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Ecological Patterns and Comparative Nutrient Dynamics of Natural and Agricultural Mediterranean-Type Ecosystems

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ABSTRACT / An agricultural watershed, situated on an island of the Aegean archipelago, was studied in order to gain insight into the structure and the design of a typical terrestrial ecosystem of the Mediterranean region. Fieldwork was focused on the comparative study of seasonal patterns of inorganic nutrients, organic nitrogen, and erosion over the most abundant vegetation types of the area, such as olive groves, maquis, and wetlands. Nutrient losses via the pathway of erosion were provided by the determination of nutrient concentrations in runoff sediments. Results showed that nutrient levels are higher and more susceptible to rapid changes in the zones that host agricultural activities and animal husbandry. The behavior of nitrogen and phosphorus showed remarkable stability in the maquis, where dynamic processes were mainly affected by soil erosion, which led gradually to land degradation, especially on sloping terrains. The aim of this study was to form the basis for the quantification of the interconnections within the Mediterranean-type ecosystems and to conceptualize their operational properties.

Viewing agroecosystems as intermediates between solar-powered natural ecosystems and fuel-powered urban–industrial systems helps to put current agricultural dilemmas in perspective. Increasing industrialization of agriculture has increased energy and chemical inputs concurrently with chemical pollution and soil erosion outputs (Woodmansee 1984). In the past decades, awareness of environmental protection has grown and formed an incentive for research towards the reduction of soil disturbance and development of environmental protection policies. The central concept is sustainability, which may be pursued through an effect-oriented or a source-oriented approach. The objective of the former approach is to preserve important soil properties and to prevent adverse effects from pollution; the latter approach aims at the isolation, monitoring, and control of point and nonpoint sources of pollution (De Haan and Van der Zee 1994).

Considering soil as a source of pollution, it is necessary to emphasize that it is not a simple container but rather a complex system involving many biological, chemical, and physical factors, which must be taken into consideration (Lal 1994). The overall dynamics of an inorganic nutrient, which in turn is in equilibrium with the organic form of it as a result of microbiological activity, are controlled by a group of factors including: (1) climatic factors such as rainfall and evaporation, aeration and temperature of the soil; (2) the chemical, physical, and biological properties of the soil; and (3) agricultural practices, such as the type of crops and fertilizer practices (Hornung 1990). In general, terrestrial ecosystem dynamics involve a matrix of producers and consumers modified by climate and physiographic features (Barber 1984). Therefore, the demand for effective environmental management and soil protection presumes basic knowledge of its structural and functional complexity (Jorgensen 1997).

As a result of this consideration, during the last decade, ecological studies emphasizing energy flows, nutrient cycling, primary production, and species diversity have reached an advanced level on the ecosystems of North America and Europe (Forsberg 1994, Arroyo and others 1994, Vogt and Gordon 1996). Meanwhile, comparable analyses for Meditteranean-type ecosystems are still in a primary phase of development and considerable gaps in the literature exist regarding assessments of their trophic dynamics and interactions among biotic and abiotic components (Margaris 1992, Davis and Richardson 1995). Existing knowledge in this geographic area is primarily based on descriptive works about morphological and physiological adaptive strategies of plant communities and the evolutionary significance of fire and other physical stresses (Margaris 1981, Moreno and Oechel 1995).

KEY WORDS: Nutrient dynamics; Soil erosion; Agroecosystems; Ecological patterns; Mediterranean-type ecosystems; Aegean Sea

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The goal of this study was to assess spatial and temporal variability of some basic ecological processes in a typical terrestrial ecosystem of the Mediterranean Basin. Properties of the study site resulted directly from economic, social, cultural, and environmental components of the Greek region. The experimental procedure focused on the comparative study of seasonal patterns of inorganic nutrients, organic nitrogen, and erosion over the most abundant vegetation types of the area, such as olive groves, maquis, and wetlands. Special emphasis was given to the determination of nutrient concentrations in runoff sediments, the most visible pollutant originating from nonpoint sources, in order to quantify the outflows of the ecosystem's nutrient budget. The aim of this comparison of the magnitudes of nutrient losses among natural ecosystems and agroecosystems is to quantify the impact of human intervention in the degradation process of soils, considering the typical characteristics of agricultural practices in the Mediterranean zone, with a view to preserving agricultural productivity and diminishing nonpoint pollution.

Materials and Methods

Study Area

This study was conducted within the Gulf of Gera Basin, a 194.01-km^2 drainage area, on the island of Lesvos (Figure 1A), where flora belongs to the *Oleo–Ceratonion* zone. According to Thornthwaite's classification system, the local climate in Lesvos is of the type $C_1dB'_3b'_4$ (Karras 1974) and in addition the study watershed is characterized by an annual rainfall between 600 and 800 mm; an annual evaportranspiration potential of 900 mm and a high mean temperature of 19°C. The geological substrate of the area consists mostly of metamorphic rocks (marbles, mica schists), igneous rocks (granites, basalts) and alluvial depositions.

Assessment of the morphological and hydrographic status of the area was obtained by using GIS software (ARC/INFO, version 7.0.2, Environmental Systems Research Institute, Redlands, California). In general, the study area can be considered as a typical terrestrial ecosystem of the Mediterranean region, especially the Greek islands of the Aegean Sea, characterized mostly by shallow and infertile soils, steep slopes, water deficiency, and limited cultivable areas. Most of the local rivers are characterized by a torrential regime, which is considerably influenced by local precipitation characteristics (intensity, duration, frequency of occurrence, antecedent precipitation) and physiographic features of the area (size, slope, land cover, permeability, and capacity of groundwater formations). Shortage of land in the watershed, as a common practice around the Mediterranean, has been compensated by the construction of extensive systems of terraces, which not only provide soil for cultivation but also minimize soil erosion.

The landscape of Lesvos is characterized by a traditional monoculture of olive trees, which occupy one quarter of the total area of the island. The study distinguishes between two types of olive plantations: cultivated and abandoned. Cultivated plantations are the olive groves in which cultivation takes place annually and wild woody plants are limited. Abandoned plantations are the olive groves in which the canopy of the olive trees is limited, wild woody plants have started to spring up, and wild olive trees have begun to appear (Loumou and others 2000). Meanwhile, the mountainous zones of the catchment are covered with evergreen sclerophyllous plant communities (Maquis), phrygana in combination with coniferous trees (*Pinus brutia*), constituting the climax stage of natural ecosystems in the Mediterranean region, the so-called Mediterranean-type forest. The livestock of the area numbers about 5500 sheep and goats, and the animal husbandry is mostly of the domestic type, whereas free grazing is kept at low levels.

The basic structure of the analysis was to compare these land-cover categories (ecosystems) that have different types of human activities on them and use the differences in nutrient and erosion characteristics to determine the impact of anthropogenous treatments to ecosystem features. Thus, the essence of the research is a spatial comparison from which causal associations and dynamics relative to human factor are inferred.

Experimental Design

A landscape analysis was performed to detect the most abundant vegetation types of the area and estimate accurately their extent. The land-cover data were based on a 1987 Landsat Thematic Mapper (TM) image, using unsupervised (cluster analysis) and supervised classification (maximum likelihood method), with 30- × 30-m cells (Hatzopoulos and others 1992).

In order to obtain an objective analysis of the ecosystems, the sampling procedure covered the entire watershed and took into consideration all possible sources of variance that could affect their dynamic behavior such as topography, geology, altitude, and hydrography. The network of the present study, consisting of 51 sampling sites, is shown in Figure 1B. Each dot represents sample collection from a different land cover category numbered 1 to 4 (1: cultivated olive groves, 2: abandoned olive grooves, 3: maquis, and 4: wetlands); A, B, and C correspond to altitudes of

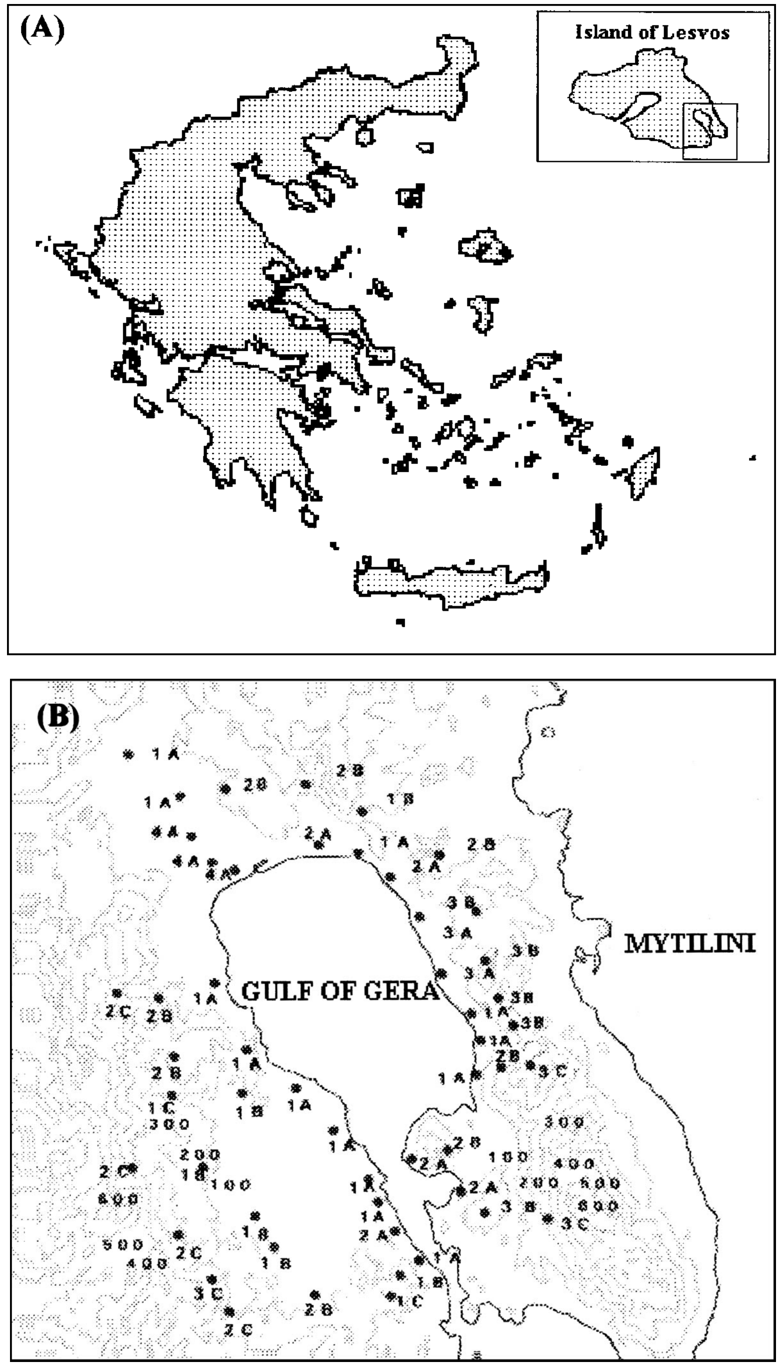

Figure 1. (A) Map of Greece with the island of Lesvos. (B) Locations of sampling sites along the Gulf of Gera Basin. Land cover categories are: 1, cultivated olive groves; 2, abandoned olive groves; 3, maquis; and 4, wetlands. Letters A, B, and C correspond to the altitudes of <150 m, 150–300 m, and >300 m, respectively.

<150 m, 150–300 m, and >300 m, respectively. Vertical distribution of nutrients was obtained by taking soil samples from three different horizons (0–15, 15–30, and 30–45 cm). Sampling was carried out on a seasonal basis—the middle month of each season—for two years, and bulk density, pH, texture, nitrate, ammonia, phosphate, and organic nitrogen were measured. Each soil sample consisted of 10–30 subsamples, sieved to <2 mm, and stored at 4°C until analysis. Bulk density was determined on soil clods by using paraffin as impermeabilizer; pH was measured electrometrically and texture by the Bouyoucos method (Barber 1984). Organic nitrogen was measured by the Kjeldahl method; $N\text{–}NH_4^+$ extracted with 2 M KCl was determined with the Nessler method; $N\text{-}NO_3^-$ in an aqueous extract was measured by

the salicylic acid method and; $NaHCO_3$-extractable phosphorus was measured spectrophotometrically by the method of Murphy and Riley (1962).

Quantitative and qualitative assessment of sediment loss from various ecosystems of the catchment area was obtained on a monthly basis by using Gerlach-type collectors (Morgan and Davidson 1986); metal gutters were placed at the lower sites of experimental plots—three plots for each land-cover category—which were 10 m^2 in size with 50% average slope. Collected eroded materials were filtered, dried, and weighed in the laboratory at the end of each month. Adoption of a smaller temporal study scale for erosion was due to its significant variability controlled by several factors, such as rainfall intensity, soil properties, vegetation, topography, and human activities. Moreover, the above pretreated samples were converted, using the chemical analysis, into nutrient losses per unit area.

Emphasis in the composition of plant communities was given to woody perrenial species due to the fact that they are consistent components dominating the physiognomy of the study systems. Furthermore, annual standing biomass was measured *en masse,* in ten subplots of 1 × 1 m, separately for each of the land covers. Sampling took place between May and June, before the end of the growth period, when maximum rates of biological activity are observed due to favorable climatic conditions in the Mediterranean.

Statistical Analysis

Statistical analysis focused on detecting significant differences among the different types of land cover by taking into account the seasonal patterns of nitrate, ammonia, phosphate, organic nitrogen concentrations, and soil erosion. Primarily, these variables were tested for normality with the Kolmogorov-Smirnov test (Conover 1980). In the cases that showed a good fitting to the normal distribution (nitrate, ammonia, and organic nitrogen), the testing for intergroup differences was obtained by application of two-factor analysis of variance, in order to examine for significant interaction effects among the type of land cover and the season of the year concerning nutrient concentrations and soil erosion. The variables that not normally distributed (phosphate, annual standing biomass, and sediment loss), were analyzed nonparametrically by the use of the Kruskal-Wallis test (Zar 1984). Moreover, the multisample comparisons, in order to determine the sources of significance between the samples, were based on the application of the parametric and nonparametric Tukey test (Zar 1984).

Table 1. Land cover categories in the catchment area of Gera

Land cover	Area (km^2)	Number of sampling sites
Olive groves		
Cultivated	75.71 (39.02%)	21
Abandoned	40.78 (21.02%)	17
Urban areas	8.37 (4.33%)	—
Maquis	62.42 (32.17%)	10
Wetlands	6.73 (3.46%)	3
Total	194.01	51

Results

Cultivated olive groves represented 39% of the total area (Table 1), constituting the basic agroecosystem type of the watershed and characterized mostly by man-induced properties. In contrast, the maquis comprised 32% of the area and their study revealed the natural features of Mediterranean-type ecosystems. Abandoned olive groves (21%) were considered intermediate between the previous two types of vegetation; since they are not subject to human activities but the existing terraces partly control soil erosion processes. Furthermore, wetlands of the area, although minor in size (3.5%), were considered essential to the study due to their intensive use as pastures for sheep and goats all year.

Perennial species (woody and geophytes) present in each of the experimental sites are shown in Table 2. Generally, there are no significant differences among the land-cover categories in woody species richness. The richest system in species is that of abandoned olive groves, including 13 species, and the poorest one is that of wetlands, including 9 species; maquis and cultivated olive groves were intermediate, with 12 and 10 species, respectively. Each of the ecosystems has a dominant species; that is *Quercus coccifera* in maquis, *Origanum vulgare* in the zones of cultivated olive groves, *Arundo donax* in the wetlands, and *Cistus incanus* in the abandoned olive groves.

Results of the aforementioned experimental procedure concerning soil physical and chemical properties are given in Table 3, where the term "mean annual values" refers to the mean over all seasons, horizons, and sampling sites of a land cover category. In addition, their temporal variations are represented graphically in Figure 2; the graph dots correspond to the mean seasonal values of the land-cover categories. Study area consists mostly of acid soils with a sandy loam texture and an organic matter content below 3% (Figure 3). The cultivated olive groves showed the highest concentrations of nutrients and a seasonal variability, with

Table 2. Perennial species (woody and geophytes) present in each land-cover categories of the study area

Species	Cultivated olive groves	Abandoned olive groves	Wet-lands	Maquis
Arundo donax	—	—	+	—
Asparagus acutifolius	+	+		
Ballota acetabulosa	+	+		
Calamagrostis arundinacea	—		+	
Calicotome vilosa	—			+
Cistus incanus.	+	+		+
Clematis alba	+			
Erianthus ravennae			+	
Festuca ovina glauca			+	
Festuca tenuifolia			+	
Fumana arabica				+
Genista acanthoclados		+		
Koelaria grauca			+	
Medicago sativa			+	+
Micromeria graeca	+			
Olea europaea	+	+		
Olea oleaster				+
Origanum vulgare	+	+		
Pennisetum setaceum			+	
Phagnalon rupestre	+			
Pinus brutia				+
Pirus amygdaliformis		+		
Pirus communis		+		
Pistacia lentiscus		+		+
Pistacia terebinthus		+		+
Quercus coccifera	+	+		+
Salvia argenta			+	+
Teucrium chamaedrys	+	+		+
Thymus capitatus		+		+

Table 3. Summary statistics of nitrate, ammonia, organic nitrogen, phosphate, pH, bulk density, sediment loss, and annual standing biomass on ecosystems of Gera's watershed

Variables[a]	Cultivated olive groves	Abandoned olive groves	Maquis	Wet-lands
Nitrate (μg N/g soil)				
MAV	27.85	8.88	0.61	10.27
SD	11.08	1.39	0.12	0.70
CV (%)	39.77	15.69	20.00	6.85
Ammonia (μg N/g soil)				
MAV	46.82	9.48	6.42	8.67
SD	24.80	3.51	0.55	0.82
CV (%)	52.97	37.06	8.55	9.42
Org. Nitrogen (μg N/g soil)				
MAV	822.54	879.31	830.37	936.25
SD	31.95	12.12	12.42	6.32
CV (%)	3.88	1.37	1.49	0.67
Phosphate (μg P/g soil)				
MAV	22.60	8.64	5.02	9.53
SD	11.88	1.44	0.12	4.35
CV (%)	52.57	16.67	2.39	45.69
pH				
MAV	5.92	5.53	7.56	6.27
SD	0.07	0.03	0.04	0.02
CV (%)	0.24	0.49	0.53	0.32
Bulk density (g/m^3)				
MAV	1.35	1.34	1.33	1.36
SD	0.11	0.03	0.01	0.02
CV (%)	8.15	2.23	0.75	1.47
Sediment loss (kg/ha)				
MAV	0.56	0.24	1.81	—
SD	1.45	0.40	3.94	—
CV (%)	260.82	161.94	217.94	—
Standing biomass (g/m^2 dry wt)				
MAV	109.13	28.99	1.14	208.19
SD	20.97	2.62	0.18	15.47
CV (%)	19.22	9.04	15.78	7.43

[a]MAV: mean annual values; SD: standard deviation; CV, coefficient of variation.

maxima in spring period. These observations can be regarded as results of fertilizer applications in combination with the bacterial mineralization of organic nitrogen supplies due to optimum temperatures (20–35°C) that prevail in this season in the Mediterranean area. Verification of these findings was obtained by the statistical analysis (Table 4–7), where it can be seen that nutrient levels of the cultivated olive groves are significantly higher at the 5% level, in comparison with the other ecosystems of the watershed. Their temporal variations are reflected in the statistical significance of their interactions with the warm seasons of the year (Table 6). Analogous trends were detected in the wetlands, hosting mostly the animal husbandry of the area. Special emphasis must be given to their high levels of organic nitrogen (mean annual value of 936 μg N/g soil), especially in the winter period, due to the excretions of grazers in combination with the release of the plant residues of nitrogen because of decomposition activity of soil microorganisms.

It was also found that the zones that are not susceptible to human activities, such as the maquis and the abandoned olive groves, had the lowest levels of nutrients. The statistical evaluation of this observation was based on the application of the parametric and the nonparametric Tukey test (Tables 6 and 7). Results indicated that these natural ecosystems form a statistically significant distinct group (95% confidence interval), due to the low values of their chemical parameters. Moreover, the dynamic behavior of nitrogen and phosphorus in these areas, especially in the abandoned olive

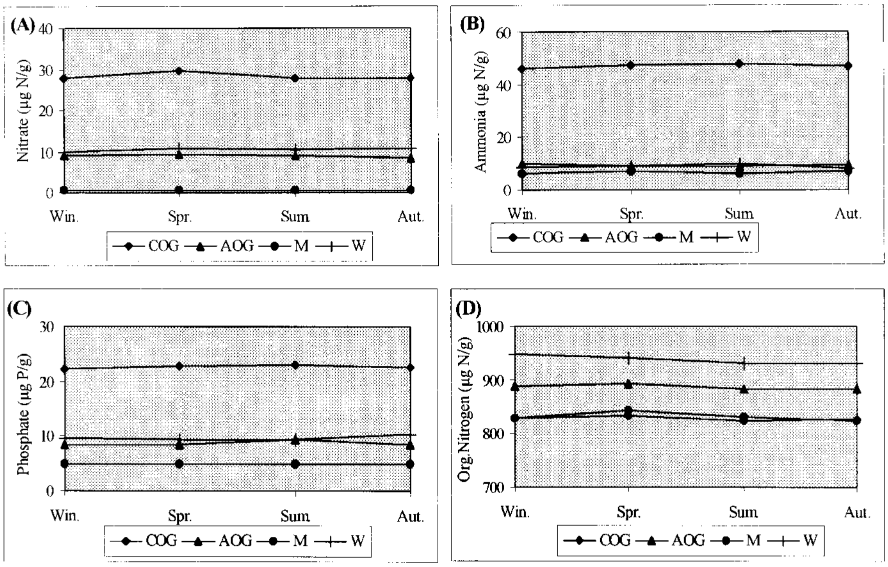

Figure 2. Seasonal patterns of (A) nitrate, (B) ammonia, (C) phosphate, and (D) organic nitrogen concentrations on the vegetation types of the study area. (AOG: abandoned olive groves, COG: cultivated olive groves, M: maquis, W: wetlands).

Table 4. Two-factor ANOVA for testing differences among types of ecosystems and seasons of year for nitrate, ammonia, and organic nitrogen concentrations

Sources of variance	Degrees of freedom[a]	F ratio	F $ratio_{0.05}$	Level of significance
Nitrate				
Ecosystems	4/299	13.65[b]	2.83	0.00
Seasons	4/299	1.92	2.83	0.11
Ecosystems × seasons	16/299	6.02[b]	1.85	0.00
Ammonia				
Ecosystems	4/299	14.47[b]	2.83	0.00
Seasons	4/299	1.65	2.83	0.17
Ecosystems × seasons	16/299	5.59[b]	1.85	0.00
Org. nitrogen				
Ecosystems	4/220	55.85[b]	2.85	0.00
Seasons	4/220	3.39[b]	2.85	0.02
Ecosystems × seasons	16/220	4.49[b]	1.87	0.00

[a]DF of groups/DF of error.
[b]Significant value at 0.05.

Table 5. Kruskal-Wallis single-factor ANOVA for testing differences among types of ecosystems and seasons of the year for phosphate concentrations, annual standing biomass, and sediment loss

Sources of variance	Number of observations	Value of test statistic H	Level of significance
Phosphate			
Ecosystems	324	101.36[a]	0.00
Seasons	324	0.61	0.96
Annual standing biomass			
Ecosystems	60	115.75[a]	0.00
Sediment loss			
Ecosystems	78	47.21[a]	0.00

[a]Significant value at 0.05.

groves, was stable with minor seasonal fluctuations. This temporal trend reveals a well-established balance among the supplies of nutrients due to biotic activity and the losses due to plant uptake, erosion, leaching, and volatilization. The tendency to persist through space and time was also demonstrated from the low values of their coefficients of variation (CV), in particular ammonia in the maquis (8.55%) and phosphate in both maquis (2.39%) and abandoned olive groves (16.67%).

The significance of the anthropogenic activities in the vertical distribution of nutrients was studied by comparing the soil profiles of abandoned and cultivated olive groves. The graph lines of Figure 4 refer to the mean concentrations of the soil horizons for all the temporal (seasons) and spatial (sampling sites) data of each land-cover category. The highest concentrations of the cultivated olive groves were measured in the surface horizon (0–15 cm), where the application of the fertilizers is taking place in order to contribute to the inorganic nutrition of plants. Meanwhile, it can be characterized as the zone that is mainly affected by processes of erosion and surface runoff, determining mostly the magnitudes of the nonpoint loads. In contrast, the organic nitrogen concentrations have showed cumulative trends to inferior horizons, resulting in an increase from 20% to 40%. This observation can be

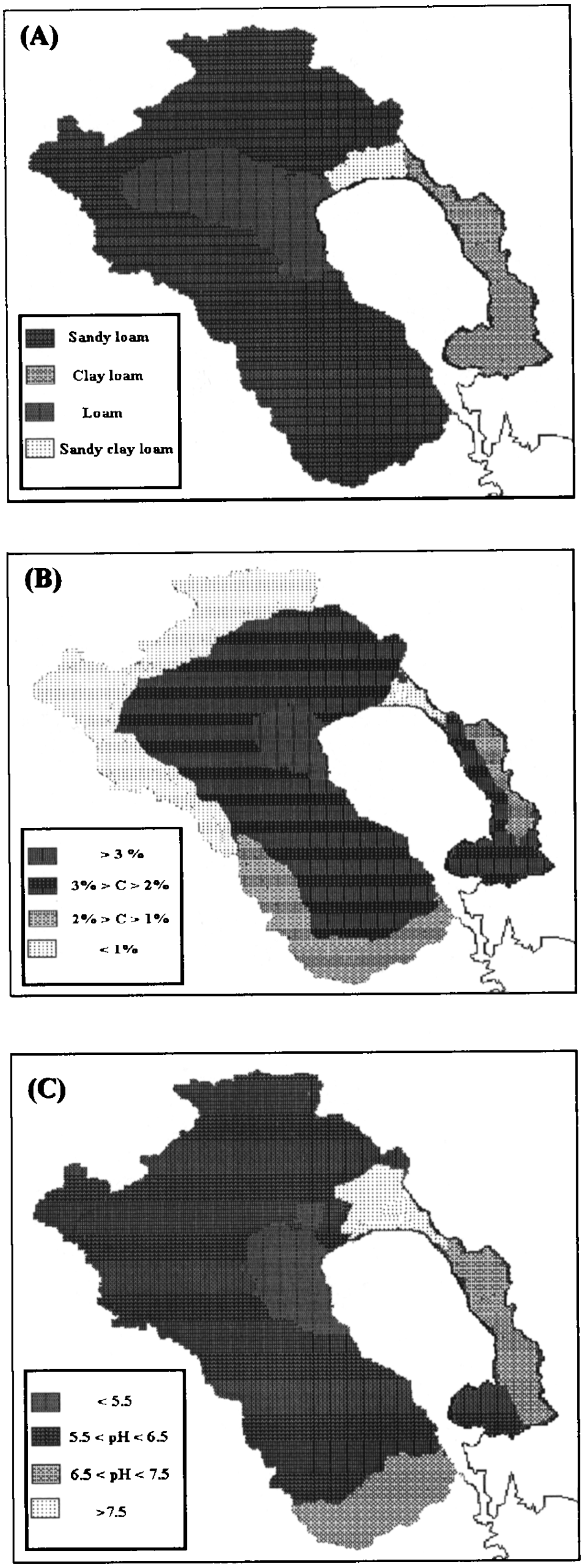

Table 6. Tukey's test for multiple comparisons among the types of ecosystems and their interactions with seasons of the year for nitrate, ammonia, and organic nitrogen concentrations (statistical significant groups at 5% probability level)

Group	Ecosystems[a]	Group	Ecosystems × seasons
Nitrate			
1	M-AOG-W	1	The remaining interactions
2	COG	2	W × Spr 96
		3	COG × Spr 96
Ammonia			
1	M-AOG-W	1	The remaining interactions
2	COG	2	COG × Sum 96
		3	W × Sum 96
		4	COG × Spr 96
Organic nitrogen			
1	COG-AOG	1	The remaining interactions
2	AOG-M	2	M × Spr 96
3	W	3	COG × Spr 96–W × Win 96
		4	W × Win 97

[a]AOG: abandoned olive groves, COG: cultivated olive groves, M: Maquis, W: Wetlands, Spr: spring, Sum: summer, Win: winter.

attributed to the intensity of organic matter decomposition in the surface area, as a consequence of the favorable conditions of aeration and temperature. The zones of abandoned olive groves that are not subject to human-induced stresses have showed a more uniform profile of their chemical parameters.

Results concerning the aboveground standing biomass of annual plants in each of the vegetation types of the basin, are given in the Table 3; "mean annual values" refers to the mean of a land cover category over all sites (subplots) for the two years of the experiment (2 × 10 measurements for each system). It is evident that in natural ecosystems, annuals do not abound due to a parallel increase of woody species accompanied by shading and competition effects (Crubb and Hopkins 1986). The lowest values of annual standing biomass have been observed in the maquis (1.14 g/m^2 dry wt), whereas the corresponding values in the abandoned olive groves were 28.99 g/m^2 dry wt. These results are reversed in all sites that undergo anthropogenic stresses, such as agricultural activities, where the yearly

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Figure 3. Spatial distribution of (A) texture, (B) organic matter content (%) and (C) pH in Gera's watershed.

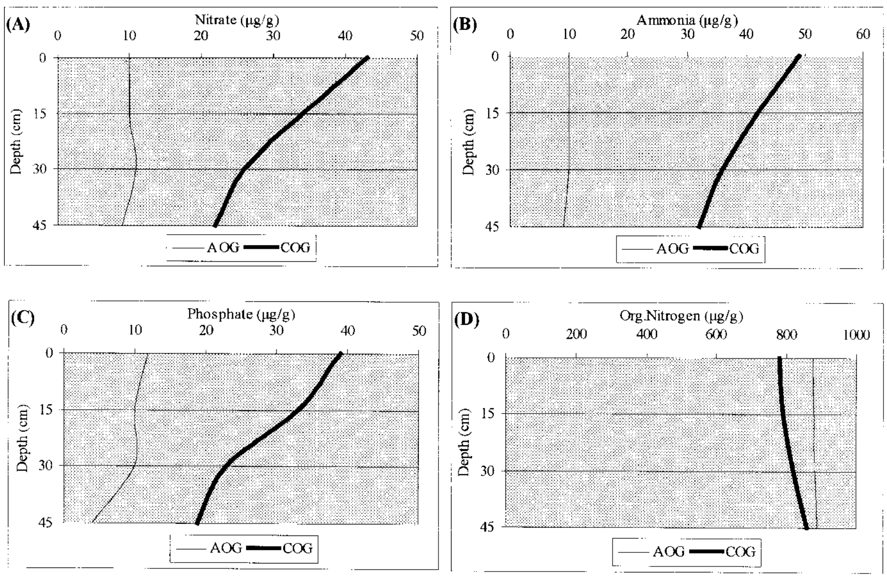

Figure 4. Soil profiles of abandoned and cultivated olive groves, concerning (A) nitrate, (B) ammonia, (C) phosphate, and (D) organic nitrogen concentrations (AOG: abandoned olive groves, COG: cultivated olive groves).

Table 7. Nonparametric Tukey's test for multiple comparisons among types of ecosystems, for phosphate concentrations, annual standing biomass, and sediment loss (statistical significant groups at 5% probability level)

Group	Ecosystems[a]
Phosphate	
1	M-AOG-W
2	COG
Annual standing biomass	
1	M-AOG
2	COG
3	W
Sediment loss	
1	AOG
2	COG
3	M

[a]AOG: abandoned olive groves, COG: cultivated olive groves, M: maquis, W: wetlands.

produced biomass exceeded 100 g/m^2 dry wt. Special emphasis must be given to the wetlands, where the mean annual productivity was 208.19 g/m^2 dry wt, revealing the role of the natural nutrient subsidies that the habitats of this plant community receive due to recycling processes and to their inherent capability to interact with surface waters and surface runoff and abstract nutrient loads (Weller and others 1996).

Sediment loss data was collected on a monthly basis, during April 1996–May 1998 over the most abundant vegetation types of the watershed (Table 3). The lack of data concerning erosion processes over the wetlands was due to the absence of a surface with appropriate slope in the specific watershed. Results exposed the vulnerability of the maquis to soil erosion processes, showing a mean annual value of 1.81 kg/ha; this observation was associated mostly with their low values of annual biomass. Annuals, as compared with perennial plants and shrubs, should be considered more effective in preventing the detachment of individual particles from the soil mass and their transport by erosive agents. This capability is attributed mostly to their dense root system, consisting of numerous and highly branched root hairs that are accumulated in the topsoil layers and sustain the soil cohesive character (Crubb and Hopkins 1986). Significant resistance to erodibility has been observed in the abandoned olive groves, with a mean rate of 0.24 kg/ha/yr, whereas sediment loss from the cultivated olive groves was double (0.56 kg/h/yr). This twofold increase of soil loss on the agricultural lands is indicative of the dominant role of disturbances caused by human activities to the magnitudes of soil erosion processes. However, it is evident that the zones of olive groves are more resistant to erosion, in comparison with the maquis, and this is due to the local use of mechanical control methods, such as bench terraces, especially at steep slopes up to 50%. These terraces are constructed across the slope and consist of a series of alternating shelves and risers with masonry support. The aim of such a soil conservation practice is to intercept excess water, to reduce the velocity of surface runoff at a nonerosive level, and to shorten slope length (Morgan and Davidson 1986). The temporal variations of sediment loss, in combination with the monthly rainfall of the area, are represented graphically in Figure 5A. Each point of the plot corre-

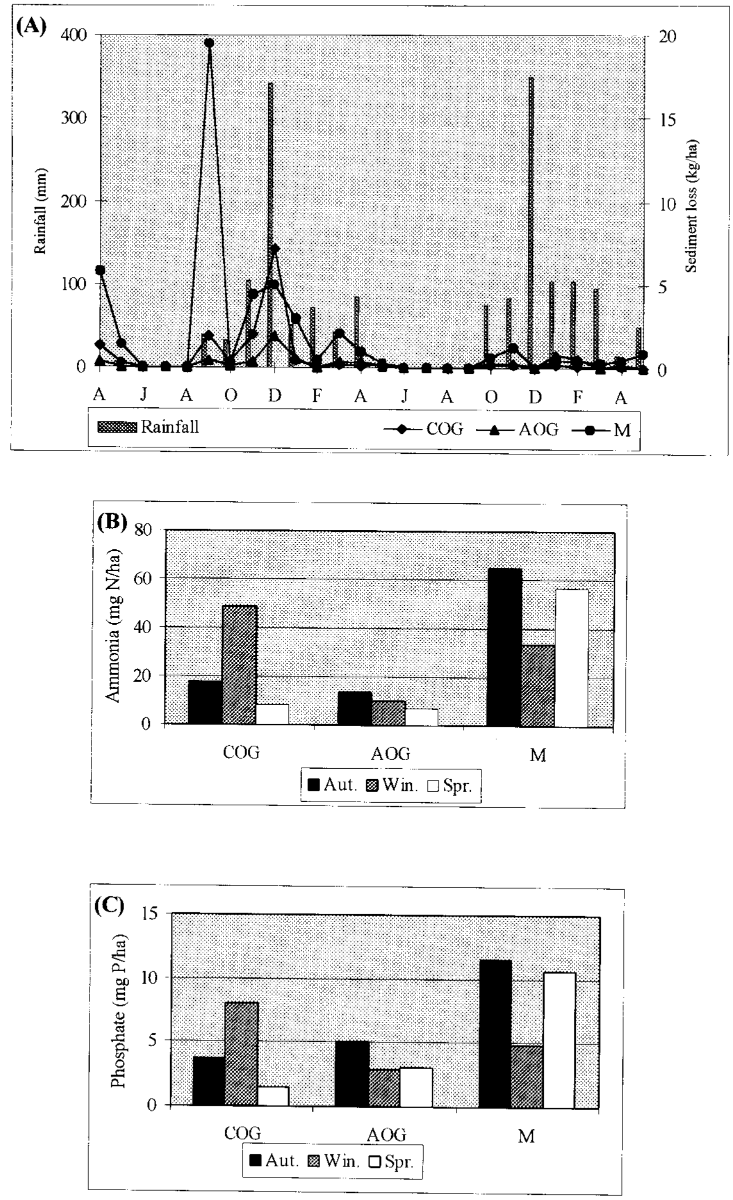

Figure 5. Monthly pattern of sediment loss (A), and seasonal patterns of ammonia (B) and phosphate (C) losses from the ecosystems of Gera's watershed. (AOG: abandoned olive groves, COG: cultivated olive groves, M: maquis).

sponds to the mean sediment loss per month for each of the land-cover categories. Results showed that significant quantities of soil are lost in the winter period, whereas in the summertime the losses approach zero.

Comparative study of nutrient loss due to erosion from the various ecosystems of the Mediterranean area was based on second annual cycle results (Figure 5B and 5C). It was inferred that nutrient fluxes via the pathway of erosion could be considerable at the maquis, with a total amount of 154 mg N/ha/yr and 27 mgP/ha/yr for ammonia and phosphate, respectively. Significant quantities of nutrients have also been exported from the cultivated olive groves; these discharges can be attributed mainly to the accumulation of inorganic nutrients and organic matter on the topsoil layers, due to fertilizer applications and grazer excretions. Soil eroded and delivered from these zones as sediment contains a higher percentage of finer and less dense materials, such as clay particles and organic residues, and consequently higher concentrations of nutrients, than the parent soil due to their greater adsorption capacity (Barber 1984). Furthermore, the corresponding values from the abandoned olive groves were less than 30 mg N/ha/yr and 10 mg P/ha/yr, revealing their resistance to these mechanisms of degradation.

Discussion

Losses of nutrients from ecosystems can take place via a number of pathways and should always be quantified in any comprehensive study of ecosystem dynamics. Pathways and magnitudes of nutrient loss vary for different nutrients and with various environmental factors, e.g., climate, soil type, topography, and with the stage of development of the ecosystem (Hornung 1990). The present work represents an initial attempt to quantify some basic elements of structure and design of the most characteristic vegetation types of Mediterranean region. The combination of plantation, climate, and socioeconomic conditions we studied is fairly widespread in Mediterranean coastal zones; thus this paper could be regarded as a mode to generalize in wider geographic areas. This approach was based on the comparative study of temporal patterns of inorganic nutrients and organic nitrogen and on the quantitative and qualitative analysis of erosion. Supplementary knowledge of ecosystem functioning was gained by measuring annual standing biomass.

The results showed that the levels of nutrients are higher and more susceptible to rapid changes in the zones that host agricultural activities and animal husbandry. The maximum values were observed in the spring period as a result of fertilizer applications and microbial activity, accelerated by favorable abiotic factors (temperature, solar radiation, moisture) that prevail in this season in the Mediterranean region (Moreno and Oechel 1995). Another characteristic of these zones is the high values of the biomass of annuals produced yearly. Moreover, nutrient losses as a result of erosion were considerable in the cultivated olive groves, and these losses should be ascribed mainly to anthropogenic disturbances. Remedial measures necessary to offset lost agricultural productivity and to control erosion require increasing fertilizer, water, and energy inputs and conservation management practices beyond the eroded fields (Forsberg 1994).

The abandoned olive groves have moderate levels of nutrients and an indisputable resistance of their soil to both detachment and transport. This is attributed to the increased canopy interception of rainfall in combination with the existence of bench terraces, which favor soil protection and sustain its cohesive character. It was also found that the dynamic behavior of nitrogen and phosphorus in the maquis was mainly affected by soil erosion, which led gradually to degradation, especially in sloping terrains. This tendency is directly related to factors concerning the low values of annual biomass due to shading and competition effects by perennial species and the lack of soil erosion control practices. The resultant losses of fertility, tilth, and water capture disturb the natural balance of these ecosystems and reduce their productivity potential (Arroyo and others 1994).

An unfavorable perspective for the Mediterranean-type agroecosystems, especially in the islands of the Aegean Sea, is the progressive abandonment of the intense cultivation of the olive groves by the local farmers and their usage solely as pastures (Margaris 1992). The abandonment of cultivated lands, although detrimental in socioeconomic terms, could eventually be beneficial to the natural environment. It initiates the process of recovery of natural vegetation and, as nature takes over, complex ecosystems develop in place of the simplified man-made agroecosystems (Giourga and others 1998). However, the aforementioned exposure of these zones to free grazing from sheep and goats interferes with secondary succession and constitutes a severe long-term threat for ecosystem properties, especially on these mountainous areas. The nonrecovering vegetation in conjunction with the progressive destruction of control techniques, due to their lack of conservation, leads to intensified soil erosion and has repercussions on water economy (Giourga and others 1998). Moreover, the observed maquis properties, such as significant sediment loss and low values of nutrient concentrations, can be perceived as indicative of the possible alteration of the features that characterize the zones of olive groves. It is realized therefore that local areas should develop large-scale cost-effective managerial schemes in order to avoid the ongoing degradation process and secure sustainability (Margaris 1992).

The results of the present study can be regarded as basic knowledge, necessary to understand the fundamental mechanisms of Mediterranean ecosystems, especially in the Greek Islands of the Aegean Sea. In general, the types of phenomena that can be perceived as essential for their objective analysis are: species richness in various components; functional properties, such as energy flow and nutrient cycling; and ecosystem response to perturbation and the allelochemical regulations (Jackson 1984). The last case refers to the interactions among the biotic and abiotic components of ecosystems that can lead to the maintenance of functional integrity, biotic persistence, and self-regulation (Hauhs and others 1995). This particular aspect of ecosystem dynamics, considering the uniqueness of the structure of the Mediterranean type and their well-documented resilience, constitutes a significant aim of on-going research.

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