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Use of ^{137}Cs isotopic technique in soil erosion studies in Central Greece .

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ABSTRACT

The ^{137}Cs technique was used to study soil erosion and deposition rates in soils in the Viotia prefecture, central Greece. Three sites with different soil types were selected and studied. Soils were sampled along transects and analyzed for ^{137}Cs. The main goal of this field investigation was to study the ^{137}Cs 3-D distribution pattern within key sites and to apply this information for the assessment of soil redistribution. The erosion and deposition rates were estimated using the proportional and the simplified mass balance models (Walling and He, 1997). Erosion and deposition rates predicted through the spatial distribution of ^{137}Cs depended on the location of the profile studied in the landscape and were determined by the soil plough depth, the soil structure (bulk density), and the calibration model used to convert soil ^{137}Cs measurements to estimates of soil redistribution rates. Estimated erosion rates for the Mouriki area site, varied from 16.62 to 102.56 t ha $^{-1}$ y $^{-1}$ for the top of the slope soil profile and from 5.37 to 25.68 t ha^{-1} y^{-1} for the middle of the slope soil profile. The deposition rates varied from 7.26 to 42.95 t ha $^{-1}$ y $^{-1}$ for the bottom of the slope soil profile.

Key Words: Erosion rates. Cesium 137. Erosion. Cs-137 distribution.

INTRODUCTION

Water soil erosion is one of the main degradation processes to occur under the Mediterranean bioclimatic conditions for soils in Greece. This is the reason why most of the soils have lost their fertile top A horizon. They are, therefore, now described as Lithosols and Regosols (FAO, 1988), or ENTISOLS (SOIL TAXONOMY, 1975).

Soil erosion is a very complicated process depending on many parameters, which in most cases interact, while they operate under significant temporal and spatial variability. The need to understand, describe, predict and quantify soil erosion is self-explicit, and is important for the adoption of suitable anti-erosion measures. It is also necessary in order to estimate the economic impact of loosing fertile soil (with all its nutrient elements) in the context of soil degradation or pollutant charging of ground and surface waters.

Three techniques are used, worldwide, on different scales in order to measure soil erosion i.e. plot experiments, surveys and tracers. The general impression by

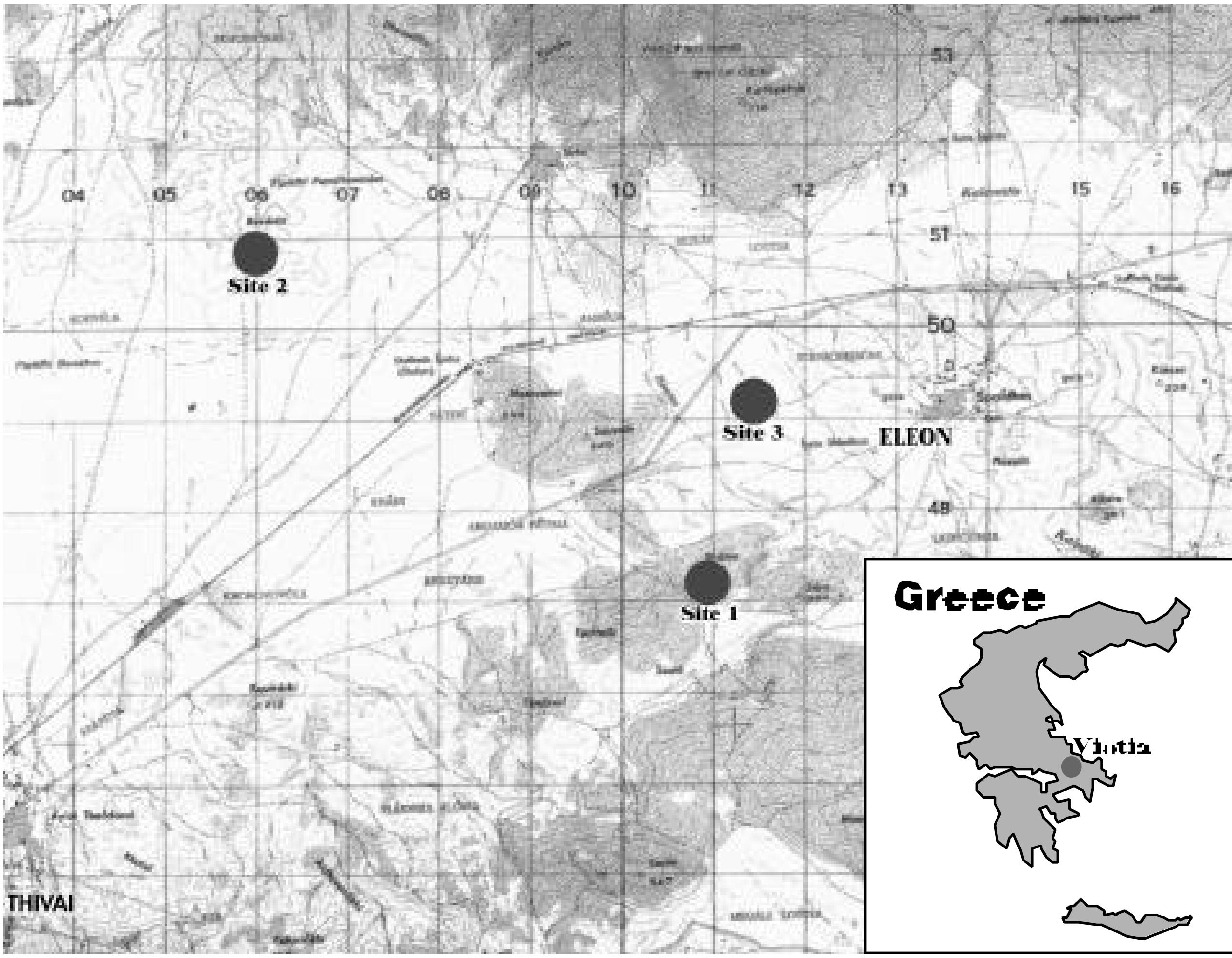

Figure 1. Greece, Viotia area and studied sites 1,2,3. Scale 1:50000

reading the relevant bibliography (Quine et al., 1994) is that long term erosion rates data from direct measurements is missing. For Greece, it seems that quantitative long period data do not exist at all.

Recently, many models have been proposed in the bibliography, as described by Nearing et al., (1994), and de Roo (1993), aiming to describe, predict and estimate erosion in time and space on different scales i.e. experimental plot, field scale, mapping unit, land management unit, catchment scale. The complexity of the process, the interaction of the factors, the inherent temporal and the spatial variability, have favored the development of many models such as EUROSEM (Morgan et al., 1992), WEPP (Nearing et al., 1989). These models, in most of the cases, are not related to each other and generally do not predict similar erosion rates.

Field quantitative data for wind and both sheet and rill water erosion have come from several studies which have been carried out throughout the world using radionuclides as tracers (Quine et al., 1994). Also radionuclide tracers have been used for the investigation of ecological processes, related to the degradation of natural resources such as soil, water, plants and animals (Praundle, 1994, Dalhguard 1994, Florou and Chalalou, 1997). The ^{137}Cs technique was originally used for the study of soil water erosion in the United States (Rogowski and Tamura, 1965, 1970), and later in Europe (Vanden Berche and Culinck, 1987, in Belgium; Walling and Quine, 1991, in the United Kingdom). This technique, which seems to pose important advantages, is well described by Van den Berghe and Gulinck (1987), Walling and Quine (1991), and Quine and Walling (1991,1992).

Table 1. Physical and chemical properties of soils studied.

Code	Site	Depth (cm)	Gravels %	Clay (%)	Silt (%)	Sand (%)	Class	$CaCO_3$ (%)	O.M. (%)	CEC (meq/ 100g)
52614	Thiva P1	0-35	10	32	22	46	SCL	4.2	3.3	33.76
52615	Thiva P1	35-62	8	30	24	46	SCL	11	1.7	33.56
52996	Mouriki	0-15	10	38	20	42	CL	0.8	2.6	
52991	Mouriki	0-15	8	34	20	46	SCL	0.6	3	21.1
52992	Mouriki	15-30	8	36	18	46	SCL	0.6	2.3	19.22
52993	Mouriki	30-60	5	40	18	42	C/CL	0.6	1	
53054	Eleon	0-15	4	44	16	40	C	20.2	0.8	5.5
53055	Eleon	15-30	5	46	16	38	C	17.6	1.2	4
53056	Eleon	30-60	4	42	18	40	C	17.6	1.8	4

In Greece neither quantitative long-term soil erosion data exist, nor has the ^{137}Cs technique been used before for long term quantification of soil erosion. This project aims to investigate the potential of this technique and to measure long term soil erosion losses. This was done first in Viotia prefecture area, central Greece.

In this paper is described the 3-D distribution of ^{137}Cs in the landscapes studied and the development of the ^{137}Cs technique as a tool to study soil erosion and deposition rates. Also the results obtained so far from this project, funded by the I.A.E.A., in arable land in the Viotia prefecture central Greece.

METHODOLOGY

Soils study

The soils in the Viotia prefecture, in Central Greece have been studied and mapped by Theocharopoulos (1992). The qualitative soil erosion maps of the area and the criteria or parameters which determine the soil erosion have been studied by Davidson and Theocharopoulos (1992). Based on the above studies, three soils were selected and studied (Fig. 1). One in the Thiva town area, site 1, one in the Mouriki village area, site 2, and the third in the Eleon village area, site 3. These soils are classified as typical Herorthents and differ in terms of texture, structure, and depth. The Thiva area soil has a sandy clay loam texture (SCL); the Mouriki village area soil has a texture of clay loam to sandy clay loam (CL to SCL) while the Eleon village area soil has a clay (C) texture. The mean annual precipitation in the two meteorological stations of Aliartos and Tanagra, which exist in the Viotia area, varies from 678 mm.y-1 in the Aliartos to 488 mm.y-1 in the Tanagra station. Under the Mediterranean climate of the area, most of the rainfall occurs from October to March.

Soil samples were collected, using an 70 mm diameter auger, at soil depth increment up to 60-80 cm depth, the maximum depth to which ^{137}Cs may have reached (Antonopoulos, et al., 1995). Soil samples were analyzed for ^{137}Cs in the Environmental Radioactivity Lab., N.C.S.R "Demokritos", using a Hp Ge detector of 25% relative efficiency and computerized multi-channel analyzer in a total spectrum area 2000 KeV and a resolution of O.5KeV/ch. The soil samples from the designated morphogenetic horizons were also analyzed in order to determine the following parameters: C, Si, S, EC, pH, or-

Table 2. ^{137}Cs reference values for the Viotia study area.

Location	Longitude	Latitude	^{137}Cs (Bq.kg^{-1})
Kopais 1	23º 09'	38º 28'	44
Kopais 2	23º 09'	38º 26'	17
Thourio	22º 53'	38º29'	40
Levadia	22º 47'	38º 26'	63
Stroviki	23º 06'	38º 27'	48
Thiva	23º 12'	38º 21'	19
Eleon	23º 28'	38º 23'	16

ganic matter, $CaCO_3$, P, K, total N, CEC, bulk density and soil porosity. Analyses were carried out at the Soil Science Institute of Athens, according to the methodology described by Page et al., (1992). Results are shown in Table 1.

Reference ^{137}Cs measurement in the area

In Greece, the average values of ^{137}Cs depositions in the main land are estimated to be approximately 6kBq m^{-2} The average varies between <1.3 and 30 kBqm^{-2}, while local maxim up to 60 kBq m^{-2} have been observed (Kritidis et al., 1990, 1996, 1997 and Kritidis and Florou 1998). The interaction of Cesium with soil particles and its three dimensional pattern of distribution in the Greek soil ecosystem has been studied by Papanikolaou and Kritidis (1988), Apostolakis et al., (1990), Antonopoulos et al., (1987, 1995 and 1997).

The values which were recorded in Greece by Kritidis and Florou (1998) for the study area of Viotia, as kindly provided by the Environmental Radioactivity Lab, N.C.S.R. "Democritos", are presented in Table 2. In this Table it is shown that there is great variability in the ^{137}Cs reference inventory in the existing data base for the Viotia area ranging from 16 to 63 Bq.kg^{-1}, with an average of 35,29 Bq kg^{-1}. This variation led us to define local reference values in undisturbed, uncultivated and uneroded soils in our study sites.

Core samples were collected from each of these sites, up to the maximum soil depth (60 to 80 cm) and analyzed for ^{137}Cs in order to estimate the reference inventory for the study area. In the Mouriki area this was estimated to be 14424.3 Bq m^{-2}.

3-D distribution of ^{137}Cs on the field scale.

In order to investigate the 3-D distribution of ^{137}Cs, three profiles were studied in a representative eroded field in the Thiva town area site, where one of the transects were studied. Soil samples were taken up to a depth of 70 cm. and analyzed for ^{137}Cs. These profiles were taken almost in the middle of the slope in a triangle in order to have an initial idea of the 3-D distribution of ^{137}Cs. The base of the triangle was parallel to the secondary slope while the third profile was dug down slope and towards the main slope.

^{137}Cs distribution across transects

Based on the soil map of Viotia (Theocharopoulos, 1992), three eroded agricultural sites were selected in the Viotia prefecture. One in the Thiva area, site 1, one in Mouriki village area, site 2, and the third in the Eleon village area, site 3 (Fig.1).

Five transects were drawn, in the tree sites studied, i.e.:

I. Transect near Thiva area, site 1.
II. Transect North/A' near Mouriki village area, site 2.
III. Transect East/B' near Mouriki village area, site 2.
IV. Transect East/A' near Eleon village area, site 3.
V. Transect North/B' near Eleon village area, site 3.

At each point of the transect the length, the average slope at 20m intervals and the point slope every 20 m using field clinometer were measured. At the sampling points, ^{137}Cs levels and the physical and chemical properties of the soil samples were determined.

Quantification rates of erosion and deposition

The technique used to study and quantify long term soil erosion and redistribution in soils, in the Viotia prefecture, central Greece, was based on the approach described in detail by Walling and Quine (1991), Quine and Walling (1991,1992) and Quine et al., (1994).

The critical point of the technique (Quine at al., 1994) was the local reference inventory for each site. Also the establishment of the relation between ^{137}Cs loss/gains or percentage residuals in each sampling profile and the soil redistribution can be some drawbacks for the technique. In this approach the spatial pattern of percentage ^{137}Cs residuals was used to compare the pattern of soil erosion and deposition along the transects within individual fields. These residuals represent the cumulative effect of erosion, transport, and deposition process from wind, sheet and rill water erosion.

The local inventory and the percentage loss or gain of ^{137}Cs were defined along the transects. Walling and He (1997) related these residuals and percentage residuals to the soil erosion losses using the models developed. These calibration models convert ^{137}Cs measurements to estimates of soil redistribution rates on cultivated and uncultivated soils.

Table 3. 3-D distribution of ^{137}Cs in Thiva town area, site 1, soil profiles.

Code	Sample	Location	Depth (cm)	^{137}Cs (Bq/Kg)
Profile 1	1	top left	0-10	18
	2		15-25	42.9
	3		35-45	1.3
	4		55-65	1.3
Profile 2	5	top right	0-10	1.9
	6		15-25	11.9
	7		35-45	0.8
	8		55-65	0.1
Profile 3	9	mid.below	0-10	2.3
	10		15-25	1.8
	11		35-45	0.4
	12		55-65	0.9

Four models were studied and evaluated as they were developed, described and kindly offered to us by Prof. D.E. Walling. The Proportional Model, the Simplified Mass Balance Model (Mass Balance Model 1) and Mass Balance Model (Mass Balance Model 2) and the Mass Balance Model Incorporating Soil Movement by tillage (Mass Balance Model 3). Due to the lack of available input data at the moment only the first two models mentioned above, i.e. the Proportional Model and the Simplified Mass Balance Model, were used in this study.

RESULTS AND DISCUSSION

3-D ^{137}Cs distribution in the studied soils

In Table 3 it is shown that the 3-D distribution of ^{137}Cs in the studied field, varies greatly both between profiles and in depth inside the same profile. Provided that, in this field, the ^{137}Cs fallout could be considered homogeneous it seems that microrelief, soil plough depth, and erosion deposition processes determine the 3-D redistribution of ^{137}Cs. In Table 4, the distribution of ^{137}Cs along a transect in the same field is shown. From this Table it is shown that, due to the process of soil erosion and deposition, ^{137}Cs which is bound to soil clay particles was moved from the top of the landscape and was deposited at the bottom.

Presented in Tables 5 and 6 are the concentration of the ^{137}Cs data distribution across the two transects one north and the other east in the Mouriki village area (site 2). In these Tables, the redistribution of ^{137}Cs is also observed and increased concentrations in the soil profiles at the bottom of the transects.

Tables 7 and 8 present the 3-D distribution of ^{137}Cs along two vertical transects in the Eleon village area, site 3. In these two Tables the reduced ^{137}Cs concentrations in the soil profiles are shown, in relation to the other two

Table 4. ^{137}Cs measurements in Thiva town area, transect site 1.

Code	Sample	Location	Shape	Slope %	Distance (m)	^{137}Cs (Bq/Kg)
52603	1	top	flat	0-2	0	30.2
52604	2	top	sloping	7-8	20	31.8
52605	3	middle	sloping	13-15	75	26.4
52606	4	bottom	flattening	2-4	135	49.6

Table 5. ^{137}Cs measurements in Mouriki village area, site 2, transect North/A.

Code	Sample	Location	Shape	Slope %	Depth (cm)	Distance (m)	^{137}Cs (Bq/Kg)
52988	SF1/S1	top	flat	1-2	0-15	0	23.0
52989	SF2/S2	middle	sloping	7-8	0-15	50	38.8
52990	SF3/S3		sloping		15-30		16.1
52991	SF4/S4	bottom	flatteing	3-5	0-15	180	54.7
52992	SF5/S5				15-30		23.3
52993	SF6/S6				30-60		3.0

sites, and redistribution pattern of ^{137}Cs with increased concentrations at the bottom of the landscape unit. Irregularity with the soil sampling depth, in the distribution of ^{137}Cs in the deposition points is also observed. Considering the relief and the morphology of the site, the increased concentration of ^{137}Cs at the soil depth 30-60 cm could be explained by the deposition of previously eroded soil material maybe before the Chernobyl accident.

These data highlight the effect of soil erosion and deposition processes on the 3-D redistribution of ^{137}Cs in the studied soils. They also prove the validity of the use of the ^{137}Cs technique to estimate erosion and deposition rates under Mediterranean conditions.

Erosion and deposition rates in the studied sites

In Figure 2 are presented the erosion (-) and deposition (+) prediction rates by the Proportional Model (PM) and the Simplified Mass Balance Model (SMBM) (Walling and He, 1997) for different plough depths for the Eleon village area, site 3, soils. The SMBM estimates, in all soil profiles, indicated increased erosion and deposition rates compared to PM. Both erosion and deposition rates are proportionally increased in both models with the increase of the plough depth. These facts demonstrate the need to validate and calibrate the models with empirical long-term erosion data for local soil and climatic conditions. They also highlight the need for accurate plough depth monitoring in order to have soil erosion and deposition rates close to the reality, since the plough depth has changed greatly the recent four decades due to the introduction of the heavy machinery in the area.

In Figure 3 are also presented the erosion (-) and deposition (+) prediction rates by the Proportional Model (PM) and the Simplified Mass Balance Model (SMBM) (Walling and He, 1997) for different soil bulk densities, for the Eleon village area, site 3, soils. This soil property is an input to the models and is defined or related to other soil properties such as texture and organic matter content. The SMBM estimates in all cases increased erosion and deposition rates compared to PM. Both erosion and deposition rates are proportionally, but slightly, increased in both models with the increase of bulk density. This might be due to the fact that the determined bulk density in the soils of the area varies from 1.41 to 1.65 g cm^{-3}, while the mean bulk density for the Eleon village area site is 1.53kg.m^{-3}. These data demonstrate the importance of soil bulk density and the need for its accurate determination in the studied soils.

Table 6. ^{137}Cs measurements in Mouriki village area, site 2, transect East/B.

Code	Sample	Location	Shape	Slope %	Depth (cm)	Distance (m)	^{137}Cs (Bq/Kg)
52994	SF7/S7	top	flat	1-2	0-15	0	29.0
52995	SF78/S8	up. Slope	sloping	18	0-15	55	35.2
52996	SF9/S9	low Slope	sloping	21	0-15	155	46.4
52997	SF10/10	bottom	flattening	9	0-15	215	37.6
52998	SF11/S11				15-30		10.0
52999	SF12/S12				30-60		0.5

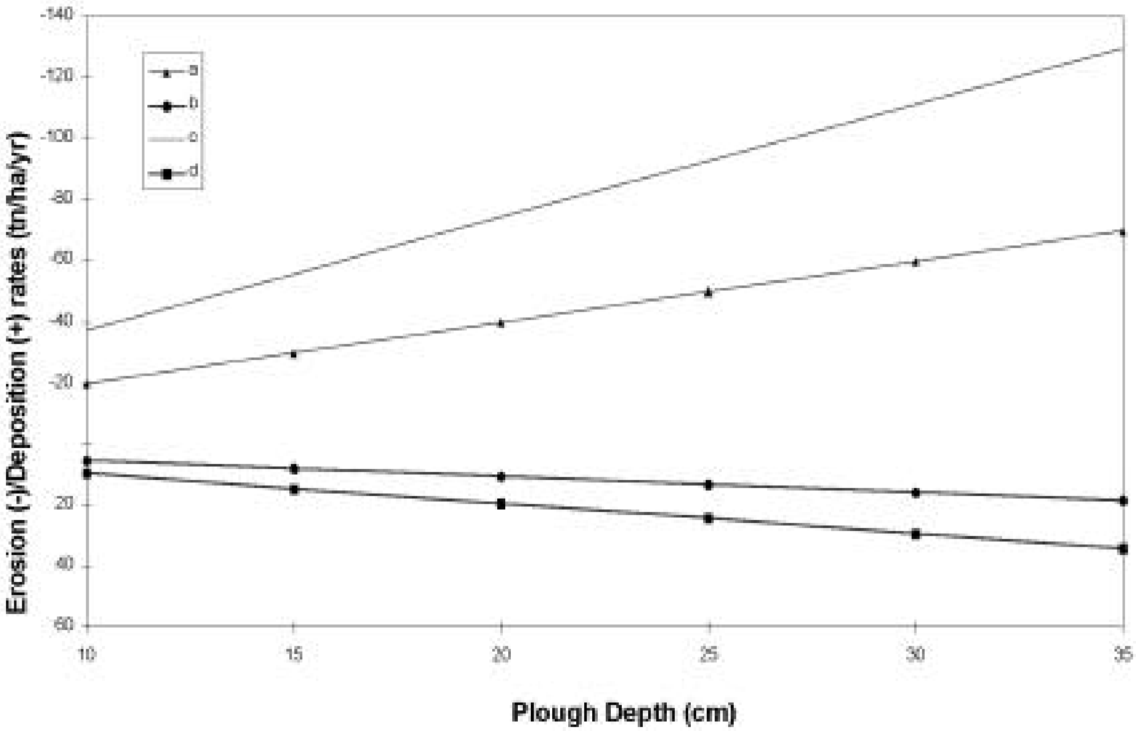

Figure 2. Eleon site, soil erosion and deposition prediction rates for different Plough depths. proportional model: a) top of the transect and b) bottom of the transect. Mass Balance model: c) top of the transect and d) bottom of the transect.

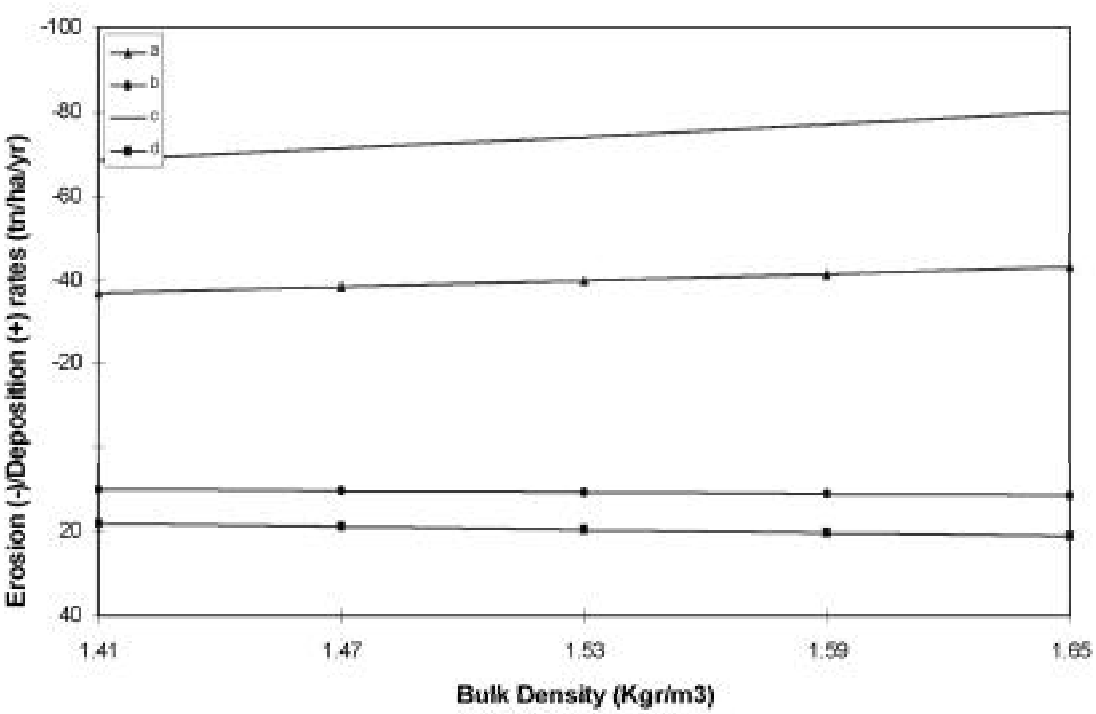

Figure 3. Eleon area, site 3, soil erosion and deposition prediction rates for different bulk densities. Proportional model a) top of the transect and b) bottom of the transect. Simplified Mass Balance model: c) top of the transect and d) bottom of the transect.

Table 7: ^{137}Cs measurements in Eleon village area, site 3, transect East/A.

Code	Sample	Location	Shape	Slope %	Depth (cm)	Distance (m)	^{137}Cs (Bq/Kg)
53047	A	top	flat	0-2	0-15	0	9.5
53048					15-30		2.5
53049	B	slope	slope	4	0-15	60	12.8
53050					15-30		1.9
53051	C	bottom	bottom	3	0-15	170	11.8
53052					15-30		2.7
53053					30-60		10.3

The Mouriki village area, site 2, erosion and deposition rates are presented in Figure 4, for the Proportional Model (PM) and the Simplified Mass Balance Model (SMBM) (Walling and He, 1997). These are for the different plough depth based on the local ^{137}Cs reference inventory. This approach was adopted because the plough depth has changed since the early sixties after heavy tractors were introduced for ploughing. For the top of the slope soil profile (Fig. 4, a) the erosion rates estimated by the PM vary from 16.62 tn ha $^{-1}$ y $^{-1}$ (10 cm plough depth) to 58.17 tn ha $^{-1}$ y $^{-1}$ (35 cm plough depth). From the SMBM the estimated erosion rates (Fig. 4, d) vary from 29.30 tn ha $^{-1}$ y $^{-1}$ (10 cm plough depth) to 102.56 tn ha $^{-1}$ y $^{-1}$ (35 cm plough depth). For the middle of the slope soil

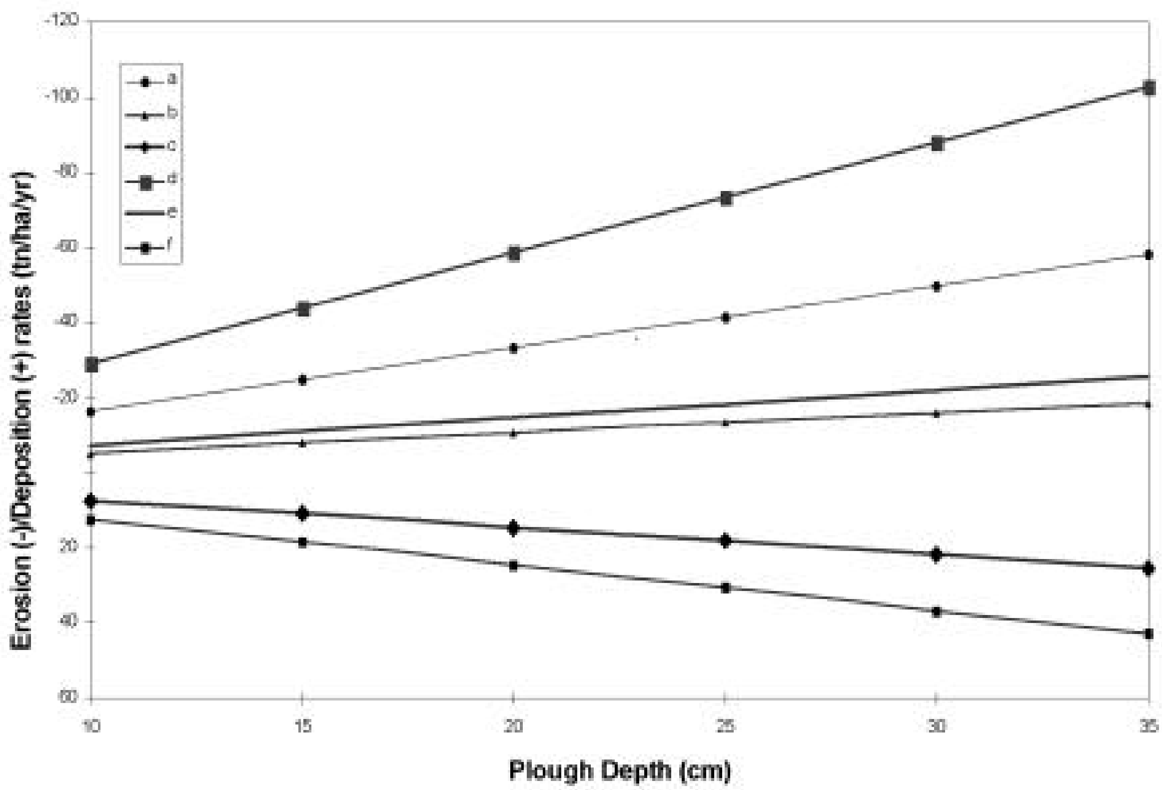

Figure 4. Mouriki site, point erosion and deposition rates for different plough depths. Proportional model: a) top of the transect, b) middle of the transect and c) bottom of the transect. Mass Balance model: d) top of the transect e) middle of the transect an f) bottom of the transect.

Table 8. ^{137}Cs measurements in Eleon village area, site 3, transect North/B.

Code	Sample	Location	Shape	Slope %	Depth (cm)	Distance (m)	^{137}Cs (Bq/Kg)
53051	C	top	sloping	3	0-15	0	11.8
53052					15-30		2.7
53053					30-60		10.3
53054	D	bottom	flattening	1-2	0-15	160	14.9
53055					15-30		0.5
53056					30-60		12.7

profile the erosion rates estimated by the PM vary (Fig. 4, b) from 5.37 t ha^{-1} y^{-1} (10 cm plough depth) to 18.78 t ha^{-1} y^{-1} (35 cm plough depth). From the SMBM the estimated erosion rates vary (Fig. 4, e) from 7.34 t ha^{-1} y^{-1} (10 cm plough depth) to 25.68 t ha^{-1} y^{-1} (35 cm plough depth). For the bottom of the slope soil profile the deposition rates estimated by the PM vary (Fig. 4. c) from 7.26 t ha^{-1} y^{-1} (10 cm plough depth) to 25.41 t ha^{-1} y^{-1} (35 cm plough depth). From the SMBM the estimated deposition rates vary (Fig. 4,f) from 12.27 t ha^{-1} y^{-1} (10 cm plough depth) to 42.95 t ha -1 y -1 (35 cm plough depth).

These data highlight the importance of tillage on soil erosion and more significantly the plough depth, which is not stable in time and sometimes from point to point in the same landscape due to microrelief.

CONCLUSIONS

From the above results the following could be concluded:

The ^{137}Cs distribution in the studied soils demonstrate higher concentration of ^{137}Cs in the soil profiles near or at the bottom of the slope and lower concentrations in the soil profiles on the top of the slope.

This uneven ^{137}Cs distribution pattern, at short distances, in the soils of the area, combined with the fact that ^{137}Cs is bound to soil particles and moves with them, offers a tool to investigate soil redistribution due to erosion and deposition processes in the area. It also offers the possibility of developing the ^{137}Cs technique to study soil erosion under Mediterranean conditions.

The ^{137}Cs isotopic technique presented many advantages and potentials for long term soil erosion and deposition quantification under Mediterranean conditions. This ^{137}Cs isotopic technique could, after proper calibration, be used for the soils and climatic conditions of Greece.

Among the main factors, plough depth and soil bulk density seems to be the crucial parameters for soil erosion and deposition rates determination.

Erosion and deposition rates predicted through the calibration models that convert ^{137}Cs residuals or percentage residuals to soil redistribution rates vary greatly. Estimated erosion rates for the Mouriki area site varied from 16.62 to 102.56 t ha^{-1} y^{-1} for the top of the slope soil profile and from 5.37 to 25.68 t ha^{-1} y^{-1} for the middle of the slope soil profile. The deposition rates varied from 7.26 to 42.95 t ha^{-1} y^{-1} for the bottom of the slope soil profile.

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