion control efforts in the Mattole watershed were based on a five-phase process. The first step was to identify the problem including the scale and extent of the soil erosion. The Mattole TMDL, NCWAP, and Watershed Plan provided this baseline data. The MRC provided the critical role of

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bridging the gap between landowners and government agencies who provided the funding for the projects and included the State Water Board (SWRCB), CA Department of Fish and Wildlife (DFW), CA Department of Water Resources (DWR), US Fish and Wildlife (USFW), National Oceanic and Atmospheric Administration (NOAA), US Department of Agriculture (USDA), and others.

The second phase of the efforts involved developing a long-term strategy to attract funding. In the case of the Mattole watershed, the majority of the potential funders were focused primarily on fisheries and water quality while USDA was more focused on cattle ranching and forestry. Based on the funding sources and local watershed knowledge, a systematic approach for treating the soil erosion was developed. This included dividing the Mattole watershed into sub-regions based on levels of erosion, on-the-ground community support, and potential success of erosion control efforts. The Mattole headwaters area (Figure 2 – "South") was chosen as the first target sub-region based on its hydrologic and geomorphic positioning (it is difficult to treat erosion problems in the lower reaches of a river while the upstream area remains heavily impacted). In addition, the Mattole headwaters hosted strong community support, excellent fish habitat potential, and relatively treatable sediment sources primarily caused by roads and not massive landslides as seen in other portions of the watershed. The plan was to continue moving systematically down the watershed, by sub-region, until human-induced erosion sources in the entire watershed were treated.

The third phase of the efforts involved a field assessment of the erosion sources, requiring funding of approximately US$20 per hectare. Sediment assessments were funded by a host of government agencies and were completed utilizing the Star Worksheet Methodology (SWM)[1]. The SWM included office review of aerial photography series, followed by field reconnaissance where data was collected at significant erosion sources. This field data was synthesized to determine soil erosion potential, treatment costs, and prioritization. Results from the erosion assessment provided a foundation for the implementation phase. The primary sediment sources identified were: a) road crossings over creeks where undersized culverts made them susceptible to failure during winter storms; b) gullies caused by roads bisecting natural hydrologic drainage patterns; and c) stream bank erosion and landslides caused by removal of the riparian corridor and increased sediment bed loads.

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During phase-four, grants were written and government agencies provided funding of approximately $1,500,000 per year between 2004 and 2011. These widespread sediment reduction efforts treated the highest priority sites identified in the assessment phase and generally followed guidelines set forth in DFW's California Salmonid Stream Habitat Restoration Manual[2]. On-the-ground activities consisted of approximately five teams of local heavy equipment contractors with 2 - 5 employees each. During this period, 18 fish barriers were removed and replaced with bridges or pipe-arches, 640 culvert and rock armor stream crossings were upgraded to meet 100-year flow capacities, 150 abandoned stream crossings were decommissioned, and 80 road segments were reshaped and surfaced with gravel. As efforts moved away from the Mattole headwaters into more erosive portions of the watershed, landslide stabilization became a focus.

Figure 3. Pre- and post-project photos of bank/landslide stabilization efforts

Overall, over 250 streambank/landslide sites were treated through the placement of riprap rock, large logs/roots, and live willow trees. Utilizing heavy equipment, the creek or river channels were diverted away from the failing banks, and the rock and wood structures were placed. Restoration efforts

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took into consideration the available construction materials, site accessibility, topography, hydrology, and geomorphology to design cost-effective projects specifically tailored to each site. Some inaccessible sites were treated with a labor crew using hand tools including winches and rock bars to modify channel features and prevent bank erosion. Some highlights of the project include: a) stabilization of 17 landslides along a one-mile reach of ranchland creek with 2000 tons of rock; b) work at the toe of a large and active landslide (Figure 3 – top photo set); and c) bank stabilization efforts on 200 meters of bank along the lower Mattole River main-stem (Figure 3 – bottom photo set).

Results

The fifth and final phase of the erosion control efforts included monitoring the implementation activities. Monitoring has primarily consisted of repeated field visits and photographic documentation. To date, road related project have experienced a degree of success greater than 99%. It is more difficult to judge the success of stream bank and landslide stabilization projects, as actions often slow, but do not entirely stop soil erosion. In order to capture general watershed trends resulting from streambank/landslide stabilization efforts, targeted channel monitoring activities were completed in stream reaches directly downstream from the landslide treatments. Monitoring protocols included measurements of bed material size classes in both pools and riffles as well as general trends in pool volumes and channel longitudinal profiles. Based on channel monitoring results from the Mattole headwaters in 2011, it was determined that in-channel sediment levels within this sub-region had fallen to within the acceptable threshold according to the SWRCB. In addition, monitoring results taken downstream from areas with intensive landslide treatments are showing promising trends such as coarsening of the channel bed material, although excessive silt is still filling many pools. These channel indicators are supported by photographic documentation of the upstream landslide treatments that show channel stability and strong vegetation growth along the riparian corridor and upland slopes.

Conclusion

Four primary conclusions can be drawn from the work in the Mattole watershed. First and foremost, it is critical to practice best management soil

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conservation so that the problems evident in the Mattole do not arise in the first place. The environmental impacts caused by poor land-use are very costly to repair and negatively affect the local fish, timber, and ranching economies. Although approximately US$12,000,000 was spent in the Mattole watershed on erosion control projects, these efforts account for less than 10% of the watershed-wide erosion reduction needed to meet the goals of the Mattole TMDL. If soil erosion wasn't such a problem, governments could support other critical issues such as water scarcity and education. The second conclusion to be drawn from this paper is that under existing conditions in the Mattole watershed, the activities described above provided an efficient and watershed-scale approach for addressing soil erosion. Third, this process is highly dependent on government support as well as a general consensus around a treatable solution for addressing excessive soil erosion. Although nearly 75% of the Mattole watershed has been covered by some type of sediment reduction activity, efforts slowed in 2012 due to a combination of factors: a) a decrease in the availability of public funds; b) treatment was completed in the highest priority areas; and c) the remaining sediment sources required treatment actions that were complex and massive-scale. As a final conclusion, when tailoring these types of efforts to another region, it is important to look at the site-specific environmental, social and political circumstances and develop a strategy that can attract broad support for landscape-level action. For example, as opposed to the fisheries focus of the Mattole watershed, sub-regions seeking to address soil erosion in Colombia could target the agricultural and forestry sectors as well as donors supporting land restitution and carbon sequestration.

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Chapter 13

Restoration of degraded catchments by applying bio-engineering works in active gullies

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Abstract. In this study, we have evaluated the effects of bio-engineering works aiming to stabilize degraded catchments. Five micro-catchments (0.2 up to 5 ha) have been selected within a 3 km^2 area in the lower part of the Loreto catchment (Southern Ecuadorian Andes). The five micro-catchments differ in vegetation cover and implementation of bio-engineering works. The experimental design consisted of three micro-catchments: (1) DI with conservation works, (2) DF with reforestation by *Eucalyptus sp* and (3) DT with no conservation works. Two micro-catchments have been monitored in an agricultural area: with (AI) and without (AT) bio-engineering works in the active gullies. Water flow has been measured in every micro-catchment, while sediment traps were constructed to monitor sediment transport.

Results show that bio-engineering techniques are effective to stabilize active gullies. Deposition of sediments in manmade dams is strongly dependent on previous rainfall events, as well as gully channel slope, and its vegetation cover. From the experimental data, an $I_{30\,max}$ threshold value was determined. Above this threshold value, all micro-catchments are actively contributing sediment to the main river system.

Keywords: degraded soils, erosion, sediment, restoration, reforestation

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Introduction

Intensive land use in the central parts of the Andean basin has lead to widespread land degradation. The formation of badlands dates back from the 1950s and 1960s. Several studies indicate that human activities have accelerated mountain erosion rates by up to 100 times [3, 9]. It poses important limitations to the development of agriculture (on-site), but also affects water yield and sediment transport to downstream areas threatening drinking water extraction and hydropower generation. Reduction of crop productivity is another serious problem associated with the elevated soil loss [7] The restoration of these badlands was largely an initiative taken by the INECEL (and later UMACPA, CGPaute, Senagua) to restore highly degraded catchments and reduce sediment transport in the river system.

In this paper, we will analyze the effect of small dams constructed in active gully channels on sediment mobilization and sediment export to the river network.

Materials and Methods

The study area is located 23 km from the Cuenca city in the Southern Ecuadorian Andes (Figure 1). The area is characterized by the presence of active gullies, and elevated soil erosion rates. The land use is very fragmented, with a mix of cultivated land, pastures, shrubs and bushes, and patches of forests of *Eucalyptus sp*. and *Pinus sp*. (Figure 2). The rainfall regime is bimodal with two rainy seasons, registering between 600 and 1000 mm of yearly rainfall [2]. In the study area, a total of 1100 mm was measured for the period from February 2011 to January 2012.

Five experimental micro-catchments in the Loreto catchment were selected for the study. Of these, 3 micro-catchments are situated in a badland area: (DI) with conservation works, (DT) without conservation works and (DF) reforested with *Eucalyptus sp*. and 2 micro-catchments in an agricultural area (AI) with conservation works and (AT) maintained as reference. Each of these micro-catchments is equipped with San Dimas hydraulic flumes to measure the discharge from the water level detected by diver sensors, and with a 0.5 m^3 sediment trap. Two rain gauges were installed in the Loreto catchment to monitor rainfall intensity. Small checkdams were constructed in the gully floors of two of the micro-catchments in the badland area (DI) and the agricultural area (AI). The checkdams are made of wood and tires.

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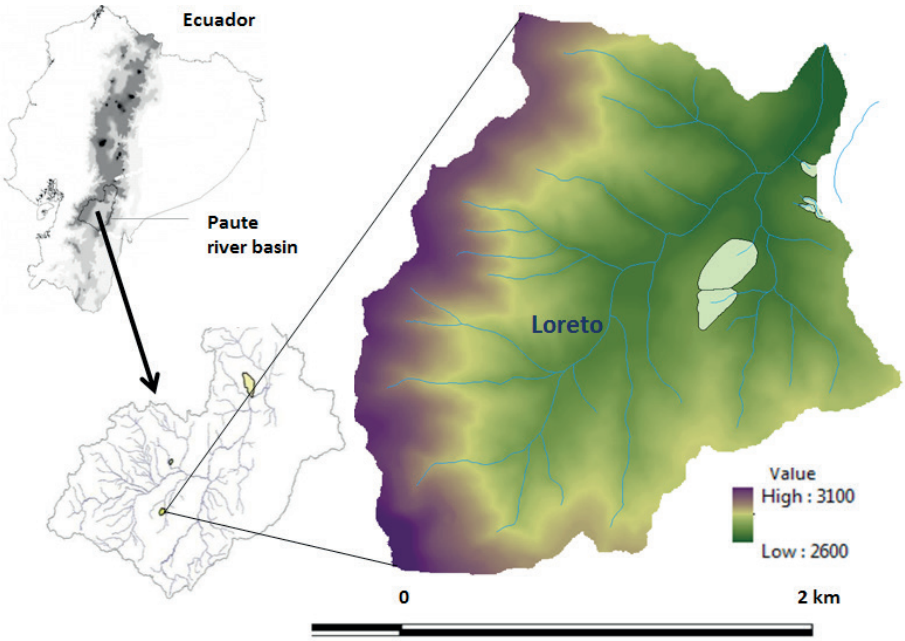

Figure 1. Location of the study area

During two rainy seasons, the sediment accumulated behind the check-dams was measured. In addition, sedimentation in the traps at the outlet of the micro-catchments was measured to estimate the quantity of sediment exported out of the micro-catchments. Every trap was situated at the outlet of the 4 micro-catchments (DI, DT, DF and AI) and consisted in a pit of 1x 1 x 0.40 m. Sediment height was measured regularly behind check-dams to estimate the volume of sediment retained based on the measurement of the geometry of the section. Additionally, the height of the sediment accumulated in the traps was measured for volume determination. In order to estimate the mass of accumulated sediment, measures for bulk density from 400 soil samples taken in metallic cylinders was made. The average bulk density of the soil was determined in 1.45 Mg m^{-3} (standard deviation = 0.12, median = 1.454). The material accumulated in sediment traps was measured at the same time that in check dams.

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a) degraded land b) cropped land

b) forested land b) small dam for sediment control

Figure 2. Characteristics of the study zone

Results and Discussion

The results show that in all dams the sediment accumulation was very low until 05 / 10 / 2011 (285 days) when a significant increment in sediment accumulation is shown (Figure 6 and Figure 7). Dam 11 is the first in filling (12/10/2011) 285 days for DI micro-catchment. Dam 1, 7 and 9 are filled in 01/11/2011 (305 days). All of them are dam made with wood. In general the dams of wood are filling faster than the dams of tires.

While all dams are in the same micro-catchment (DI) the response to rainfall is not in the same amount. In the Figure 3 is evident that in the upper part of catchment the dams respond better than dams in the lower part. This could be due to the cumulated effect of all dams working in combination. However the 2 dams at the outlet of catchment show a good correlation.

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The same tendency was observed for I_{30max}, more distant dams present a better correlation between sediment measured (Figure 4). In AI micro-catchment (Figure 5) this tendency is not so clear, one of the reasons could be the fact that the level of alteration due to human activities is very high: roads, irrigation channels, crops, infrastructure. Dams near to roads were filled faster.

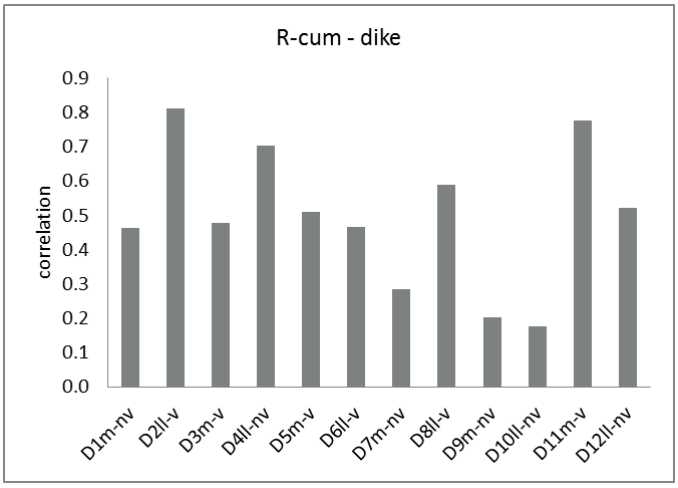

Figure 3. Correlation between amount of rain cumulated during the period of time corresponding to the measures of sediment and the amount of sediment accumulated for DI

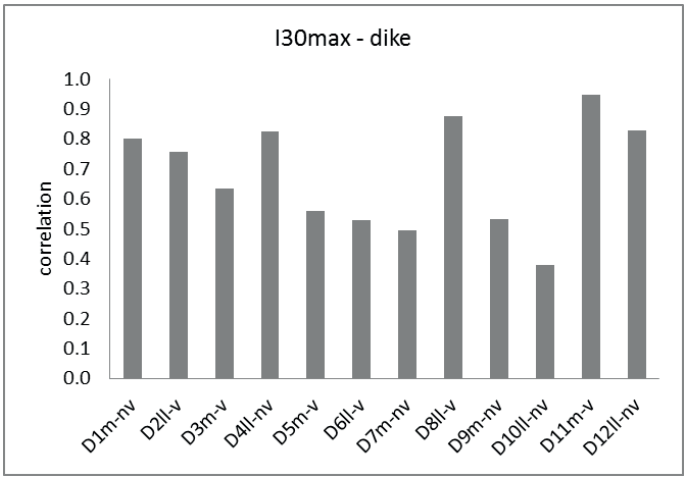

Figure 4. Correlation between sediment cumulated in dams and I_{30max} data for DI

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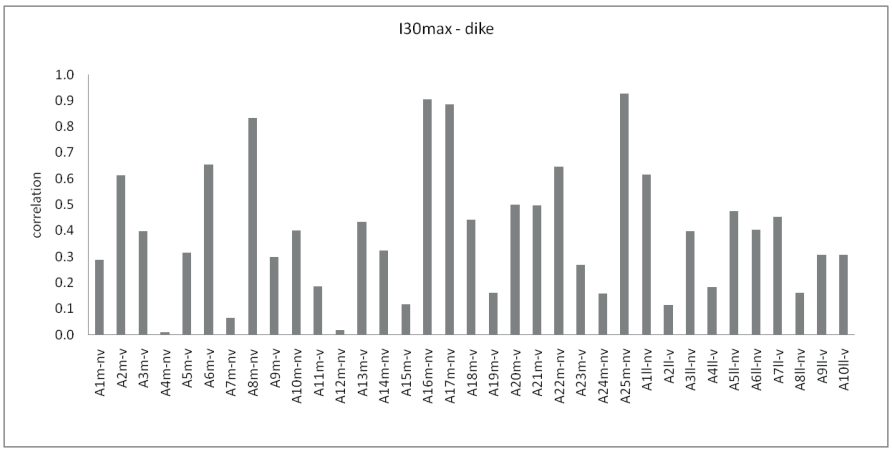

Figure 5. Correlation between sediment cumulated in dams and I_{30max} data for AI micro-catchment

Differences between sediment produced in degraded micro-catchment according to type of material of dam construction are very clear (Figure 6 and Figure 7). Dams constructed with wood are more efficient retaining sediment due to different reasons. The same tendency was observed in cropped micro-catchment (AI), which shows a clear dependency of efficiency of source of storage.

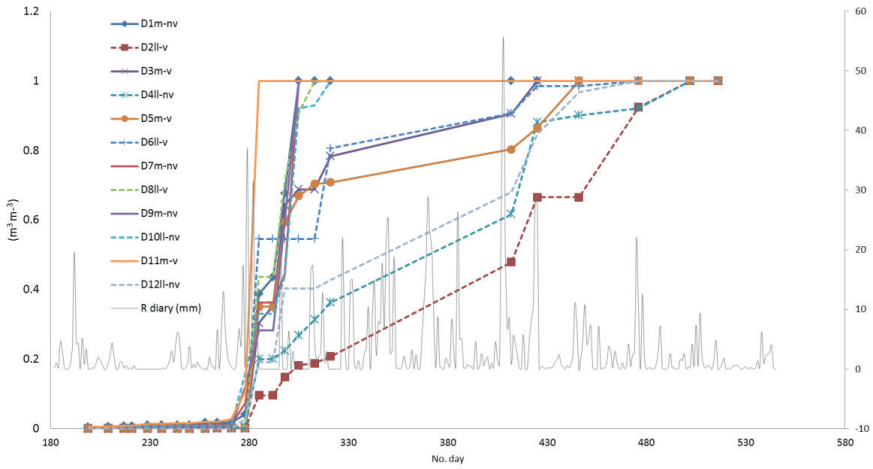

Figure 6. Cumulated sediment for all dams in micro-catchment DI, standardized data. Wood: solid line and tires: dashed lines

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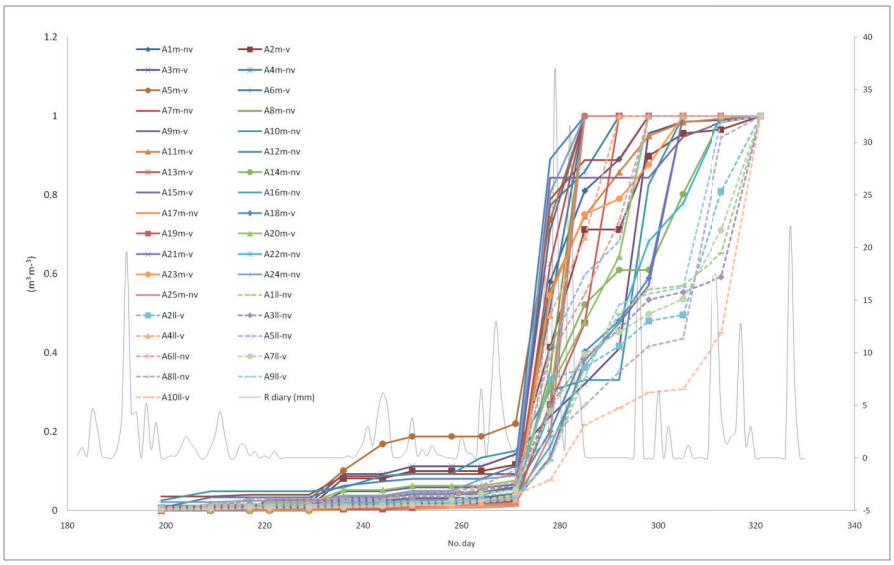

Figure 7. Cumulated sediment for all dams in micro-catchment AI, standardized data. Wood: solid line and tires: dashed lines

Small dams are efficient to reduce sediment mobilization. About 77 % of sediment is retained in dams. This allows stabilizing the gullies gradually while some species begin to cover the accumulated material providing protection to other species. Efficiency depends on construction of dam, position in the gully, rainfall intensity, connectivity between other gullies, etc. Interaction between these factors are very important so relatively small changes in landscape connectivity have the potential to alter erosion and vegetation dynamics. [6]

The rate of erosion in the study site DI was estimated in 120 T ha^{-1} y^{-1}, in cropped micro-catchment (AI) the rate of erosion was estimated in 25.8 T ha^{-1} y^{-1}. The estimation was made based in data measured behind of small dams. The average sediment yield for the Paute catchment is currently ~ 650 T ha^{-1} y^{-1} [4]. Data from resent studies report estimations for sediment yield of 0.26 to 151 T ha^{-1} y^{-1} in different catchments inside Paute river basin [5].

Sediment trap data show that sediment export highly depends on land cover of the catchments, where export from reforested basins is very low (1.8 T ha^{-1} y^{-1}), in contrast with degraded catchments (DI = 37 T ha^{-1} y^{-1} and DT = 100 T ha^{-1} y^{-1}). Sediment export is affected by construction of dams, mainly

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during medium events ($10 < I_{30max} < 20$). During very high events ($I_{30max} >$ 20 mm h^{-1}) the capacity of dams and also traps is exceeded and the surface runoff affects all micro-catchment due to Hortonian and saturation overland flow. The maximum I_{30max} registered in the study area was 80 mm h^{-1}, that corresponds to a diary precipitation of 55.6 mm.

The traps at the outlet of micro-catchments give us a good idea of how efficient are the dams and the amount of sediment that is not trapped inside the catchment. There is a good correlation between data from trap in degraded intervened (DI) and trap in degraded forested (DF) (Figure 8).

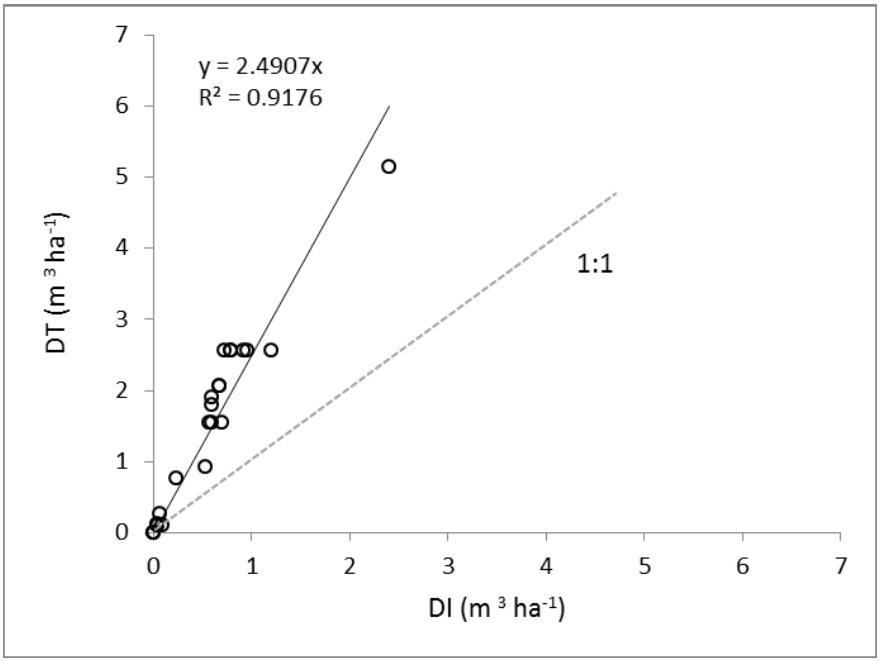

Figure 8. R^2 for the relation of sediment data between trap DI and DF

The effect of dams construction can be seen in the Figure 9, were amount of material accumulated in sediment trap is greater than in the degraded micro-catchment without conservation works. Data from sediment trap show certain relationship with sediment in dams with respect to distance Figure 10, dams in the extremes of catchment are more correlated with data registered in sediment traps.

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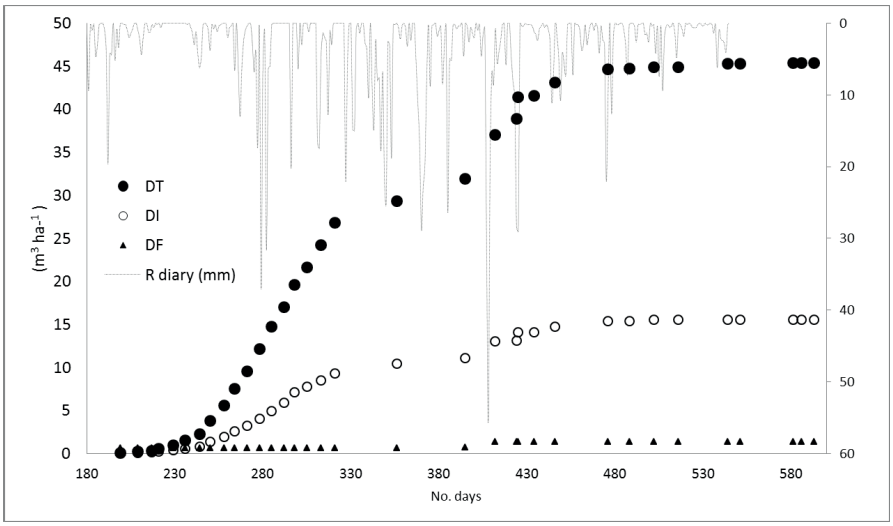

Figure 9. Sediment retained in traps (cumulative) at the outlet of micro-catchments in degraded land: DT, DI, DF

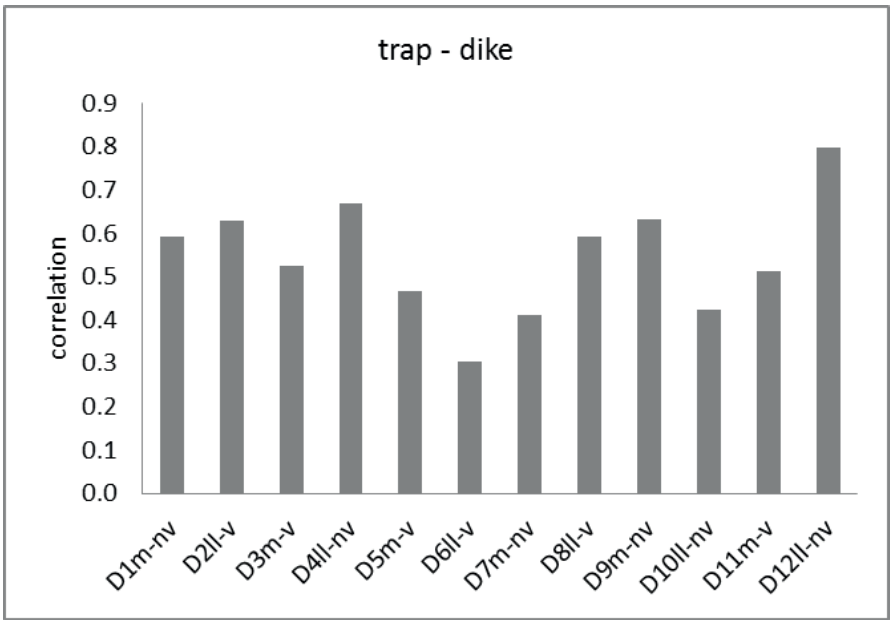

Figure 10. Relation between sediment cumulated in dams and in trap at the outlet of micro-catchment

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Based on the relationship between the data of retained sediment within the micro-catchment inside constructed dams and sediment retained in traps at the outlet of the basin it was found that the efficiency of the dams in sediment retention would be 70%.

This means that in a micro-catchment with active gullies where conservation works have been established, a 30% of all the sediment would be exported out of catchment. In degraded watersheds without any conservation work, however, there is still a certain percentage of sediment that is stored inside, sediment is to a large extent trapped locally in the catchment [1]. This depends on several factors including: topography, shape of the drainage network and connection between gullies, vegetation cover, etc.

In general all dams respond to rainfall events but not in the same magnitude. It was found a certain tendency to show that dams of the lower part of the micro-catchment were filled in less time. In the lower part the total surface that contribute with sediment load is major in combination with major velocity of water and predominant areas with less vegetation cover. Respect to slope in the upper part of catchment there are more steep slopes in the main channel of gully with sections characterized with abrupt changes in height.

Vegetation appears to be much related with amount of sediment stored in dams. Comparing standardized data for volume of dams is evident that the dames with greatest amounts of cumulative sediment are those which predominant vegetation cover is very low in percentage. However is observed that some dams, in zones surrounded by eroded surfaces (low vegetation cover) but constructed with tires, cumulated less amounts of sediment in comparison with dams in same conditions but made with wood.

Respect to the I_{30max} is observed that in order to produce an accumulation of sediment in all dams is necessary achieving certain values of I_{30max}. An I_{30max} of 43 mmh^{-1} produced that all dams inside the study area show and important increment of sediment (Figure 11). After this event an I_{30max} of 24 mm h^{-1} also produced that all dams registered sediment accumulation. Intensities of 10 - 13 mm h^{-1} apparently would not be significant, however still are responsible for produce sediment in micro-catchment. In the other hand an I_{30}max of 80 mm h^{-1} do not produced and important amounts of sediment, one of the reasons could be that the main part of total available volume of the dams already was in use. This assumption could be confirmed by the fact that

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the amount of sediment accumulated for these I_{30max} in the 3 sediment traps at the outlet of catchments was the biggest of all registers. In micro-catchment degraded forested (DF) this was the second time that the sediment trap register accumulation of sediment, the first was after a rain of 26.4 mm cumulated during these day. This reflects the benefits of *Eucaliptus sp*. and *Pinus sp*. forestation in bad lands, as a result of a process that begins with land abandonment due to intense soil erosion after low agricultural productivity [8].

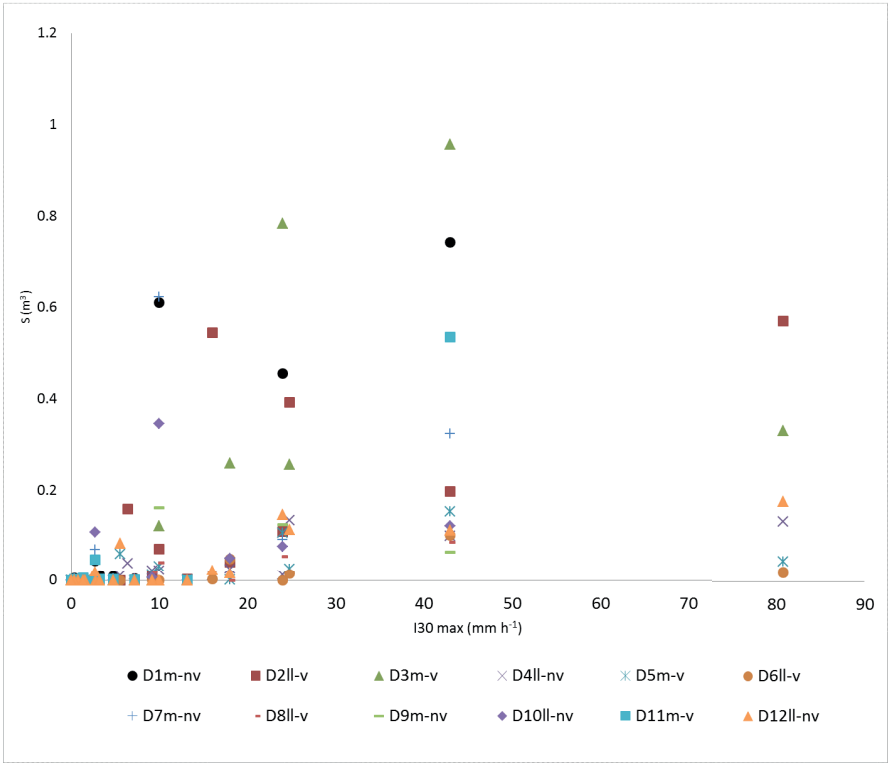

Figure 11. Relationship between I_{30max} and Sediment accumulated in dams (DI)

Conclusions

Accumulation and transport of sediment in the dams and from them within the micro-catchment depends on how factors like: catchment, vegetation, topography and connectivity of gullies and drainage network interact. This is responsible for certain areas of sediment storage within the basin.

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The dams built with wood and tires have an efficiency of 70% and would be effective in the task of stabilizing active gullies in bad lands through significant reduction (about 62%) of the amount of sediment coming out of a catchment. The comparison of erosion rates of bad lands and cropped lands makes clear that one of the main sources of sediment and erosion are not cultivated areas but rather areas with active gullies. In the same way a road or highway produce a large amounts of sediment which it was found in the dams that were located next to these conservation works.

Likewise forestation of bad lands would have a very positive effect in the sense of stabilization and restoration of the area.

Rain is a very important factor in connection with the generation of sediment. Faced with strong rain events conservation works may be limited in their effectiveness however the effects are evident e.g. at hydrological behavior level where peak flows are less pronounced compared to non intervened areas.

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Chapter 14

European polices for soil protection, land use and biofuel production

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Abstract. Soil resources in many parts of Europe are being over-exploited, degraded and irreversible lost due to inappropriate land management practices, industrial activities, forest fires, salinization and land use changes that lead to soil sealing, contamination, erosion and loss of organic matter. The European Commission has being developing proposals for soil policy for many years but to date soil protection is not a specific objective of any EU legislation but it features in various legislation as a secondary objective. To close the gap the Commission proposed a Soil Thematic Strategy (COM (2006) 231) and a Soil Framework Directive (COM (2006) 232) in September 2006 that aspires to become a pan-European common framework for soil protection.

Land use changes are one of the most important drivers of soil degradation. Soil sealing occurs when agricultural or non-developed land is lost to urban sprawl, industrial development, tourist infrastructures or transport networks. In last decades the European Union's territory had undergone dramatic changes in land use. There are great variations among the Members States but as current average 4, 4% of the EU territory is classified as artificial surface, while 2, 3% is actually sealed. Between 2000 and 2006 the EU average loss increased by 3%, but by 14% in Ireland and Cyprus and by 15% in Spain. Soil sealing means covering of the soil by a completely or partially impermeable material or infrastructure (asphalt, concrete, building, etc) causing an irreversible loss of soil and its biomass production capacity and ecological functions as water regulator or temperature buffer.

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In this context there are also concerns that increased biofuels production may lead to inappropriate land management practices and increased level of soil degradation. To evaluate the impact of land-use changes due to biofuel production The European Commission (JRC) has developed guidelines to quantify changes in the amount of organic carbon in soils and biomass.

The paper features a perspective of the European efforts into delineate principles, measures and policies to face the challenge of to preserve soil resources as a key element in a changing environment under socio- economics and climate pressures.

Introduction

Historically, Soil Conservation Science has maintained a clear orientation towards agrarian production, with a long and significant record of scientific and applied contributions. These contributions have been of considerable relevance to humanity. However, in recent decades, there have been important changes towards more holistic objectives, including environmental aspects. It is anticipated that important and new scientific paradigms will develop, owing to the wide recognition of the fundamental role of soil in the support and functioning of terrestrial systems. In particular, there are emerging and important aspects related to soil protection that require scientific analysis and conceptual developments. These objectives include maintaining biodiversity, regulation of the hydrological cycle and water reserves, implications for the landscape, bioengineering for soil conservation, the tendency towards more ecological agriculture, the implications of global approaches, the agro-environmental implications of the production of biofuels and the role of soil as a source and sink of greenhouse gases and other interactions with weather change, such as desertification and salinization.

The challenge ahead for the EU Soil Protection is to elaborate schemes that could be considered valid and adequate for the economic, environmental, societal and political situation of the EU of today. The present political discussions should take into consideration how to meet the social and environmental demands on protecting the soil for the sound functioning of the biosphere.

The paper features a perspective of the European efforts into delineate principles, measures and policies to face the challenge of to preserve soil resources as a key element in a changing environment under socio- economics and climate pressures.

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Background

The concept of soil conservation/soil protection in its wider sense has undergone important changes through history. Perceptions of soil as a crucial base of life in ancient cultures progressively evolved to a more pragmatic vision, with close connection to food production for survival. For centuries, agrarian production and the provision of food for humankind remained for centuries as the main and crucial vision of the interaction of societies with soil. However, there are also some other new and important concepts related to soil which have progressively developed.

Soil conservation history shows important evolutionary stages, both in conceptual aspects and in technological-scientific developments (Rubio,2007). Some items of this evolution are mainly related to perception and to adaptation of new societal needs and demands. Progressively, farmers have been accumulating records and registers of performance of the land and plants in response to different practices. Therefore, over the centuries, basic adaptations to the potential and limitations of the natural environment underpinned successful approaches to the use of the land. The poor adaptation to the basic ecological conditions of the territory or the variability and impacts of extreme climatic events often represented failures in crop production and problems of famines or even survival. Food production is the 'leif motif' of agriculture and soil conservation. There is no need to insist in this aspect, considering the exponential growth of world population, food shortages and increased prices of basic foods. However, in developed countries the success in increasing the agrarian productivity and some socio-economic trends, resulted in substantial changes in the proportion of the population dedicated to agrarian activities. Furthermore, during the last third of the 20th century, society began to be increasingly concerned with impacts and environmental deterioration. Agricultural activities started to be critically examined. High yields, high productivity and surplus of agricultural products reduced the need for agricultural surfaces. Because of these tendencies, much land will probably undergo important changes in land use, at least in the EU and other developed countries. Newly abandoned land will require the development of new conceptual approaches and management schemes to maintain ecological functions, landscape features and biodiversity. In this new framework, soil conservation will have room for substantial contributions.

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The development of soil conservation is strongly connected to schemes of socio-economic development, territorial colonization and agricultural production, and has been recorded in abundant literature related to the history of soil conservation in different countries. The global phenomenon of the 'Green Revolution,' at a global scale, also implied new perspectives and adaptations of soil conservation schemes to the challenges of the demands for more soil productivity to cope with feeding an increasing world population. The recent developments on the world food shortage issues pose new demands for increased soil productivity, which impinges on soil conservation issues.

The Rio de Janeiro Summit of 1992 represented a landmark and a point 'of no return' in the consideration of the environmental dimension and implications of human economic activities, including agricultural and soil aspects. The subsequent UN Conventions on Biodiversity, Climate Change and Desertification globally institutionalized the need to incorporate new and more intelligent approaches in our interaction with our natural resources.

At present, globalization and new trade and market schemes are introducing new elements affecting agriculture and soil conservation. In these new global dimensions and more than before we still have the fundamental challenge to produce food for the inexorable demographic growth. Nevertheless and slowly, new visions and perceptions of soil conservation are evolving to include new aspects such as soil diversity, soil ecological functions, soil as a crucial environmental link, soil threats and new soil uses, besides the traditional role of soil for biomass production (agriculture, pasture and forest).

The European Strategy for Soil Protection

Soil resources in many parts of Europe are being over-exploited, degraded and irreversible lost due to inappropriate land management practices, industrial activities, forest fires, salinization and land use changes that lead to soil sealing, contamination, erosion and loss of organic matter.

The European Commission has being developing proposals for soil policy for many years but to date soil protection is not a specific objective of any EU legislation but it features in various legislation as a secondary objective. To close the gap the Commission proposed a Soil Thematic Strategy -STS (COM (2006) 231) and a Soil Framework Directive-SFD (COM (2006) 232)

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in September 2006 that aspires to become a pan-European common framework for soil protection.

The antecedent of the STS and SFD is the EU initiative launched in April 2002 through the Communication of the EU Commission entitled 'Towards a Thematic Strategy for Soil Protection.' This document is a comprehensive analysis of the situation of Europe's soils, highlighting the importance and dimension of soils as a threatened and non-renewable natural resource. This European approach is cleraly innovative in the sense of incorporating new and wider environmental perspective. The efforts of the EU are oriented to a wider consideration of the role of soil and its environmental functions.

The main soil functions considered in the EU Strategy for Soil Protection are:

a. Biomass production, including agriculture and forestry
b. Storing, filtering, transforming nutrients, substances, water
c. Biodiversity pool, habitats, species and genes
d. Physical and cultural environment for humans and human activities
e. Source of raw materials
f. Acting as carbon pool
g. Archive of ecological and archaeological heritage

The Strategy also identified eight threats to soil:

a. Erosion (including also desertification)
b. Decline in organic matter
c. Soil contamination
d. Salinization
e. Biodiversity loss
f. Compaction
g. Soil sealing
h. Floods and landslides

It was created an Advisory Forum, a Secretariat and five Technical Working Groups (Monitoring, Erosion, Organic matter, Contamination and Re-

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search) wich developed an intensive activity elaborating several important documents as background information on the status of soil and soil problems in Europe. The documents and publications can be downloaded in http://www.ec.europa.eu/environment/soil.

After a promising start come a long period of several years of discussions, negotiations and confrontations owing to the different economic, political and social interest of the EU State Members and stakeholders related to soil.

Finally in September 22, 2006, as mentioned, the European Commission proposed a Soil Thematic Strategy (STS) and a proposal of a Soil Framework Directive (SFD).

The objective of the Soil Thematic Strategy is the "protection and sustainable use of soil by preventing further soil degradation and preserving its functions and also restoring degraded soils to is functionality and considering cost implications" (COM 2006, 231).

The STS includes four pillars:

a. the development of a framework legislation
b. integration and horizontal implications
c. identification of knowledge gaps on soils
d. the need to enhance public awareness in relation to soil

The STS also includes the identification of Specific Risk Areas related to Erosion, Organic Matter Decline, Soil Sealing, Contamination and Landslides.

The integration of STS on existing EU policies is emphasized. Its includes

a. Environmental, Nature and Landscape Policy
b. Agricultural (CAP reform) and Forestry
c. Rural Development
d. Energy, Industry and Transport Policy
e. Research Policy

The Soil Strategy received favourable opinions from the Committee of the Regions (February 2007) and the European Economic and Social Committee (April 2007)

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Also the first reading by the European Parliament adopted in November 2007 was in a favourable opinion on the Soil Strategy by supporting the Commission in its general approach and underlining the importance for climate change mitigation, biodiversity loss and desertification

The European Parliament also adopted a favourable opinion on the Directive. In the amendments adopted the EP maintained all the key elements of the Commission proposal, providing more flexibility in some provisions and strengthening others.

Despite these positive and important decisions the Soil Strategy confronted many problems. The difficulties in the development of a proposed Soil Framework Directive implies not only conceptual and technological disagreements between EU national members. There are also societal problems related to the absence of a shared common vision on Soil Protection under legislation, scope of protection, economic considerations, definitions and governance aspects.

Again we faced another long period of intense discussions between all soil actors and Members Sates. Particularly during the active Portuguese Presidency of the EU in 2007. Substantial changes were introduced in the Presidency compromise texts in the direction of adding flexibility and more margin of manoeuvre for the Member States. However the European Council did not reach a political agreement on 20 December 2007, despite numerous efforts by the Presidency. Five Members States (Germany, France, United Kingdom, The Netherlands and Austria) formed a blocking minority again the favourable opinion of the majority of twenty-two Members States. The negative decision was for reasons of subsidiarity in the case of DE, NL, AT and of proportionality/costs in the case of UK and FR.

In summary the present situation is that after a thorough development process we have the STS adopted by the Commission on 22 September 2006 (EC, 2006) which approaches a wide range of soil threats and creates a common framework to protect soil. "Its objective is to halt and reverse the process of soil degradation ensuring that EU soils stay healthy for future generations and remain capable of supporting the ecosystems on which our economic activities and our well-being depend" (JRC,2012)

Hopefully, the EU Strategy will open the door to conceptual and practical implications of soil as an important regulating system of both climate and the water cycle. The implications of the 4th IPPC Report and its alarming projec-

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tions oblige us to consider the potential of every natural system to buffer the trend of global warming. The regulating capacity of soil in relation to gases with greenhouse effects (such CO_2, methane and nitrogen oxides) and its role as a source of dust and aerosols, deserves attention for its strong potential for both conserving soil and contributing to ameliorating the rapidity of climate change. Perspectives on water scarcity are also linked to soil. Evaluations and prospective analysis from international organizations (e.g. the UN, EEA, OECD, WRI and WWI) unfold a worrying future panorama. The three developments in aggravating water scarcity are: permanent and sustained increases in water demand (persistent since 1950); reduction in precipitation owing to climate change (drylands) and loss of the soil regulating capacity. This last aspect is clearly linked to the need to promote good soil stability and soil health to increase its important role as a regulating system of infiltration/runoff and as a water reservoir.

Land use change and soil sealing

Land use changes are one of the most important drivers of soil degradation. Soil sealing occurs when agricultural or non-developed land is lost to urban sprawl, industrial development, tourist infrastructures or transport networks. In last decades the European Union's territory had undergone dramatic changes in land use. There are great variations among the Members States but as current average 4, 4% of the EU territory is classified as artificial surface, while 2, 3% is actually sealed. Between 2000 and 2006 the EU average loss increased by 3%, but by 14% in Ireland and Cyprus and by 15% in Spain. Soil sealing means covering of the soil by a completely or partially impermeable material or infrastructure (asphalt, concrete, building, etc) causing an irreversible loss of soil and its biomass production capacity and ecological functions as water regulator or temperature buffer. According to the report "Overview of best practices for limiting soil sealing or mitigating its effects in EU-27. Final Report" (Unweltbundesamt, 2011), most social and economic activities depend on the construction, maintenance of sealed areas and developed land. New housing, business locations and road infrastructure are mostly realized on undeveloped land outside or at the border of existing settlements, usually resulting in new soil sealing.

Between 1990 and 2000, land take was around 1000 km^2 per year (275 hectare per day) within the territory of EU27 and artificial surfaces increased

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by 5,7%. Between 2000 and 2006 high increase of artificial land with more than 7, 5% were observed in the Netherlands, Portugal, Ireland, Cyprus and Spain.

Tier 1: Prevention of Soil Sealing.
To "pave the way" for successful prevention of soil loss the following basic principles need to be implemented at the policy level:

- to establish the principle of sustainable development in spatial planning
- to define realistic land take targets for the national and the regional level
- to integrate the "prevent, limit, and compensate" principle for soil loss in all policy sectors
- to streamline existing funding policies accordingly (i.e. public funding for private housing, subsidies for developments on the green field sites, commuter bonuses, etc.)

According to the individual regional needs the following key action lines are proposed:

- to steer new developments to already developed land
- to provide financial incentives for the development of brownfield sites
- to improve the quality of life in large urban centres
- to make small city centres more attractive to counteract dispersed settlement structures in rural regions with shrinking population
- to designate agricultural soils and valuable landscapes with development restrictions

Tier 2: Limit Soil Sealing as far as possible
Whenever soil loss is unavoidable, mitigation measures shall be implemented as far as possible, this can be realised by,

- respecting soil quality along planning processes and steering new developments towards less valuable soils
- by applying technical mitigation measures to conserve at least a few soil functions (i.e. permeable surfaces on parking areas)

Tier 3: Compensate soil losses
For specific infrastructure developments even top quality soils will be lost and valuable landscapes fragmented. In such cases controlled compensation measures shall be carried out to facilitate soil restoration measures somewhere else where they make sense. This can be achieved by,

- establishing qualified compensation measures
- facilitating new opportunities

Figure 1. The "prevent — limit — compensate" principle for soil sealing. Source: Umweltbundesamt. 2010

In 2006 almost 2, 3% (100 000 km^2) of the EU´s territory are actually sealed and each EU citizen was on average stocked with 200 m^2 sealed surface.

Some of the policy and measures to reduce land take and soil sealing includes:

a. Improvement of quality of life in large urban centers
b. Brownfield development
c. Protection of agricultural soils and landscapes
d. Sustainable spatial planning
e. Policy targets for land take
f. Technical measures to mitigate soil sealing

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g. Compensation measures for soil loss

h. Consideration of soil quality along planning processes

In the following box it is show the scheme of the "Prevent-limit-compensate" principle of soil sealing.

Biofuels

There are concerns that increased biofuels production may lead to inappropriate land management practices and increased level of soil degradation and GHG emissions.

According to the report "The state of Soil in Europe" (JRC, 2012), there is considerable interest in the possible impact of increased biofuel production on soil quality and soil functions. The conversion of sugars from bioenergy crops into fuel or biomass into liquid fuels such as ethanol and biodiesel or gaseous fuels such as methane are increasingly being regarded as sustainable alternatives to fossil fuels. To assess the impact of land- use due to biofuel production, the JRC has developed guidelines to quantify changes in the amount of organic carbon in soils and biomass (Carré et al., 2010; Hiederer et al., 2010). The guidelines follow the IPCC guidelines for national GHG inventories and are supported by comprehensive global data processed by the JRC. The guidelines formed the basis for the European Commission's decision on the guidelines for the calculation of land stocks. Based on the guidelines, a method was developed to estimate GHG emissions from land-use changes due to biofuel production.

New demands for soil protection

Today's soil conservation frameworks should expand to include new perspectives and interlinkages in the context of the integrated functioning of terrestrial ecosystems. However, it is crucial that we maintain essential aspects from previous schemes, including maintaining soil fertility and improving soil-water interactions. Today we can see a steady trend in the pattern of soil use in Europe, with important future consequences for landscapes and the functioning of terrestrial ecosystems. This trend, which is also a world trend, represents a change of soil use from the traditional ones (agriculture, pasture and forestry), to relatively new ones that will increase in relative importance (i.e. nature conservation and urbanization). This trend of change should be

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seriously evaluated for its implications on soil conservation and soil quality in the context of multiple uses and multi-functional approaches. Under this perspective, an important question arises: for what purpose should soil conservation be oriented? As we have highlighted above, agricultural aspects have been the core of soil conservation, but now we should consider new conceptual schemes. These affect the standards we apply to our present evaluation of soil quality. For example, a salt-affected soil is of poor quality for agriculture. However, saline soils imply a special terrestrial ecosystem with specific pedoedaphic conditions that support adapted and specialized vegetation. In turn, this contributes to the richness of biodiversity and landscape diversity. The same considerations apply to wetlands soils. They are unsuitable for agriculture, but they play crucial roles for nature conservation, by maintaining singular sites of specialized fauna and flora, thus also contributing to landscape quality. Therefore, we have soil types that should not be used for agriculture, that need new schemes for their adequate management and protection, including standards and indicators of quality soil. These considerations should be expanded to further develop soil conservation to include the implications of soil as a natural entity with intrinsic diversity expressed in different soil types. The various soil types have different properties, characteristics, system dynamics, potential for uses and functions and responses to impacts.

Modern society places demands on the soil science community to develop new ideas, new information schemes and new conceptual developments to deal with new perceptions of the role of soil in the global and local functioning of terrestrial ecosystems. The demands for biodiversity maintenance (including pedodiversity), carbon cycle regulation, combating desertification, food production, water resource regulation and landscape maintenance require new soil protection paradigms that should be developed under soil multifunctional and multiuse approaches. The concept of soil as a crucial and menaced natural resource demands a general framework for sustainable use of soils that should be developed under the wider consideration of soil as a multifunctional medium, including new technological developments in soil management in accordance with ecological principles.

A multidisciplinary and coordinated effort to further develop a conceptual scheme on Soil Protection should include attributes of soils as a multifunctional medium, with soil quality for different uses, and strategies to include soil protection within a wider soil sustainable management framework.

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Chapter 15

Re-discovering our values; hope for the future

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Introduction

At the New Delhi meeting of ISCO we explored the merit of knowing more about our roots and the wisdom that indigenous populations could impart to us about the sanctity of nature and the need for reverence of all life. The global situation today is graver and it is time for us to re-discover our values as the major source of hope for the future. The openness and willingness to help others has always been a part of ISCO and it reminds me of greeting each other with a "Hello, ISCO" meaning that "I'm Seeking Collaborative Opportunities".

As a prelude to some philosophical considerations, it is often helpful to let your mind relax and take a break from the personal cares and problems that each of us face at this moment. I commonly do this by imagining scenes that I like and they help me shift gears. For example, imagine the subtle sunset on distant Patagonian mountains as the day slowly eases into twilight, or the wonderful sets of flooded rice terraces in southern China where for several millennia people have found solutions for their existence and survival while making the terraced landscape a thing of beauty. The patterns displayed by strip cropping of corn and hay on gently undulating slopes reveals an artistry

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best seen from above and one senses the serenity of a harmony of man and nature. An image of tractors working the land adjacent to the high rise buildings of the nearby city reminds us of the growing conflict of land uses as our populations increase so rapidly.

Because my motivation is to improve your memory, I ask you to imagine two barnyard figures. One is a holy cow, that is a cow with a halo overhead, and the other is a big fat red rooster, both of whom will be symbols to help you remember something very important. And lastly imagine an apple that has been carved and sculpted to resemble our planet. It is a reminder that our world relies on food most of which is derived from the land.

Some things we know

For all of the exploration of the cosmos, it appears that we are all alone. Within our Milky Way Galaxy we are the only "blue planet, the one whose surface is 70% water. Unfortunately it is not potable for humans. As humans we have a vision, a mission, and a passion to provide care for this globe. It is up to us because there are no outsiders. It is a grand challenge and we would like to be the "good hands people" helping the cause.

History, both geological and environmental, along with the events of civilization has one constant and consistent record. It is the fantastic story of change. We live on a restless earth; change is sustainable, it will happen, it will bring responses – physical, biological and for us , also mental.

Consider that there are limits to growth on our planet. A simple graph shows a fixed amount of natural resources combined with an exponentially increasing amount of consumption of those resources. This model has been with us a long time and we know it, but often choose to ignore it. As consumption continues it eventually crosses a threshold and continues to rise, but then it starts a downward trend and the supply of resources cannot keep up and over time the system collapses giving rise to much lower amount of resources and a markedly decreased consumption of goods and services. Collapses of past civilizations have experienced this for their limited territories. We crossed the threshold in about 1980 and currently use the resources equivalent to 1.25 worlds.

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Wisdom from the past

It is extremely important that this ISCO meeting is in Colombia, South America. We need help because the 'Rio+20' conference last year offered hope but there is still a lack of concerted effort to promote sufficient global mitigation activities. Let us consider another vision of hope for our future. To the north of us is the Sierra Nevada de Santa Marta, known locally by the Kogi people as "the Heart of the World". It stretches from the warm Caribbean Sea to the highest snowcapped tropical mountains on Earth. It is fabulous.

The indigenous tribes believe Mother Earth has made them the guardian of our Earth. Their shamans, the wise men and women who are keepers of the wisdom are called Moma's. They have spent many years learning the ways of ' the life of the mind' and the heavy responsibilities of caring for our Mother Earth. They are the Elder Brothers and we, you and I, are the Younger Br others. Several decades ago they issued a warning,

"Younger Brother. Stop doing it. You have already taken so much. We need water to live. The Mother told us how to live properly and how to think well. We are still here and we haven't forgotten anything ".

Because the Kogi are the keepers of the Heart of the World and struggle to live in harmony with nature, they began to notice declines in the snows, running water, and biodiversity qualities indicating serious changes in the health of the world. They strongly urge the Younger Brothers to change their ways before it is too late to save Mother Earth.

More recently another Elder, speaking through an interpreter said to us,

"You may speak the different languages of the world but it does not suffice to speak them; you need to know the language of Nature; the language of all that surround us. It is full of experiences, full of life, and if you do not understand that in this way, it is because you use only those objects that please you."

These views stand out as especially cogent and moving pleas for ecological wisdom by all humanity.

Some current wisdom

A few years ago a group from one of the United Nations universities evaluated the values of people of different ages, genders, races, cultures, and

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economic and social status. Their work supported the ideas of Dr. Kidder about five values that shape beliefs which in turn shape actions and responses. These five are: honesty, compassion, fairness, responsibility, and respect. These are ideals of what people value in interpersonal relationships. If we actually let these values guide our actions, would the world change for the better? That is, more or less, the question and challenge of today, isn't it?

I like very much this saying of Rev . Coffe, *"the world is too dangerous for anything but truth,and too small for anything but love*". Sounds like the first two values listed above. And a saying attributed to L. Tsu about economics and the balance of positive and negative feedback is "*To know when you have enough is to be rich"*.

Globally we are in an overshoot mode of operation, as was indicated by crossing the threshold between supply and demand of natural resources. Stabilization is obviously desirable as we try to figure out meaningful balances between positive and negative feedbacks. We know that sustainability is not a technological issue, it is a morality and human rights issue. The 20th century was not only the age of awesome technology development; it also produced the most horrendous means of destruction ever known. We were neither riche, nor wise!

Looking ahead

There are many questions about what will happen on the near horizon, that probably is a given. But if we gaze farther, there is Hope on the far horizon. A blind paleontologist, Professor Vermeij, has increased sensitivity which enables him to better understand why and how sea shells evolve through the millennia. He believes that we may be reaching a tipping point that we haven't seen for a very long time in geological history. He says that conservation must go beyond simply protecting the complement of plants and animals we know today, and focus on preserving their capacity to adapt in the face of change. He says that adapting to environmental change has always been guided by the principle of "redefining what it means to thrive". With this in mind, there is HOPE.Let us consider a "what if" proposition. What if the universal values are also a part of the language of nature? What if Mother Earth with her restless lands with whom we interact, also understands and responds to our actions based on the beliefs of these values?

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Honesty – learning to be truthful about what we know about soils, land, water and biology. How about a realistic cost accounting of what we plan and do and produce. And these for all uses of land everywhere. What a daunting challenge that is!

Compassion – caring for land, soil, and all natural resources so that their responses will not be in constant conflict with our desires and needs for human development. When I see hilltop strip mining I have empathy for the hill and its ecosystems.

Fairness – what is fair about the way we treat the Earth? We act as though it is ours and not just a temporary loan. Domestication of animals and plants and the advent of people as food producers changed our minds about land and who has right to it.

Responsibility – means being accountable for our responses and our actions, in many different ways and under a myriad of circumstances. We can try to pass on our guilt but the Earth does not judge. For that, we may be lucky.

Respect. We have to earn it. If we do not believe the above values and let them guide our actions, who or what will ever trust us? All life need air, water, food and shelter and if we truly respected these needs there could be peace and a harmony of civilization and nature.

Now with all of this wandering around in our minds, I have two gifts for us. They are symbols that help us recall these values of the language of Nature. The first gift is a holy Cow – she reminds us of Honesty and Compassion. The second gift is a Fat Red Rooster – he reminds us of Fairness, Responsibility, and Respect.

Concluding remarks

Because I am a pedologist I would like to remind us that soils do not make judgments, they only can respond. A society once decided to cut down the forest, dig out the stumps and grow food crops. The soils were so poor in nutrients that almost nothing grew, even ten years later.

Pedology teaches us that Soils Offer Important Lessons, if we choose to be students. It is well to remember that we are defined not only by what we create, but more so by what we refuse to destroy.

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In closing I leave you with a burning question from Rabbi Nahman in the 18th century,,

"If you won't be better tomorrow than you were today, then what do you need tomorrow for?"

You have five fingers to remind you of the language of nature. Five little words of wisdom:Honesty, Compassion, Fairness, Responsibility, and Respect. This is our vision and our hope for tomorrow.

Acknowledgements

When working on a Powerpoint presentation I get so engrossed with pictures and my thoughts that I do a terrible job of giving appropriate recognition for the sources. I would not intentionally plagiarize any writings or pictures and I apologize for such oversights. I sincerely thank the sources for their wonderful triggers of imagination they have provided me.

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