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Impacts of agricultural practices on soil and water quality in the Mediterranean region and proposed assessment methodology

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Abstract

In countries around the Mediterranean basin, the degradation of soil and water resources is a serious threat for the human welfare and the natural environment as a result of the unique climate, topography, soil characteristics, and peculiarities of agriculture. The detrimental effects of agricultural practices on soil quality include, erosion, desertification, salinization, compaction, and pollution. The resultant impacts on water resources include pollution due to nutrient and pesticide leaching and intrusion of seawater into aquifers. In order to select the appropriate sustainable strategies for preventing those impacts, research should focus on development of an accurate soil quality monitoring system at multiple scales based on a functional evaluation of soils. The objectives of this work are: (a) to point out the peculiarities of the Mediterranean region; (b) to underline the most important impacts of agricultural practices on soil and water quality, in respect to the above peculiarities; and (c) to propose a simple and cost effective methodology for the assessment of soil quality at a watershed scale, based on zones of specific functional interest. The proposed assessment methodology would provide information about the status of the soil resources, correlate soil quality with management and aid with the development of sustainable management practices.

Keywords: Mediterranean; Agriculture; Soil quality; Watershed; Assessment methodology

1. Introduction

The dramatic change of agricultural practices during the last 50 years is one of the main driving forces for environmental degradation in the Mediterranean region especially through its impacts on soil and water resources. Food and fiber productivity soared due to new technologies, mechanization, increased chemical use and governmental policies that favored maximizing production. Although these changes have had many positive effects on farming, there have also been significant costs. Prominent among these is the

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degradation of soil and water resources (Lal and Stewart, 1990). In the last decades there is an increasing interest in crop production systems that optimize yields while conserving soil, water, energy, and protecting the environment (Stamatiadis et al., 1996). This interest for sustainable agriculture is garnering support and acceptance within mainstream agriculture.

Soil quality is a critical component of sustainable agriculture. While the term soil quality is relatively new, it is well known that soils vary in quality and that soil quality changes in response to use and management. The soil system is characterized by attributes that both range within limits and interrelate functionally to each other. Therefore, these attributes can be used to quantify soil quality (Larson and Pierce, 1994). Additionally, soil is an open system, with inputs and outputs, that is bounded by other systems collectively termed environment (Jenny, 1941). Sustainability then, while multidimensional, is certainly focused both on the quality of the soil resource base, the relations between its use and management, and the environment (Larson and Pierce, 1994).

Soil quality is defined by Doran and Parkin (1994) as "the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health". Soil functions derive from the physical, chemical, and biological processes that take place within the soil as a result of the soil attributes. The soil functions as proposed by Karlen et al. (1997) are as follows:

- sustaining biological activity, diversity, and productivity;
- regulating and partitioning water and solute flow;
- filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric deposition;
- storing and cycling nutrients and other elements within the earth's biosphere; and
- providing support of socioeconomic structures and protection for archeological treasures associated with human habitation.

Many agricultural practices cause alteration of soil attributes that result in soil malfunction and, ultimately, in the degradation of soil and water resources. The major objective of soil quality assessment is to predict, from the knowledge of soil properties, the ability of the soil to support specific quality/health functions for the crop, animals–humans, and water target systems (Harris and Bezdicek, 1994).

The challenge to the agricultural community is to understand the complex effect of farming practices on environmental quality and to think holistically about management approaches at both farm and watershed scales. The agricultural impacts on the quality of the soil and water resources of a region, should be studied within the context of the characteristics and particularities of the broad area in which these activities take place. Especially in the Mediterranean region, the soil quality assessment is a difficult task. The area is characterized by high soil and climate diversity which results a large number of management practices in a narrow area. In addition, the small size of farm holdings creates a complex web in which the scientists should be able to study and assess the soil quality and the stakeholders should be able to adopt sustainable management plans. Therefore, there is a need to develop a coordinated and multidisciplinary approach to assess the quality of soil and water resources and evaluate their potential and limitations. The aims of this work are: (a) to point out the Mediterranean particularities; (b) to underline the most important impacts on soil and water resources in the region; and (c) to propose a simple and cost effective methodology for the assessment of soil quality at a watershed scale, based on zones of specific functional interest.

2. Climate, soil and agriculture in the Mediterranean region

In the Mediterranean region, the degradation of soil and water resources is a serious threat for the human welfare and the natural environment as a result of the unique climate, topography, soil characteristics, and peculiarities of agriculture.

2.1. Climate

Mediterranean climate is characterized by mild rainy winters and warm to hot dry summers, with high solar radiation and high rates of evaporation (Boydak and Dogru, 1997). The climate may be broadly defined as Mediterranean and one in which winter rainfall is more than three times summer rainfall (Aschmann, 1973; Wigley, 1992). This seasonal contrast is most pronounced in the south and east of the region, where most of the annual rain may fall in a few days of torrential downpours. In parts of Tunisia, as much as 60% of the annual rain often falls on a single day (Lal, 1990). In the south, the influence of the sea makes coastal areas cooler and rainier. Mountains, such as the Alps, the ranges in North Africa, and those in former Yugoslavia, western Greece and Lebanon, receive more rain. This complex pattern of spatial and seasonal variability is exacerbated by the unpredictability of rainfall from year-to-year (Hulme, 1994).

The Mediterranean region is marked by relatively young orogenic systems with high, sharp folded and faulted mountains and hills rising close to the coast. The uplands are highly dissected, complex and partially unstable, with many slopes and shallow rocky soils. Therefore, they are very vulnerable to sheet and gully erosion when their protective vegetation is denuded and their shallow soil mantle is exposed to desiccation in the dry summer and torrential rains in winter (Navel and Lieberman, 1984).

2.2. Soil types

The soils throughout the Mediterranean region have some common features. Red and reddish-brown soils of heavy texture have been developed over limestone, the Chromic Cambisols and the Chromic Luvisols. Despite their high clay content, these soils are well drained because of their texture and the presence of permeable subsoil. They are associated in level areas and in depressions with heavy dark clay soils, the vertisols, which, although fertile, present management problems because of unfavorable physical properties and shrink/swell characteristics. The luvisols are sensitive to erosion and they are used for vineyards, olive and citrus cultivation (EEA, 1995). Shallow and stony soils (lithosols, cambisols, and rendzinas) are also present in the Mediterranean region. Although these soils are unsuitable for intensive arable farming and use of heavy machinery, they are commonly used for such agricultural practices in the plains. In contrast with the soils of northern Europe, Mediterranean soils are not so vulnerable to acidification due to their calcareous parent material. However, the procedure of neutralizing the acidity (caused from extensive use of fertilizers) by $CaCO_3$ could lead to the loss of CO_2 to the atmosphere. Mediterranean sandy soils have humus-poor topsoil with limited capacity for absorption of pesticides and heavy metals. These contaminants are, therefore, available for uptake by soil fauna and flora and for leaching from the topsoil (EEA, 1995).

2.3. Farming systems

Agriculture in Mediterranean countries is characterized by farm holdings of small sizes. There are a large number of holdings of less than 10 ha, which are less efficient in terms of economic costs than larger farms. Although the farms are of a small size, the traditional methods of farming have changed over the last decades. Today, the duration of rotations has been minimized to 2 or 3 years and farming has been focused on more commercially productive crops (Papadopoulos and Salapas, 1978). In addition, agriculture has become more intensive with extensive use of heavy machinery, fertilizers, agrochemicals, and large irrigation schemes. As a result of the small farm size it is rather difficult to apply a management plan on a watershed scale in order to sustain the agricultural production and minimize the environmental risks (EEA, 1995).

3. Impacts of agricultural practices on soil and water quality in the Mediterranean

Agriculture has both indirect and direct effects on the quality of soil and water resources. These effects depend on both macro- and microscale factors. Macroscale factors such as climate, landscape topography and parent material have broad effects on regions. These factors characterize the ecosystems based on the similarity of inputs (Odum, 1983), and establish the type of agricultural practices that are possible. The science base is still very incomplete in explaining how different ecosystems work and how different environmental factors interact to control functioning (Maltby, 1991). Microscale factors, such as the management and the land use at a watershed or a farm scale, will affect the quality of soil and water resources within a region.

Because of the unique site characteristics and the agricultural peculiarities of the Mediterranean, the main impact of agriculture on soil quality is erosion, salinization, compaction, reduction of organic matter, and non-point source pollution. As a consequence, the degradation of soil quality impacts water quality through leaching of pesticides and excess nutrients into surface and ground water along with seawater intrusion into aquifers.

3.1. Land degradation

Land degradation in the Mediterranean region has increased recently for a variety of reasons and is estimated to threaten over 60% of the land in southern Europe (UNEP, 1991). The renewed pressure on land resources through migration, the changes in agriculture both in terms of what is produced (cash-crops) and the mode of production (intensive agriculture), the increased demands of water through the development of irrigation schemes, together with the impact of land degradation on flooding, ground water recharge, salt water intrusion and soil salinization has in many cases been responsible for land desertification (CEC, 1994).

3.2. Soil salinization

An important impact of agriculture on the quality of soil and water resources in the Mediterranean is the increasing conductivity and associated salinization of soils and the intrusion of seawater into the groundwater aquifers near the coast. The salt accumulation in Mediterranean soils is a natural process favored by the region's ecological conditions (Zalidis et al., 1999). The movement of salts in the weathering crust and in the soil profile is through soil solution. Thus, salt accumulation in a certain area is governed first and foremost by the water balance of the area and particularly by the ratio of evapotranspiration to drainage (Richards, 1989). The two latter processes are controlled by natural ecological factors, both abiotic (climate, geomorphology, hydrogeology, etc.) and biotic (flora and fauna). Human activities may profoundly modify these ecological factors in multiple direct and indirect ways and, therefore, may cause salt accumulation (Misopolinos, 1990). The modification pertains mostly to relatively flat arable land. The results of human modifications have been fairly well documented in the countries of the Mediterranean region (Kovda et al., 1973). Salinization has a direct negative effect on soil biology and crop productivity, and an indirect effect leading to loss of soil stability through changes in soil structure (Szabolcs, 1996).

Considerable areas of salt-affected soils have been revealed in the past following the numerous large-scale flood control and wetland drainage projects. Man-induced salt accumulation occurred in previous salt-free soils due to errors in designing and constructing irrigation projects. In recent years, there has been an effort to correct these errors except in the case of some coastal areas where the low altitude constraints the maintenance of naturally trapped salts below the rooting zone. Presently, the cardinal salt accumulation problem is due to the continuing deterioration of the quality of groundwater used for irrigation. This deterioration was caused by overpumping and the consequent intrusion of seawater into the ground water strata (Zalidis et al., 1999).

3.3. Excessive use of fertilizers

The excessive application of fertilizers (including quantity and frequency of application) usually exceeds the functional ability of the soil to retain and transform the nutrients and synchronize the availability of nutrients with crop needs. In many cases, the saturation of the soil with nitrogen or phosphate, have led to losses of nitrates into shallow groundwater and saturation of the soil with phosphate, which may also move into groundwater (Breeuwsma and Silva, 1992). In intensive horticultural systems, interaction between high fertilizer inputs and major irrigation schemes enhances nitrate leaching and non-point source pollution of surface and ground water (EEA, 1995).

Acidification in Mediterranean soils, although not frequent, is caused by land use through the removal of base cations from the soil by harvesting, careless use of nitrogen fertilizers and soil drainage. On the farm scale, acidification causes the depletion of the soil's buffering capacity and the decline of soil fertility. Major effect of acidification is the mobilization of aluminum from clay minerals which the soil might have accumulated (Logan, 1990).

3.4. Pesticides

The extensive use of pesticides in agricultural land influences both the biotic and abiotic processes within the soil. As a result, several soil functions are degraded including the food web support, the retention and transformation of toxicants and nutrients, soil resilience, and the ability of soil to protect surface and ground water. On a farm scale, pesticides cause the destruction of part of the soil flora and fauna, which in turn causes both physical and chemical deterioration. Effects on non-target organisms in soil occur frequently (Pimentel and Levitan, 1986). Pesticides may also cause severe yield reductions in crops, which follow in rotation due to the presence of residual herbicides. On watershed scale, the main problem derives from the leaching and drainage of pesticides into the surface and ground water. Additionally, the reduction of the soil's ability to remove other pollutants, due to the alteration of soil properties by pesticides and the degradation of soil's toxicant retention and transformation function, allows the movement of those pollutants to adjacent water bodies.

3.5. Compaction and erosion

The major physical impacts of agricultural practices on Mediterranean soils are compaction and erosion. Soil compaction has been caused by the repetitive and cumulative effect of heavy machinery. The resulting decrease of soil porosity reduces root penetration and access to the soil nutrients and alters biological activity on the farm scale. On the watershed scale, soil compaction increases surface runoff since less rainwater is able to percolate. This increases the risk of water erosion, loss of topsoil and nutrients, and non-point source pollution of water resources (EEA, 1995).

Soil erosion is also caused by several other macro- and microscale factors that are characteristic of Mediterranean regions and it has negative impacts not only at the site where soil is lost but also in aquatic systems, natural and human-made, where the material accumulates. About 20% of the land surface in Greece and 10% in Italy is subject to high erosion risk (CORINE, 1992). Local costs of erosion include diminished infiltration and water availability, loss of organic matter and nutrients and an ultimate loss of production potential (Hillel, 1991). Downstream impacts include disrupted or lower quality water supplies, siltation that impairs drainage and maintenance of navigable river channels and irrigation systems, and increased frequency and severity of floods (Pimentel et al., 1995). Deforestation for agricultural needs and overgrazing on well-drained loamy and clayey soils have led to severe erosion in the past. The occurrence of frequent fires and summer droughts on these systems has led to irreversible desertification (UNEP, 1987). The problem of degradation by overgrazing is particularly severe in the Mediterranean. In Portugal, for example, more than 20% of the current agricultural land is highly erodible (Gardner, 1990).

3.6. Loss of organic matter and plant diversity

Many agricultural practices are also responsible for the biological degradation of soils. Mediterranean soils have limited amounts of organic matter and its loss results in the decline of soil fertility and structure. Loss of soil organic matter reduces root penetration, soil moisture and permeability, which in turn increases the risk of erosion and runoff and reduces biological activity of Mediterranean soils (EEA, 1995). The role of microorganisms in agroecosystems is often understated (Kennedy and Smith, 1995). The microbial functions help maintain a soil system with available nutrients aggregate stability which reduces erosion and maintains water holding capacity (Kennedy and Gewin, 1997). Recent publications reported varied responses of microbial communities to environmental disturbance. Reduced above-ground plant diversity as a result of tillage, overgrazing, pollutants, and pesticides decreases the microbial diversity in the soil ecosystem and disturbs its normal functioning (Christensen, 1989; Boddy et al., 1988).

4. Approaches to assess soil quality

The way that these activities have modified soil quality is not well documented in the countries of the Mediterranean region. In addition, the role that soils play at a watershed scale to promote ecosystem health is not yet fully understood (Maltby, 1991). The way that agricultural practices, policies and soil and water management interact and thus modify the soil resource is similarly poorly understood (Zalidis et al., 1999). Therefore, a cost effective methodology for the assessment of soil quality at the watershed scale is needed.

4.1. Assessment methodology in order to prevent degradation

The way that agricultural practices impact soil and water quality is driven by strong interactions among biological, physical, chemical, socioeconomic, and political factors. The processes, causes, and factors of soil and water quality degradation need to be clearly understood, at both farm and watershed scale, with respect to the ecosystem characteristics in which they take place.

In the Mediterranean region, the variability of soils and climate, in addition to the small size of farm holdings, resulted in a large number of soil management practices. The assessment of soil quality in such a complex landscape is not only difficult but also costly and time consuming, because of the numerous samples and measurements that it requires. In order to overcome such problems, there is a need to develop a new low-cost assessment methodology which should correlate the soil quality with the management, in order to provide information about the status of the soil resources, and aid with the development of sustainable management practices. An improved understanding of the relationships between soil characteristics and soil management practices will enable appropriate land use decisions to be made.

To establish a system of obtaining relevant soil quality data for the assessment of sustainability of agricultural management practices, an entire region should be sampled using a cost effective and scientifically planned sampling design that gives soil quality data at both the micro and macro scales. For this purpose, a watershed could be divided into strata of specific functional interest (Fig. 1), based on the classification of importance of soil functions in different parts of the watershed. The different steps for soil quality assessment in a hypothetical watershed are as follows.

1. Division of the watershed into strata (A, B, C) of specific functional interest (Fig. 1a).

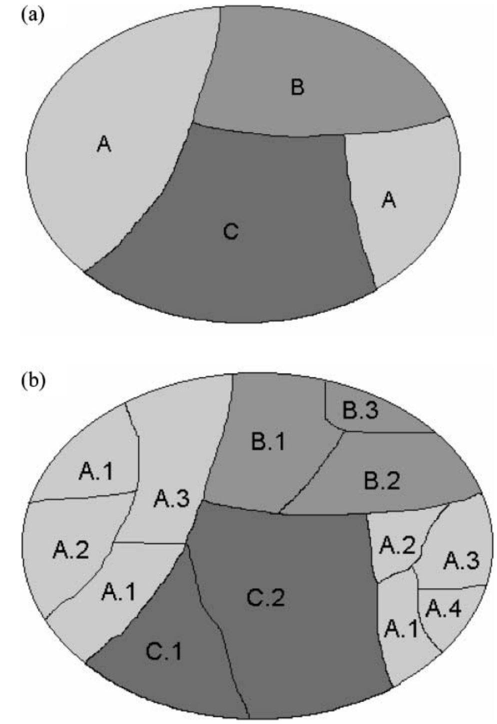

Fig. 1. Soil quality assessment in a hypothetical watershed.

2. Identification of PSAs (A.1, A.2, A.3, A.4, B.1, etc.) based on soil type and land management within each stratum (Fig. 1b).
3. Random selection of permanent sampling points within all types of PSAs (note, PSAs will be randomly sampled as would A.1, A.2, and A.3. All other PSAs will be selected since there is only one PSA in each of the remaining categories).
4. Sampling and measurement in the PSAs, of the soil quality indicators related to the function or functions of interest in each stratum.
5. Evaluation of the soil functions of interest within each PSA.
6. Development of zonation maps that will propose specific management practices to conserve or restore soil functions.

Each stratum is defined as an area, or collection of areas, with similar soil functions of major importance, compared to other soil functions of minor importance for the area. For example, in a plain used for agricultural production the function of sustaining biological activity, diversity, and productivity is far more important than the function of structural support. Of course, the opposite occurs in urban areas. Primary sampling areas (PSAs) should be identified within each stratum based on the soil type and the management (Fig. 1). All the PSAs identified within a stratum will have the same soil functions of major importance but they will differ at least in the soil type or management. The PSAs which belong to the same stratum, soil type, and management class should be similar, and so randomly choosing from this group should result in "representative" PSAs. To minimize costs, PSAs within a stratum, soil type, and management would be randomly sampled using the probability of selecting a PSA proportional to its size. Within each randomly selected PSA, several sites, representative of the PSA, would be chosen and long term experimental plots would be established at each site, and soil indicators relevant to the soil characteristics and the prevailing management practices would be monitored. Despite the shortcomings of the proposed methodology, relative to systematic and spatial sampling plans, it is a simple and practical approach which can be implemented based on a reasonable amount of data associated with the inventory of soil resources.

4.2. Identification of primary sampling areas (PSAs)

The identification of the PSAs and their associated stratum is a critical step in this sampling plan. Modern technology offers several possibilities for more accurate and reliable identification of strata and PSAs, and monitoring of soil and water quality at the watershed scale. Remote sensing can be used to assess the crop pattern, water, and soil resources and their spatial and temporal alterations (Paul et al., 1989). These broad scale measurements can be interpreted using a geographic information system (GIS). Procedures that are based on spatial decision support tool (SDST) can also be followed not only to determine the types, extent and spatial distribution of the suitable crop pattern (Apostolakis et al., 1998), but also to identify the strata with specific functional interest. Predicting accurately across scales is a major constraint that must be alleviated through combinations of scale modeling, ground truth surveys, and remote sensing (Lal and Stewart, 1990). One of these efforts to stimulate soil health has been recently made at Michigan State University (Gerakis, 1999, personal communication). A model has been developed (systems approach to land use sustainability, SALUS) which can simulate rotation of different crops and/or fallow, with different management strategies such as tillage, residue application, irrigation, tile drainage, and nitrogen, application, and combines crop and water balance with biochemistry simulation.

Within the PSAs a series of measurements of basic soil quality indicators will identify the soil's capacity to perform the functions of interest. The set of basic soil quality indicators should be useful across a range of ecological and socioeconomic situations in order to be practical for use by practitioners, extension workers, conservationists, scientists, and policy makers (Doran and Parkin, 1996). These indicators should:

- correlate well with ecosystems processes;
- integrate soil physical, chemical, and biological properties and processes, and serve as basic inputs needed for estimation of soil properties or functions, which are more difficult to measure directly;
- be relatively easy to use under field conditions and be assessable by both specialists and producers;
- be sensitive to variations in management and climate;
- be components of existing soil databases where possible.

The measurement of the soil quality indicators will permit a valid and rapid evaluation of the functions of interest. This will lead to the development of zonation maps that will propose zones of specific management practices. The zonation maps in combination with the understanding of how each management practice affects soil functions will give decision makers the necessary tools for the development of the appropriate management practices for each type of PSA.

For instance, differences in land management and flooding impact are considered to be more important in determining denitrification rates (as part of the storing and cycling of nutrients function) than differences between soil types under similar management (Maltby, 1991). These complex interactions between management factors at various scales ranging from on-site fertilizer regime to catchment land use and detailed soil characteristics, determine the role and capacity of soils to function as nutrient sinks. For example, the ability to predict denitrification according to soil types (especially wetness class) and management regime can be converted to a catchment zonation map. This map can identify the target areas which can be particularly important for denitrification, and hence, of a particular value in maintaining soil and water quality (Maltby, 1991).

4.3. Development of zonation maps

The detection of the pressures at a watershed scale, the identification of the strata for minimizing the cost of the survey and the measurements of the appropriate soil quality indicators within each PSA type, will lead to the development of zonation maps that will include specific management proposals. These zonation maps will be the products that scientists provide to the decision-makers.

The appropriate authorities, after having evaluated the data obtained as described above, will select the suitable strategies for sustainable management, which build water and soil quality and health. The adoption of more sustainable soil management practices is expected to sustain crop production and minimize environmental risk, potential for rainfed agriculture in semiarid and arid climates, such as Mediterranean (Stamatiadis et al., 1996).

At a watershed scale, the proposed strategies in addition to determining zones with specific functional interest and proposing appropriate crop pattern and water use, will identify the spatial relations of appropriate management techniques. At the farm scale sustainable management practices can replace intensive conventional agriculture, reestablish the natural physical, chemical, and biological properties of the soil and lead to a sustainable soil environment. These strategies amongst others include the conservation of soil organic matter through maintaining C and N balance; the minimizing of soil erosion through conservation tillage and increase cover (residue, cover crops, etc.); the substitution of renewable for non-renewable resources by relying less of fossil fuels/petrochemicals and greater use of natural balance and diversity (crop rotation, legume cover crops, etc.); and the management which coexists with rather than dominates nature through optimizing productivity needs with environmental quality by synchronizing the availability of nutrients with crop needs (Doran, 1997).

5. Concluding remarks and future considerations

The soil quality assessment in relation to the management practices is a prerequisite for the sustainable management of the soil resources at a watershed scale. Major disadvantages for such an assessment so far, have been the high cost and the time that was needed, especially in regions with high diversity of soils, climate, and management practices applied. The proposed use of an assessment methodology based on areas of specific functional interest and management, is aiming to face the former problems and minimize the cost and time that was needed for such an assessment. In addition, this methodology correlates the quality of the soil resources with the management practices applied in each site. This provides to the scientists the necessary information to evaluate the impact of management on soil resources, supports the stakeholders decisions to promote the sustainable management of the soil resources at a watershed scale, and aid the farmers to adopt the appropriate management practices at the farm scale. For the establishment of the proposed methodology, further research and real data are needed. The cost benefit analysis and the comparison with other assessment methodologies at a watershed scale may provide valuable information for the implementation of the proposed methodology at a broader scale.

References

Apostolakis, A., Zalidis, G., Papadimos, D., Syllaios, N., Gerakis, A., 1998. A spatial distribution method to rehabilitate the recharge–discharge function of Anthemountas watershed. In: Katsifarakis, K.L., Korfiatis, G.P., Mylopoulos, Y.A., Demetracopoulos, A.C. (Eds), Proceedings of the IV International Conference on Protection and Restoration of the Environment. Halkidiki, Greece, 1–4 July 1998, pp. 1011–1012.

Aschmann, H., 1973. Distribution and peculiarity of Mediterranean ecosystems. In: Di Castri, F., Mooney, H.A. (Eds.), Mediterranean-Type Ecosystems: Origin and Structure. Springer, New York, pp. 11–19.

Boddy, L., Watling, R., Lyon, A.J.E., 1988. Fungi and ecological disturbance. Proc. R. Soc. (Edinburg) B, 94.

Boydak, M., Dogru, M., 1997. The exchange of experience and state of the art in sustainable forest management by ecoregion: Mediterranean forests. In: Boydak Dog, M., Dogru, M. (Eds.),

Proceedings of the XI World Forestry Congress, Vol. 6. Antalya, Turkey, 13–22 October 1997, pp. 179–199.
Breeuwsma, A., Silva, S., 1992. Phosphorous Fertilization and Environmental Effects in The Netherlands and Po Region (Italy). Winand Staring Centre (SC-DLO) Report 57, Wageningen, The Netherlands.
CEC, 1994. Desertification and Land Degradation in the European Mediterranean. Report EUR 14850, Commission of the European Communities, Directorate-General XII, Brussels.
Christensen, M., 1989. A view of fungal ecology. Mycologia 81, 1–19.
CORINE, 1992. Soil Erosion Risk and Important Land Resources in the Southern Regions of the European Community. EUR 13233. Commission of the European Communities, Luxembourg.
Doran, J.W., 1997. Soil Quality and Sustainability. Paper presented to Commission V Inventory. In: Proceedings of the XXVI Brazilian Congress of Soil Science on Genesis, Morphology, and Classification of Soils, 20–26 July 1997, Rio de Janeiro, Brazil, Palestra 5, 28 pp.
Doran, J.W., Parkin, T.B., 1994. Defining and assessing soil quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.), Defining Soil Quality for a Sustainable Environment. Special Publication no. 35. Soil Sci. Soc. Am. SSSA, Madison, WI, USA, pp. 3–21.
Doran, J.W., Parkin, T.B., 1996. Quantitative Indicators of Soil Quality: A Minimum Data Set. In: Doran, J.W., Jones, A.J. (Eds.), Methods for Assessing Soil Quality. Special Publication no. 49. Soil Sci. Soc. Am. SSSA, Madison, WI, USA, pp. 25–38.
EEA, 1995. In: Stanners, D., Boureau, P. (Eds.), Europe's Environment: The Dobris Assessment. Office for Official Publications of the European Communities, Luxemburg.
Gardner, B., 1990. European Agriculture's Environmental Problems. Paper presented at the First Annual Conference of the Hudson Institute, Indianapolis, Indiana, April 1990.
Harris, R.F., Bezdicek, D.F., 1994. Descriptive aspects of soil quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.), Defining Soil Quality for a Sustainable Environment. Special Publication no. 35. Soil Sci. Soc. Am. SSSA, Madison, WI, USA, pp. 23–36.
Hillel, D., 1991. Out of the Earth: Civilization and the Life of the Soil. The Free Press, New York.
Hulme, M., 1994. Climatic variability. In: Unwin, T. (Ed.), Atlas of World Development. Wiley, Chichester, UK, pp. 50–51.
Jenny, H., 1941. Factors of Soil Formation. McGraw-Hill, New York.
Karlen, D.L., Mausbach, M.J., Doran, J.W., Cline, R.G., Harris, R.F., Schuman, G.E., 1997. Soil quality: a concept, definition and framework for evaluation. Soil Sci. Soc. Am. J. 61, 4–10.
Kennedy, A.C., Gewin, V.L., 1997. Soil microbial diversity: present and future considerations. Soil Sci. 162, 607–617.
Kennedy, A.C., Smith, K.L., 1995. Soil microbial diversity and the sustainability of agricultural soils. Plant Soil 170, 75–86.
Kovda, V.A., Van Der Berg, C., Hagan, R.B. (Eds.), 1973. Irrigation, Drainage, and Salinity. An International Source Book, FAO/UNESCO.
Lal, R., 1990. Water erosion and conservation. In: Goudie, A.S. (Ed.), Techniques for Desert Reclamation. Wiley, Chichester, UK, pp. 161–198.
Lal, R., Stewart, B.A. (Eds.), 1990. Soil Degradation. Springer, New York, NY.
Larson, W.E., Pierce, F.J., 1994. The dynamics of soil quality as a measure of sustainable management. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.), Defining Soil Quality for a Sustainable Environment. Sol. Sci. Soc. Am., Special Publication no. 35. SSSA, Madison, WI, USA, pp. 37–52.
Logan, T.J., 1990. Chemical degradation of soil. In: Lal, R., Stewart, B.A. (Eds.), Soil Degradation. Springer, New York. NY, pp. 187–222.
Maltby, E., 1991. Wetland management goals: Wise use and conservation. Landsc. Urban Plan. 20, 9–18.
Misopolinos, N., 1990. Salinization and soil conservation — physicochemical and practical aspects. Eur. Soc. Soil Conserv. (ESSC) NEWSLETTER 1, 8–9.
Navel, Z., Lieberman, A.S., 1984. Landscape Ecology, Theory and Application. Springer, New York.
Odum, T.H., 1983. Systems Ecology: An Introduction. Wiley, New York.
Papadopoulos, G.E., Salapas, K.C., 1978. Agriculture and Reclamation Projects of Greece. Ministry of Agriculture and Greek National Committee on Irrigation and Drainage, Athens.
Paul, C.K., Imhoff, M.L., Moore, D.G., Sellman, A.M., 1989. Remote sensing of environmental change in the developing world. In: Botkin, D.B., Caswell, M.F., Estes, J.E., Orio, A.A. (Eds.), Changing the Global Environment: Perspectives on Human Development. Academic Press, New York.
Pimentel, D., Levitan, L., 1986. Pesticides: amounts applied and amounts reaching pests. Bioscience 36, 86–91.
Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., Blair, R., 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 267, 1117–1123.
Richards, L.A., 1969. Diagnosis and Improvement of Saline and Alkaline Soils. USDA Agricultural Handbook No. 60, US Department of Agriculture, Washington, DC.
Stamatiadis, S., Liopa-Tsakalidi, A., Maniati, L.M., Karageorgou, P., Natioti, E., 1996. A Comparative study of soil quality in two vineyards differing in soil management practices. In: Doran, J.W., Jones, A.J. (Eds.), Methods for Assessing Soil Quality. Special Publication no. 49. Soil Sci. Soc. Am. SSSA, Madison, WI, USA, pp. 381–392.
Szabolcs, I., 1996. An overview of soil salinity and alkalinity in Europe. In: Misopolinos, N., Szabolcs, I. (Eds.), Soil Salinization and Alkalization in Europe. European Society for Soil Conservation. Giahudis Giapulis. Thessaloniki, Greece, pp. 1–12 (special publication).
UNEP, 1987. Promotion of Soil Protection as an Essential Component of Environmental Protection in Mediterranean Coastal Zones. MAP Technical Reports Series 16. United Nations Environment Programme. UN Regional Activity Centre, Split.

UNEP, 1991. Status of Desertification and Implementation of the United Nations Plan of Action to the Combat Desertification. United Nations Environment Programme, Nairobi.

Wigley, T.M.L., 1992. Future climate of the mediterranean basin. In: Jeftic, L., Milliman, J.D., Sestini, G. (Eds.), Climatic Change and the Mediterranean. Edward Arnold, London, UK, pp. 15–44.

Zalidis, G., Gerakis, A., Misopolinos, N., Prodromou, K., Apostolakis, A., 1999. The impact of soil and water resources management on salt accumulation in Greece. In: Leone, A.P., Steduto, P. (Eds.), Salinity as a Limiting Factor for Agricultural Productivity in the Mediterranean Basin. Proceedings of the First Trans-National Meeting, Naples, 24–25 March 1997, pp. 87–95.