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Fertility decline of arable soils in a semiarid district of Crete Island, Greece

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Abstract
Twenty-five Mediterranean soil profiles originating mostly from alluvial and colluvial materials in the Island of Crete (Greece), were studied. These soils belong to the Prefecture of Herakleion, Municipality of Mallia and the main crops are olive trees, potatoes and orchards. According to Soil Taxonomy (1999), they have been classified as *Entisols* or *Alfisols*. Climatic factors and human activities strongly affected soil properties. Soil survey was conducted in order to assess nutrient status and other soil properties which affect crop yield. The texture of soil layers greatly varied and clay content ranged between 15 and 57 %. Cation Exchange Capacity was low at certain locations and ranged between 6.5 and 26.7 cmol/kg, whilst available P strongly fluctuated between 2 and 420 μg/g. The extremely high P content in some cases may be attributed to heavy over fertilization. The organic matter content in the examined soils was low due to climatic conditions and steep slopes, and varied from 2.0 to 54.0 g/kg (mean 17.6 g/kg). Exchangeable calcium was the dominant cation and the Ca/Mg was found 4.4. Free carbonates were in traces and detected only in two samples. Average concentrations of micronutrients were found in the following order Mn>Fe>Cu>Zn>B. Soil acidity, low content of soil organic matter, exchangeable potassium (K^+), phosphorus (P) and plant available micronutrients, are the main limiting factors for high yield. The following measures are recommended for sustainable soil management, such as: rational water management, tillage practices, lime application for correction of soil acidity, preservation of soil organic matter and proper fertilization practices. Physical and chemical properties of the studied soils suggest that rotation schemes with tolerant plants to drought, terracing and irrigation methods are essential for sustainable management.

General description of the study area – climate

The district of Mallia is located on the North-Central part of Crete Island, 40 km from Herakleion. The total land consists of around 5,860 ha. The main perennial crops are olive trees, citrus trees and vineyards, whilst potato is the main annual crop (Table 1).

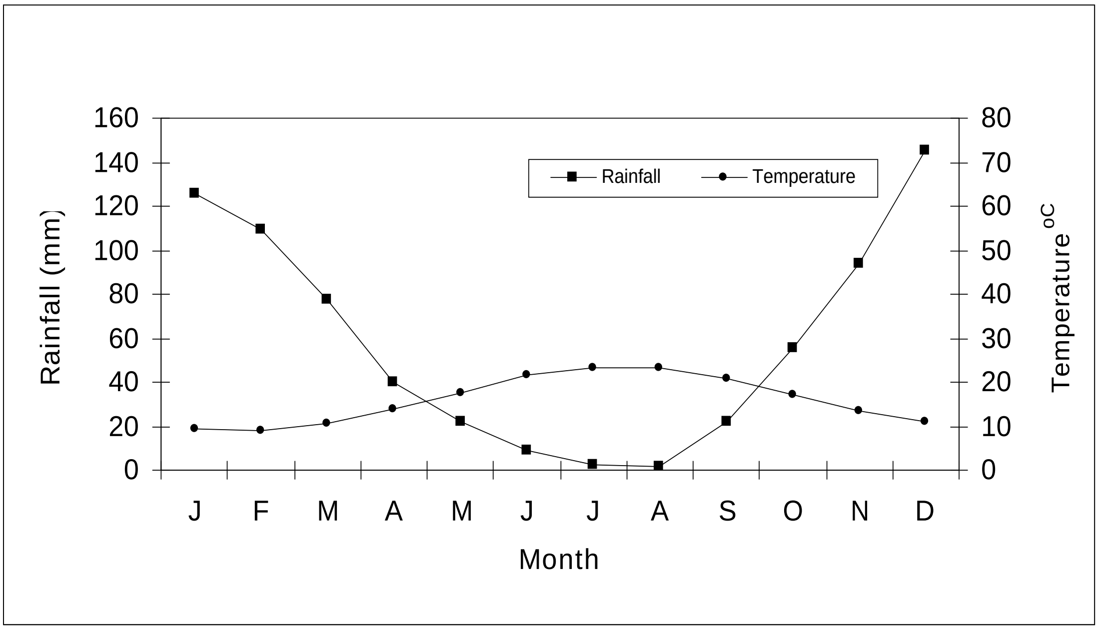
Table 1. Main crops of the Mallia district

Crop	**Cultivated area** (ha)	**Irrigated land** (ha)
Potatoes	180	175
Olive trees	1.430	255
Citrus trees	21	21
Bananas (glass house)	25	25
Vineyards	68	
Vegetables	23	23
Total area	1.447	499

The study area consists of various geomorphological elements, and soils are located mostly on alluvial and colluvial materials. A large part has been degraded and susceptibility to erosion is obvious in the steeper slopes. The risk became higher due to climatic conditions, grazing or to urbanization.

The climate of the region has the characteristics of a temperate climate with wide temperature and rainfall fluctuations. According to data provided by the National Meteorogical Service in Kasteli, (altitude 340 m a.s.l), mean maximum monthly air temperature for a period of 25 years was 23.2 ^{o}C (July) and mean minimum was 9.1 ^{o}C in February, whilst mean annual was 15.95 ^{o}C. For the same period, mean annual precipitation was 705 mm. The soil moisture regime is *xeric* (Soil Taxonomy, 1999) and moisture deficit (Fig. 1) occurs from mid–April to October (Bagnouls-Gaussen, 1957).

Fig. 1 Omvrothermic diagram of the studied area (Meteo Station of Kasteli,)



Materials and methods

A detailed survey (scale 1:10,000) was conducted in the area of Mallia and twenty five surface soil samples were collected from the classified profiles. Most of them formed through the weathering of hard limestone, gneiss and schists. The examined soils are located on shoulder or backslope and erosion risk is rather high. Thematic maps concerning the distribution of nutrient elements were compiled by using a Geographical Information System. Spatial variability of nutrients was modelled by ordinary kriging algorithm that was used to assess the values between two sampling sites by linear interpolation. Samples air–dried and the fine earth fraction (<2 mm) was used for laboratory determinations. Particle size distribution was determined by the Bouyoucos hydrometer method (Gee and Bauder 1986). The pH was measured in a 1:1 soil–H_2O suspension (McLean ,1982). Soil carbonates were determined by the volumetric calcimeter method (Allison, 1965). The method of ammonium acetate (1N at pH 7) was used for exchangeable cations (Thomas, 1982). Cation Exchange Capacity (CEC) was determined by the ammonium acetate method (Rhoades, 1982). A modified wet digestion Walkley and Black method (Nelson and Sommers, 1982) was used for the organic matter determination. Plant available phosphorous (P) was measured using Bray method in the acid soils (Olsen and Sommers, 1982). The azomethine-hydrogen method (Keren, 1996) was used for determining the plant available boron (B). The available form of

Fe, Cu, Zn and Mn was determined by extraction with 0.005 M diethylenetriamine-pentaacetic acid (DTPA), according to Lindsay and Norvell, (1978).

Results and Discussion

According to Soil Taxonomy (1999) two soil orders were recorded in the investigated area. *Xeralf* is the main suborder of *Alfisols* and *Orthent* is the dominant suborder of *Entisols*. In general, the organic matter was low, varied greatly and ranged between 2.0 and 54.0 mg/kg. Low content of organic matter, along with water shortage during summer are among the limiting factors for sustainable crop production.

Parent material, topography, hydrology and human activities have influenced soil properties (Table 2). The studied soils are generally acidic in the surface layers as a result of the $CaCO_3$ leaching to the deeper horizons and pH values ranged between 4.4 and 6.9. Cation exchange capacity varied from 6.5 to 26.7 cmol/kg with a mean value 14.5 cmol/kg .

The surface horizons of *Alfisols* are characterized by a clayey texture (average 38.9 %) with well developed structure. During the dry period, the argillic horizons are very hard and workability of these layers is very difficult. In some cases deep ploughing is suggested because favours physical soil properties and plant adaptation, as well. Concerning the exchangeable cations, the following order (Table 2) was observed: Ca>Mg>K>Na and in certain sites, only potassium seems to be at deficient level.

Table 2. Mean, maximum and minimum values of the determined soil properties (n=25)

property	**Min.**	**Max.**	**Mean**	**STD**
Clay %	15	57	38.9	11
C.E.C. (cmol/kg)	6.5	26.7	14.5	6.5
O.M. %	2.0	54.0	17.6	12.0
pH	4.4	6.9	6.1	0.7
Ca^{++} (cmol/kg)	1.87	10.7	5.3	2.63
Mg^{++}(cmol/kg)	0.25	3.05	1.2	0.8
K^{+} (cmol/kg)	0.08	2.08	0.66	0.5
Na^{++}(cmol/kg)	traces	1.0	0.2	0.3
P (μg/g)	2	420	114	141
Fe (μg/g)	4.43	80.8	25.7	24
Mn (μg/g)	6.12	111	34.6	27
Cu (μg/g)	1.0	8.4	3.9	1.8
Zn (μg/g)	0.2	9.8	2.5	2.5
B (μg/g)	traces	8.6	2.26	2.2

The distribution of trace elements greatly varied and a wide range of the elements extracted by DTPA was as follows: Fe 4.43–80.80 (mean 25.70) mg kg^{-1}, Mn 6.12-111.0 (mean 34.6), Cu 1.0 –8.4 (mean 3.9) mg kg^{-1}, and Zn 0.2 – 9.8 (mean 2.5) mg kg^{-1} (Table 2). Based on average concentration, the following decreasing order was found: Mn>Fe>Cu>Zn. Differences in micronutrients, may be attributed to parent material composition and to human activities such as: fertilization, irrigation and tillage practices. Iron deficiency symptoms are observed in citrus trees although these are restricted in limited areas and can be ascribed to the parent material heredity. Manganese deficiency was limited and its mobility may be due to the oxidation of this element during the dry and warm growing period. The increased mean Cu content seems to be related partly to application of fungicides in the vineyards, by farmers. The plant available phosphorus ranged between 2.0 and 42.0 mg kg^{-1} (mean 114.0 mg kg^{-1}), although in some locations the P level was low. It can be argued that the increased P content in certain sites can be attributed to P over fertilization of perennial crops. Potassium exhibits deficiency levels at specific locations, mainly due to empirical application of fertilizers and may be associated to the presence of magnesium.

Excess application of liming in the acidic soils should be avoided aiming to minimize the binding of micronutrients that can lead to deficiency symptoms. According to the rules for implementation of Code for Good Agricultural Practices in Greece, farmers are obliged to increase the pH at least 0.2 units for the rainfed and 0.3 for the irrigated crops, respectively.

Low concentration of plant available boron was also recorded, especially in soils derived from hard limestone, whilst the observed maximum value was 8.6 mg kg^{-1}. Deficiency problems related to absence of boron were observed, but this phenomenon is restricted at small areas cultivated with olive trees. The water deficit is an important limiting factor for crops survival and water requirements are not covered by rainfall. Based on previous experience, financial incentives for application by farmers of drip irrigation may have positive impact to water saving.

The erosion risk in soils located to slopping areas is high and there are serious difficulties in their management. Crop rotation, and maintenance of land cover with crop during the winter period are essential to control erosion, whilst discouragement of crop production is suggested in the districts where soil gradient is higher than 30-35 %. Finally, restoration of natural environment can be suggested in marginal areas depending on local social and economical conditions.

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