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Mediterranean soilscapes and climatic change. An overview

J.J. Ibáñez[a], A. García-Alvarez[a], J.L. González Rebollar[a] and A.C. Imeson[b]

[a]Centro de Ciencias Medioambientales (CSIC), Serrano 115 bis, 28006 Madrid, Spain.

[b]Fysisch Geografisch Bodemkunding Laboratorium, Universiteit van Amsterdam, Nieuwe Prinsengracht 130, 1018 VZ Amsterdam, The Netherlands

Abstract

Despite the reduced extension and spatial fragmentations of the Mediterranean region, its biogeodiversity (biologic, edaphic, geomorphic, climatic and hydrologic) is among the highest of the planet. Quantitative data published recently show great links between arid and Mediterranean soilscapes. Mediterranean soilscapes are extremely fragile and therefore potential changes due to climatic and anthropic causes may lead to desertification. Thus, future CO_2 warming will increase current desertization processes. Land degradation in arid and semiarid Mediterranean regions (rainfall less than 600 mm) is highly analogous to desertification.

1. GENERAL CHARACTERISTICS: MEDITERRANEAN LANDSCAPES AND CLIMATE CHANGE

The Mediterranean climate currently affects approximately 9,000,000 km^2 (4.6% of the continental lithosphere or 3.3% of the global pedosphere). Mediterranean ecosystems are distributed over Mediterranean Basin, California, Chile, South Africa and Australia. About 3/4 of Meditarreanean basin area enjoys a Mediterranean climate whilst 1/4 suffers greater aridity.

The Mediterranean cannot be regarded as a homogeneous morphoclimatic region. A relatively wide range of marked climatic zones exist between wet and arid. In general, the Mediterranean region is characterized by generally warm temperatures, winter or spring and autumn-dominated rainfall, dry and hot summers (of at least two or three months and up to 11 months) and a profusion of microclimates due to local terrain. Mean annual rainfall can vary from 20-25 mm in the "Mediterranean deserts" to 2000-2500 mm on mountain slopes or local maritime areas exposed to rain-bearing winds. Temperature varies widely with latitude, altitude and continentality: the annual mean may drop below 10 C or rise above 25 C. In parallel with these mean conditions the intra-annual and inter-annual climatic variability is very high, with sudden and high intensity rainfall. According to the World Bioclimatic Classification System proposed by Rivas-Martínez [1], the Mediterranean climate has the highest diversity of bioclimatic belts in the world.

The Mediterranean area is especially vulnerable to climatic change. The impact of CO_2-induced climatic change is potentially serious because of the aridity, the low rates of primary production in the drier areas, the sensitivity of the soils to degradation and erosion, and the high risk of drought and fire. The increase in aridity however is not necessarily caused by decreases in annual precipitation. Increasing aridity can be due to: (a) higher evapotranspiration; (b) a change in the frequency and magnitude of rainfall events; (c) processes of soil degradation that decrease the ability of soil to retain water [2].

Simulation models of the atmosphere's general flow predict that a doubling of the greenhouse gas concentration compared to pre-industrial periods would bring a mean worldwide temperature increase between 3 and 5.5 C [2]. Precipitation predictions are different for different GMC models. The GISS model indicates an increase in general precipitation for the Mediterranean Basin. The BMO model predicts a decrease in precipitation. Both models suggest an increment in potential evapotranspiration of 200 mm, which may cause an extension of the period with a rainfall deficit and a very large increase in soil moisture deficit [2].

2. MEDITERRANEAN SOILSCAPES AND SOIL GENESIS

2.1. Mediterranean soils and climate

Duchaufour [3] distinguishes two types of soil characteristic in Mediterranean regions. Thus, when phytoclimatic conditions are relatively moist, the development of Alfisols [4] is common. On the other hand, in arid and semiarid Mediterranean environments, the most representative soils are Haploxeroll, Argixeroll and Calcixeroll [4]. In view of the large variety of subclimates that can be included within the Mediterranean climate, it is not surprising that pedoclimates and, more specifically, humidity regimes, may be aridic, xeric and even udic in the high mountains. The dry period causes characteristic rubification of many Mediterranean soils. Incomplete profile leaching also allows frequent horizon genesis with accumulation of carbonates under the Bt horizons [3]. More acidic, weathered profiles develop on the oldest, most stable geomorphological Palaeosurfaces. These are or the Xerult and Ultic Xeralf [3, 4]. In these circumstances, the base of the Bt horizons has become silted up with clay. Impermeabilization induced by this process has the genesis of hydromorphic features and aquic regimes as a corollary.

In arid and semiarid Mediterranean subclimates highly developed, shallow calcic horizons are also characteristic. Likewise, wetting-drying cycles encourage hardening of the horizons with accumulation of carbonates, giving rise to the formation of petrocalcic horizons or calcretes [3]. In the most arid subclimates, caliche accumulation can result from the deposition of dust material. Under special conditions a distinct caliche layer can develop within several months. Where petrocalcic horizons are situated at or near the soil surface they can have serious implications for hydrology. Salt accumulation is most severe in arid and semi-arid subclimates (receiving between 300 and 600 mm of rainfall). However, this salt accumulation becomes less important in areas where precipitation drops below this level [5].

Another typical characteristic of Mediterranean environments is the low organic matter content of surface horizons, so they rarely overcome the state of ochric epipedon. This is why unevolved soils conserve a large part of the properties of their original material. In some cases, the effects of small changes in the supply and mineralization of organic matter could have a large impact on soil structure and greatly influence soil and hillslope hydrology. Soils having low organic matter contents are less stable and therefore have a lower infiltration capacity. Soils that contain low amounts of organic matter can respond by slaking, swelling, dispersion, cracking and mellowing, when they are wetted, and because of this can develop surface seals or crust. In dispersive soils, physico-chemical characteristics may trigger piping erosion which creates a positive feedback of pipe collapse producing rill and gully incision [6].

Finally, undeveloped shallow soils (Entisols with umbric epipedons, adjacent to Inceptisols and Histosols) predominate in Mediterranean mountain climates. [7].

2.2. Quantitative analysis of Mediterranean soilscapes

Ibáñez *et al.* [8], have studied the Mediterranean soil landscapes, on a global level using the data compiled by the FAO [9, 10]. This information served to draw up a matrix on which Minimum Spanning Tree and cluster analysis were performed (Figs. 1 and 2). Close connections between soilscapes of arid and Mediterranean environments become apparent [8]. There are marked, though lesser, similarities between Mediterranean and other bordering climate zones. Moreover, a common trait of Mediterranean and arid climate zones is that they both present intermediate evolution soils (Calcisols and Cambisols). These latter two climate types however, are identified by the greater abundance of shallow and saline soils in arid environments and by that of other more developed ones in Mediterranean environments (Luvisols and Planosols) [8]. Results of Minimum Spanning Tree for climate zones (Fig. 2), clearly reflect how soilscapes link in a very well defined latitudinal gradient.

References are frequently found in the literature to most characteristic pedogenetic processes of certain environments [3], [11]. However, these canonic types of pedogenesis are not necessarily those underlying soil typological units of greatest land representation. Soilscapes of Mediterranean climates are usually associated to the presence of Luvisols and Vertisols [3], [9]. Cambisols are also frequent [11]. However, Mediterranean soilscapes are very rich and quite diverse for the small surface area covered by this type of climate [8]. Likewise, if the Soil Map of the World at 1:25,000,000 scale [9] is analyzed, different Mediterranean regions in the world can be seen to have quite different soilscapes. They are products of their respective geological and palaeo-environmental histories [8]. In fact, Vertisols (3.5%) and Luvisols (15.6%) only occupy a small area of these territories, with Calcisols (20.3%) and Cambisols (16.2%) being the dominant soil types. Thus, when analyzing global soil patterns, the concept of *canonic soil types* and/or *canonic pedogenetic processes* should be supplemented with that of *territorially canonic soils types* (those with greater territorial representation) [8].

On a World level, despite the small area of the Mediterranean landscapes, their pedodiversity or richness (number of soil typological units -STU- according a FAO keys of 1989) is outstanding. Moreover, after the mountain soilscapes, the STU density (richness/area unit) of the Mediterranean pedosphere is the greatest [8]. In other words, Mediterranean and mountain climates have a STU density far higher than that of the climatic types of the rest of the world considered by these authors [8]. Therefore these two climatic types, at global level, have a diversity which is not in consonance with the area they occupy. Ibáñez *et al.* [12] also show that soil richness of countries in the Mediterranean Basin are higher than those in temperate and cold environments in central and northern EU countries (Fig. 3).

2.3. Soils and greenhouse effect

Climatic changes associated with an increase in CO_2 are comparable to differences in climate that occur locally as a result, for example, of relief and exposure. Unless threshold factors are involved, it is not thought likely that CO_2-induced climatic changes will result in a major shift in the boundaries between soil types.

The soil contains elements which vary in age from a few weeks (e.g. nutrient concentrations) to tens of thousands of years (e.g. oxic horizons). Many soil characteristics, therefore, reflect the operations of soil-forming processes under a wide range of former climatic conditions; because these conditions differed much more from the present climate than the climate predicted for a doubling of CO_2 concentration, these characteristics are not expected to be influenced to a degree that requires consideration [2].

The envisaged changes in climate are likely to have the greatest short-term (50 years) impact through the effect they have on: (a) the salt balance and salt composition of the soil; (b) the chemical precipitation of Ca/Mg carbonates in soil; (c) processes associated with the supply and breakdown of organic matter [2]. The changes in these processes might not be very significant for the long-term morphological evolution of the soil, but they are undoubtedly important with respect to soil ecology, soil hydrology, soil erosion and land uses. For example, the response of soil aggregates to wetting by rainfall is extremely sensitive to the chemistry of the soil solution and to microbial activity [5]. Slight changes brought about, for example, by longer dry seasons or changing atmospheric deposition may lead to changes in the soil structure which dramatically alter the hydrology and nutrient balance of the soil. For instance, destabilized soil aggregates break down to form surface seals or crusts. When soil surfaces are sealed by crusts, the infiltration capacity becomes reduced and overland flow occurs at lower threshold amounts of rainfall. Thus, an increase in aridity would increase the area of soils having unfavourable infiltration characteristics and higher soil erodibility values.

In sub-humid and semi-arid climatic zones, a general decrease in precipitation or increase in evapotranspiration will cause an increase in the area of soils affected by saline or sodic conditions. These changes in salt accumulation could lead to an increase in the area of soils affected by vertic conditions and physical deterioration.

2.4. Soil erosion in the Mediterranean Basin and greenhouse effects

In the past, the Mediterranean environment has proved to be sensitive and vulnerable to environmental change, and consequently the landscape in many places has been irreversibly degraded. Currently in the Mediterranean region, bedrock is exposed over very large areas and most soils are stony.

Maximum rates of denudation concur in those semi-arid areas where it rains sufficiently to develop surface runoff but not to maintain plant cover sufficiently dense to protect the soil [13]. This is the case of semi-arid and arid Mediterranean regions. Erosion is highest in areas receiving between 200-600 mm rainfall per year or with great importance of extreme precipitation events [2, 14, 15].

In sub-humid and semi-arid Mediterranean environments, erosion appears to be closely correlated with rainfall within each area [6], whereas runoff is not significantly correlated with erosion [14, 15]. This means that the response of the soil surface to rainfall is of greater importance for achieving erosion than is runoff alone, suggesting a marked influence of extreme rainfall events again [14].

According to Imeson and Emmer [2], an increase in the temperature of 3 to 4 C is argued to have the following impacts on erosion process in the Mediterranean environments: (a) higher rates of erosion on slopes and either relative or absolute increase of overland flow during extreme rainfall events; (b) higher sediment concentration in water runoff; (c) higher sediment and solute supply from badlands and/or marl areas; (d) an increase in the risk of rill and gully erosion; (e) an increase in the discontinuity of runoff and sediment transport in drainage basins; (f) lower rates of sediment transport in the major rivers; (g) adjustment of river channels, especially those carrying coarse load (braiding will increase and fans will grow); (h) A shift from certain perennial streams to ephemeral streams); (i) An increase in wind erosion.

2.5. Desertification and climatic change

At the present time, it would appear that there is a consensus with respect to the fact that the Mediterranean region is the most sensitive in Europe to the climate change which appears to be drawing near [2]. Although the cause of desertification of Mediterranean environments is a debatable matter. Nevertheless, all the evidence seems to point to natural processes strengthening the trend of human ones. Likewise, this region has undergone the most intense, prolonged exploitation known over the whole planet.

Simulation models of the atmosphere's general flow predict that a doubling of the greenhouse gas concentration compared to pre-industrial periods would bring a mean worldwide temperature increase between 3 and 5.5 C. Current calculations would seem to indicate that this event could occur half way through the twenty-first century. A global change of this magnitude would increase aridity and desertification in the Mediterranean Basin.

3. REFERENCES

1 S. Rivas-Martínez, Bioclimatic Classification System of the World, 21ª Aproximation, (manuscript), 1993.

2 A.C. Imeson and I.M. Emmer, Implications of climatic change on land degradation in the Mediterranean. In: L.Jeftic, J.D.Milliman and G.Sestini, Climatic Change and the Mediterranean. E.Arnold, 1992.

3 Ph. Duchaufour, Pedologie, 1. Pédogenèse et Classificattion, Masson, Paris, 1977.

4 Soil Survey Staff, Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys, USDA-SCS Agric. Handbook n° 436, Washington, D.C., 1975.

5 A.C.Imeson and R.S. De-Groot, Landscape-Ecological Impact of Climatic Change; Discussion Repport on Mediterranean Region. LICC, VROM-DGMH, Amsterdam, 1989.

6 G. Benito, M. Gutiérrez and C. Sancho, Z.Geomorph., 37 (1993) 199.

7 J.J. Ibáñez and R. Jiménez-Ballesta, An. Edafol. Agrobiol., 45 (1986) 961.

8 J.J. Ibáñez, V. Zucarrello, S. De-Alba and A. García-Álvarez, Catena (Submitted).

9 FAO-UNESCO, World Soil Resources. An Explanatory Note on the FAO World Soil Resources Map at 1:25.000.000 Scale, FAO World Soil Resources Reports 66, Rome, 1991.

10 FAO-UNESCO, Mapa Mundial de Suelos. Leyenda Revisada, FAO, Roma, 1989.

11 E.M. Bridges,World Soils. (2nd edition), Cambridge Univ. Press, Cambridge, 1978.

12 J.J.Ibáñez, S. De-Alba and J. Boixadera, The pedodiversity and its measurement: Aplications to soil information system. In: D. King, R.A.J. Jones and A.J. Thomasson (eds), The Development of an EU Land Information System for Agro-Environmental Monitoring. EU, Brussels, (in press), 1994.

13 W.B. Langbein and S.A. Schumm, Transactions of the America Geophysicial Union, 39 (1958) 1076.

14 M. Sala, Hillslope runoff and sediment production in two Mediterranean mountain environments. In: A.C. Imeson and M. Sala (eds.), Geomorphology in Enviroments with Strong Seasonal Contrast. Catena Supplement, 12, (1988).

15 H.N. Le-Houérou, Vegetation and land-use in the Mediterranean Basin by the year 2050: A prospective study. In: L. Jeftic, J.D. Milliman and G. Sestini, Climatic Change and the Mediterranean, E. Arnold. 1992.

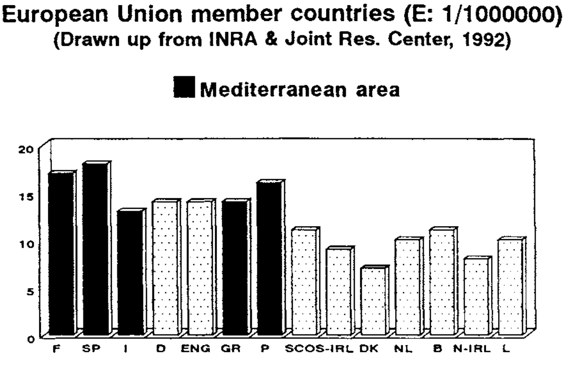

Figure 1. Richness in Major Soils Groups (FAO &UNESCO; 1974) for the soil map of EU countries

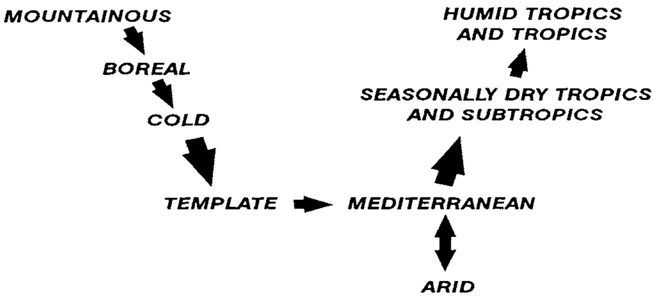

Figure 2. Minimum spanning tree analysis for climatic zones

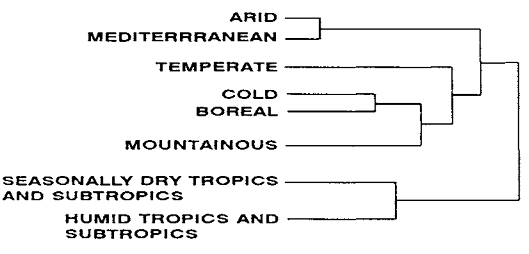

Figure 3. Dendrograms grouping climatic zones with respect to the number of their Major Soils Groups (FAO & UNESCO, 1989)