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## Desertification under climate change and changing land use in Mediterranean environments

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**1. Introduction**

The processes of land degradation affect the conservation of soil and water resources, because they are strongly linked to unfavourable changes in the hydrological behaviour affecting soil water balance and soil moisture regime. They are related to soil and climate characteristics, but inappropriate land use and management is the main factor responsible of those processes. In the past decades, the degradation of previously naturally vegetated or productive agricultural lands, leading in many cases to barren, desertified, landscapes, has dramatically extended in many regions of the World. The reasons are mainly unfavourable biophysical conditions and negative human impacts. The negative human impacts are mainly through inadequate land use, including deforestation, overgrazing, and deficient agricultural practices, leading to soil erosion, salinization and vegetation degradation, as a consequence of drastic changes in the water balance. This might be further aggravated by the ongoing threat of climate change (Figure 1).

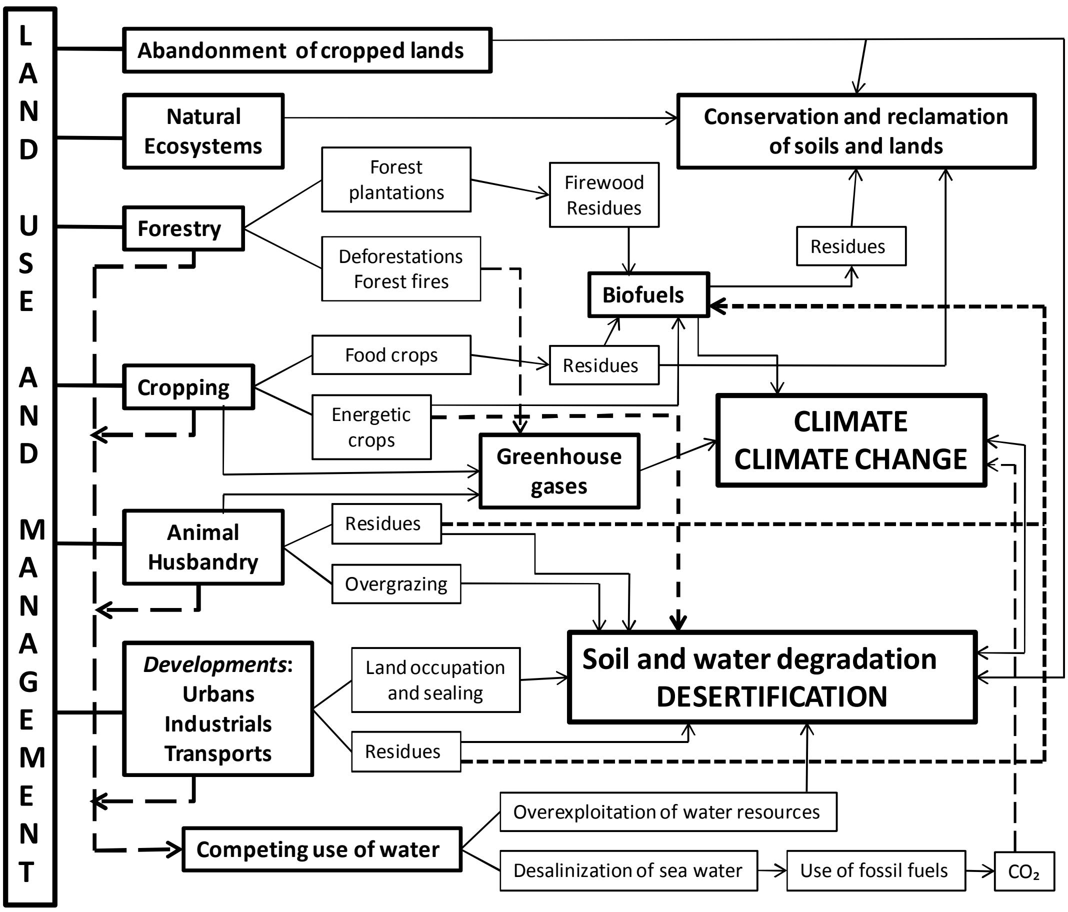


Figure 1. Relations between land use and management and climate change with soil and water degradation and desertification (Pla, 2007)

Land degradation in the more vulnerable areas with arid and semiarid climate in the Mediterranean region goes back over millennia (Dupre, 1990). The most important human actions that have triggered or intensified the processes of land degradation have been overgrazing, deforestation and forest fires, and in recent decades new land management practices, associated to agricultural intensification, mechanization, inadequate maintenance or abandonment of vast areas of terraced agriculture, over-drafting of surface and groundwater for irrigated agriculture, tourism, etc. (EC, 2003). These new land use and management practices are a consequence of changes in social economic conditions, market prices and public policy-led subsidies, consumption patterns, etc, associated to technological progress and changing production systems. Land degradation has affected more hilly sloping lands, but in valley bottoms where irrigation is being used for increasing productivity, salinization and sodification have become a widespread form of soil degradation. There are evidences that land degradation processes leading to desertification in the Mediterranean region are getting worse, because of different or mixed causes varying from one place to the other (EC, 2003).

The prevention and choice of solutions for the problems of land degradation leading to desertification must depend on the right identification of the processes involved and in the precise analysis, diagnosis and understanding of the causes and potential effects at specific places. Not doing so may lead to catastrophic effects. Despite the modernization of observation facilities by the use of satellite imagery and computer programs to analyse the data, there are still many uncertainties at the regional and national levels in the Mediterranean regions, on the causes, the extent and the seriousness of land desertification. These uncertainties prevent those who manage land resources from planning properly, and introduce constraints in operation of early warning systems with regard to agricultural production and disasters such as flooding and landslides (Pla, 2006).

## 2. Hydrology and desertification in Mediterranean environments

Water, that is often the main limiting factor of plant growth, is also the main factor directly or indirectly responsible for soil and land degradation processes. These processes are strongly linked to unfavourable changes in the hydrological processes responsible for the soil water balance and for the soil moisture regime, which are affected by the climate conditions and variations, and by the changes in the use and management of soil and water resources (Pla, 2002a).

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

| | % RUNOFF | AVAILABLE SOIL WATER RETENTION CAPACITY 50 mm | 100 mm | 200 mm | 400 mm |
|---|---|---|---|---|---|
| **DRY YEAR R: 300 mm RP: 5 years** | **0 %** | **93 d/y**** | **100 d/y*** | **100 d/y*** | **100 d/y*** |
| | **50 %** | **56 d/y**** | **56 d/y**** | **56 d/y**** | **56 d/y**** |
| **AVERAGE YEAR R: 500 mm RP: 2 years** | **0 %** | **150 d/y** | **193 d/y** | **200 d/y** | **200 d/y** |
| | **50 %** | **122 d/y*** | **136 d/y*** | **136 d/y*** | **136 d/y*** |
| **HUMID YEAR R: 800 mm RP: 10 years** | **0 %** | **196 d/y** | **207 d/y** | **230 d/y** | **266 d/y** |
| | **50 %** | **187 d/y** | **195 d/y** | **202 d/y** | **202 d/y** |

**(d/y** : Critical for any kind of crops including perennial crops as vines and olives; d/y* : Critical for annual crops like cereals (wheat, barley) and some new introduced varieties and planting densities of vines; R : rainfall/year; RP : return period)**

The soil moisture regime, determined by the changes in soil water content with time, is the main single factor conditioning moisture availability, plant growth and crop production. It is mainly conditioned by soil properties affecting the capacity and possibilities of infiltration, retention and drainage of rainwater, and the limitations to root growth under the particular rainfall characteristics (Pla, 2002a). These conditions may be modified by soil and plant management practices as tillage, irrigation, drainage, etc. Moisture availability is determined both by water gains from precipitation and water losses through runoff and evapo-transpiration (Table 1).

In the arid and semiarid Mediterranean climate, the rainfall is highly variable among years and during the year, and usually occur in erratic storms of short duration and high intensities. The concentration of rainfall in a relatively cool season (autumn and winter) permits reliable cropping in areas with annual rainfall as low as 330-400 mm (see Table 1). Under non-protected soil surface, associated to some intensive agricultural practices and overgrazing, extra precipitation in winter, occurring in intense episodes, may not be stored in the soil, but lost as runoff (Pla and Nacci, 2001). These factors increase the risks of land degradation leading to desertification processes. The previewed effects of global climate changes would mainly affect hydrological processes in the land surface, mostly related to the soil water balance. In terms of ecological and social impacts of climate change, changes in moisture availability are more important than changes in precipitation alone. Low levels of moisture availability are associated with droughts and desertification. Reductions in mean annual rainfall leads to drier conditions, but increase in climate variability during the year, or increasing frequency of very dry years, could be equally or more important. Therefore, the term aridity for evaluating desertification, instead of only considering average rainfall conditions, would be more appropriate if it also consider variability through the whole hydrological cycle as well as climatic variations and fluctuations.

Human activities leading to land degradation processes may affect more the soil hydrological processes than the previewed climate changes, or may increase the influence of those changes (Pla, 2001). Forests usually regulate stream flows, protect land from erosion, reduce flooding in adjacent areas, minimize the silting of rivers, canals and dams, and contribute to a stable hydrology essential for providing stable sources of water for human needs and irrigated agriculture. This water balance may be drastically upset by deforestation and forest fires, and especially by the consequent land degradation. Supply of available water may decrease irreversibly under unchanged soil properties and stable hydrological soil parameters due to reduced water income, increasing water consumption, or both. Under unchanged water income by rainfall, the hydrological parameters of soils may change irreversibly as a result of soil degradation (sealing, compaction, erosion, decreased water holding capacity, etc), leading to the same effects of decreasing available water supply (see Table 1).

Irrigation causes drastic changes in the regime and balance of water and solutes in the soil profile, which may result in soil salinisation, one of the processes of soil degradation leading to land desertification. The salinity problems are a consequence of salt accumulation in zones and depths where the soil moisture regime is characterized by strong losses of water by evaporation and transpiration, and by reduced leaching of the remaining salts. The salt accumulation may conduce to a partial or complete loss of soil capacity to provide the required amounts of water to plants, changing fertile lands to deserts (Pla, 1996).

From the previous arguments, it follows that approaches based on water balance models are the more adequate to predict the reliability of the water supply for a plant during its growth. This would be the main basis for determining the suitability of the land for various uses under given conditions of management. There is required research into the basic hydrological processes of land degradation, including climate and soil data. Research is also required on the hydrological changes as a result of various alternative land uses and agricultural systems and practices. The degree of aridization of soil may be quantitatively determined in terms of certain physical properties and water regime of soils (annual supply of available water in the root zone), using soil hydrological parameters (Pla, 2006).

## 3. Evaluation of desertification in Mediterranean environments

There is required a large scale integrated assessment of land/soil degradation and desertification in the Mediterranean region, in order to formulate the related prevention and mitigation strategies. Assessments should begin at the local levels, rather than begin at the global or regional levels. The assessment must include past trends, current state and prospective development of soil degradation and land desertification, which should be based mainly in soil hydrology related indicators. The most serious constraints are due to the soil data provided by the national soil surveys, which is mainly static information without any indication on changes and trends, very important for environmental protection purposes. There are also required soil monitoring systems, aim to deliver information on changing soil parameters, important for soil functions, based on systematic sampling and measurements.

Rainfall, which is very variable in the arid and semiarid Mediterranean climates, becomes the most fundamental data source for monitoring desertification. Also there is required a systematic tracking of vegetative production and soil conditions. A watershed approach for the biophysical resources would help to effectively integrate the information for estimating degradation processes. For tackling large watersheds, it is recommended to carry out first a reconnaissance level analysis of the problems to identify the areas that need focused attention, and then launch a detailed analysis in the targeted small areas.

Assessment and monitoring of desertification have the primary objective to forewarn about some impending crisis of land degradation and desertification, as well to suggest some preventive and remedial measures. These objectives cannot be met without a proper understanding of the processes responsible for desertification, which is the main limitation with the empirical methods generally used presently for assessing desertification and land degradation. There are required other methods, based on hydrological evaluations, to evaluate the problem. In most of the cases a weak knowledge of the hydrological processes involved and of the nature of desertification, and the inadequacy of the methods for the assessment and monitoring of such processes hamper the adoption of integrated use of soil and water resources and of management policies and rehabilitation programs (Pla, 1998). Oversimplified indices like drought, using climatic maps; vegetation cover, using satellite imagery, and others, which fluctuate year after year, have limited diagnostic criteria (UNCCD, 2003). When mostly qualitative indicators are used, elements of subjectivity are many times involved in the assessment of desertification, depending on interpreters experience or bias. There is a need for searching more acceptable and easily determinable criteria that are measurable.

It may be concluded that in order to assess and to predict adequately desertification there is required the collection of sufficient field observations and data, mainly of hydrological nature, to reflect temporal and spatial conditions and variations. This information would be used for the identification of the causal processes and for the development, calibration and use of simulation models that can predict future changes. In all cases the used criteria must be clear, relevant, environmentally specific and scale-specific.

**4. Modelling desertification**

The existing criteria of desertification, based mainly on climate and vegetation cover, have limited diagnostic criteria. The use of the so called soil quality attributes and indices to assess the vulnerability of soils to degradation and land desertification processes, scored from empirical judgements, do not allow to relate the evaluation to the overall sustainability of alternate land use systems for production, control of environmental impacts, etc. There are needed other ways to evaluate the problem.

An hydrological approach to the assessment and prediction of the conservation of soil and water resources against degradation and desertification processes, has proved to be essential for an adequate development, selection and application of sustainable and effective land use and management practices (Pla, 1998; 2001). The increased requirements of more quantitative results in probabilities and risks of soil degradation and land desertification, and its influence on crop production and environmental damage may be partially satisfied with the use of modelling, where the large number of important variables involved in the desertification processes, and their interactions, may be integrated. Analysis and suitable modelling of data and processes helps to find out the trends in desertification and the responsible factors, under different bio-physical and social-economical settings. Modern techniques of digital remote sensing and geographical information systems (GIS) may be very helpful in the analysis and processing of the original and generated information. Modelling desertification requires a previous identification of the main desertification processes. Appropriate models must help in gaining more insight into the processes and on the understanding of the system as a whole. Although models cannot replace deciders, they supply them with valid and quantitative alternatives, required to take successful actions. In any case, simulation modelling has to be used with caution and should be based on sufficient local information. Field-based information is essential, and data obtained through digital remote sensing need to be verified in the field to be useful (Pla, 2002b).

Empirical models, like the so called Universal Soil Loss Equation (USLE) and its revised version RUSLE (Renard et al, 1991) have been commonly used in the countries of the Mediterranean region, frequently without verification, for large scale water erosion (one of the more important soil degradation processes leading to desertification) risk mapping. Although the outputs and mapping using GIS may be impressive, they can hardly be used with a guaranty of success for development or prevention of desertification purposes (Pla, 2002b). There are required other non empirical modelling approaches mainly based on soil hydrological processes, deduced from soil hydrological properties together with historical rainfall records, under different scenarios of changing climate, soil properties, topography, and land and crop management, which may be combined in computer-based programs. The bio-physical data, mainly of hydrological nature, may be taken as surrogates for human impact, but in some models the social economic data are also fed into calculation procedures with variable success. Simulation models based on hydrological processes may be very helpful to integrate and convert the measured or estimated soil, climate, plant and management parameters into predicted soil water balances and soil moisture regimes for each particular combination of them, actual or previewed (Pla, 2002b). These models not only help to understand the complex process of desertification, but they may also serve as decision-making tools to reduce or to avoid negative environmental impacts leading to desertification under different and changing scenarios (Richter and Streck, 1998).

Hydrological approaches allow to combine the characteristics of climate with the characteristics of soils and landforms and land-use systems, for interpretation and prediction of land desertification hazards. When applied to a series of scenarios of land use and potential environment and climate change impacts, the results can be used by decision makers for future land use planning and implementation. This approach also makes the extrapolations more soundly based and provides a scientifically solid base which leaves little space for subjective interpretations leading to alternatives for different land use and management for agricultural and non-agricultural purposes. Modelling hydrological processes has proved to be a very reliable tool for evaluation and prediction of land degradation processes for guiding planning strategies for soil and water conservation and management practices, under very different climate, topography, soils, cropping and management conditions (Pla, 1997; 1998; 2001; 2002a; Pla et al. 2005).

## 5. Conclusions

A hydrological approach to the assessment and prediction of conservation of soil and water against desertification processes is essential for an adequate development, selection and application of sustainable and effective land use and management practices. Weak knowledge of the hydrological processes involved, and of the nature of desertification, and the inadequacy of methods for assessing and monitoring of such processes, usually hampers the adoption of integral resources use and management policies and rehabilitation programs in areas subjected to desertification in the Mediterranean region. The assessment of the degree of land desertification will require research on the water regime of soils under desertification, using an adequate methodology. Without such research, other considerations of degree of desertification will be mostly subjective, being based on indirect criteria and not in the direct measurement of hydrological parameters.

The evaluation of the hydrological processes, under different scenarios and changing climate, soil properties and land use and management, with flexible simulation models based on those processes may help to predict and to identify the biophysical causes of desertification at local, national and regional levels in the Mediterranean region. This is a required previous step for a rational land use planning, and for the selection and development of short and long term strategies and technologies to reduce or to control land degradation processes leading to desertification, and to the related social economic and security problems.

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