Soil Use and Management (1998) **14**, 1–5

Soil degradation and desertification induced by vegetation removal in a semiarid environment

J. Albaladejo, M. Martinez-Mena, A. Roldan & V. Castillo

Abstract. The fragile soils at the transition between semiarid and arid areas are continuously threatened by human activity, which frequently involves the elimination of plant cover. We studied the impact of vegetation removal on soil characteristics in semiarid Mediterranean Spain using two plots (15 m × 5 m), installed on a north facing slope of 23%. Vegetation was removed from one of the plots (disturbed plot), and changes in the soil characteristics were compared with an undisturbed control plot. Fifty-five months after vegetation removal the organic carbon content decreased by 35%, the percentage of stable aggregates by 31% and soil bulk density increased by 8%. The models that best represented the changes of these parameters with time were linear equations. There were no significant differences between the water retention capacity or saturated hydraulic conductivity of the treatments. The rapid loss of soil organic matter and the consequences in terms of physical soil properties were considered to be the main factors in soil degradation. No symptoms of natural recovery were observed in the disturbed plot and the tendency was for a steady deterioration in soil behaviour. This means that human activity or climatic change leading to less vegetation could result in irreversible soil degradation in semiarid areas.

Keywords: Soil degradation, desertification, semiarid zones, Spain

INTRODUCTION

Soils are a basic resource that must be 'healthy' for the rest of the ecosystem to remain diverse and productive (Whitford, 1992). Environmental changes and anthropogenic impacts are potential threats to the conservation of soil quality. Soil protection and conservation are particularly important when dealing with marginal, fragile and ecologically sensitive ecosystems such as those of the semiarid Mediterranean area, where excessive human pressure has led to irreversible soil degradation and desertification (Perez Trejo, 1994; Lopez Bermudez, 1993). More research is needed to delineate the critical limits of soil properties beyond which environmental quality is severely and irretrievably jeopardized (Lal & Stewart, 1990).

The importance of plant cover in reducing erosion and protecting soils against degradation has been widely demonstrated (Morgan, 1986). Degradation or destruction of plant cover leads to a disruption of the carbon cycle. The organic matter stored in a soil decreases and the soil's physical properties are thus degraded (Albaladejo, 1990; Diaz *et al.*, 1994). Soils rich in organic matter from udic or ustic areas with dense plant cover are very resilient and able to buffer the effects of environmental and anthropogenic changes, but the same is not true of arid or semiarid soils.

Damage to soil and plants in arid and semiarid areas is not easily repaired (Milton *et al.*, 1994). It is therefore important to understand how surface disturbance, especially vegetation removal, affects soil quality and to increase the knowledge of the mechanisms of soil degradation processes, so that environmental problems can be adequately predicted and corrected. Unfortunately, human disturbance of sensitive areas often still goes unchecked. In our hypothesis the fragile ecosystems at the transition between semiarid and arid areas are not able to recover fully after a severe disruption such as vegetation removal.

The purpose of this study was to increase our knowledge of how soils in semiarid areas will function and respond to human pressure in the future through an understanding of the dynamics of the organic matter content and associated soil properties following a drastic ecosystem disturbance. This paper reports the changes observed in selected soil properties five years after removal of plant cover. Five years is a relatively short time for changes in most edaphic characteristics, so only those features that may be expected to change significantly over such a period will be discussed.

MATERIAL AND METHODS

Study Site

The study was conducted in field plots in Santomera, about 20 km north east of Murcia, south east Spain. The climate of the region is semiarid Mediterranean with a mean annual precipitation of 300 mm, about 75% of which falls in April and October. A characteristic of the precipitation is its irregularity: rain is infrequent but very erosive (Lopez Bermudez & Albaladejo, 1990). Mean annual temperature is 17 °C, and mean potential evapotranspiration 850 mm/y. These climatic parameters lead to a pronounced moisture deficit and unfavourable conditions for good development of vegetation.

The soil was a Lithic Haploxeroll (Soil Survey Staff, 1994). The top 20 cm was a humus rich mollic epipedon (4.0%

Centro de Edafologia y Biologia Aplicada del Segura–CSIC, Apartado 4195, 30080 Murcia, Spain.

organic carbon), 48% $CaCO_3$, with a silt loam texture (sand 21%; silt 55%; clay 24%), and a high degree of structural stability (81% of stable aggregates) with no evidence of degradation. Under the mollic epipedon the parent material was consolidated limestone.

The vegetation was a semi-natural community, typical of Mediterranean semiarid lowlands, comprising planted trees (*Pinus halepensis*) and natural shrubs. The most common species were *Thymelaea hirsuta, Thymus hyemalis, Brachypodium retusum, Rhamnus lycioides and Sideritis leucantha*. The percentage canopy cover was 70%, and basal cover 46%.

Experimental design and treatments

Two 5 m-wide by 15 m-long experimental plots with a natural average slope of 23% were located on the north-facing side of a low-crested ridge; they were aligned down the maximum gradient slope and were enclosed by cement blocks 20 cm high. In December 1988 all canopy cover was cut and removed from one plot to simulate disturbance caused by human activity (Disturbed plot, D). Vegetation removal was done manually with pruning shears, the plants being clipped to ground level. Only one clipping was carried out. This plot contrasted with the natural, undisturbed plot (N). No further treatments were imposed on either plot during the experiment.

A within sampling design was established through the subdivision of the plots. For each sampling time three disturbed soil samples (0–10 cm) were collected from the upper third of both plots, three from the middle third and three from the lower third. The three samples from each third were carefully mixed and the representative samples of the upper, middle and lower third were analysed in triplicate for organic carbon content and percentage of stable aggregates. Three undisturbed soil cores one each from the upper, middle and lower thirds of the plots were collected using sample rings (5 cm diameter and 5 cm height). These samples were analysed for water holding capacity, saturated hydraulic conductivity and bulk density. Sampling was carried out every six months from December 1988 to June 1993.

Analysis

Organic carbon (OC) content was measured by pretreatment with HCl 1:10 to eliminate carbonates (Colombo & Baccanti, 1989) followed by combustion at 1020 °C, separation of CO_2 in a chromatograph column and determination by an automatic nitrogen and carbon analyzer. Water holding capacity (WHC) was determined in the laboratory using a combination of the sand box method (Stakman *et al.*, 1969) modified by Martinez Fernandez (1990) for −50 kPa suction, and a pressure membrane for −1500 kPa suction. For the estimation of dry bulk density (BD) the undisturbed samples were dried in an oven at 105 °C to determine the water content and oven-dry weight (Burke *et al.*, 1986). For % stable aggregates (PSA), air dry soil samples were sieved in the laboratory between meshes of 0.2 and 4 mm. A 4 g subsample from the sieved soil was placed on a small 0.25 mm sieve and subjected to artificial rainfall of 150 ml with an energy of 270 J/m^2. The residual soil on the sieve was dried at 105 °C and weighed (P_1). The soil was then wetted and after 2 hours, it was passed through the same 0.25 mm sieve with the assistance of a small stick that was used to break the remaining aggregates for differentiating soil aggregates from sand particles. The particles on the sieve were dried at 105 °C and weighed (P_2). The percentage of stable aggregates was calculated by $(P_1 - P_2) \times 100/4\text{-}P_2$. This method was based on the work of Benito *et al.* (1986). Saturated hydraulic conductivity (SHC) was determined in the laboratory using a constant head permeameter.

Climatological characteristics. Rainfall was measured with a tipping-bucket raingauge connected to a datalogger. Temperature in the top 20 cm of the soil was measured by means of thermistor temperature probes connected to the same datalogger. The datalogger stored data at one minute intervals from all the sensors.

RESULTS AND DISCUSSION

Climatic parameters

Mean annual soil temperature was greater in plot D (18.3 °C) than in plot N (17.6 °C) and there were clear seasonal differences between the plots. Mean soil temperatures in plot D were lower in the cold season (November–February) and higher in the warm season (March–October) than in plot N (Table 1). The buffering effect of the plant cover on soil temperatures in the top 20 cm was more pronounced under

Table 1. Summary of climatological and soil temperature data monitored in natural (N) and disturbed (D) plots over 55 months (December 1988–June 1993)

	Mean daily soil temperature (°C)		Mean maximum daily soil temperature (°C)					
Month	N plot	D plot	N plot	D plot	Rainfall (mm)	Max.I_{30}† (mm/h)	Mean I_{30} (mm/h)	Days I_{30} > (15 mm/h)
Jan	9.05	8.30	10.01	9.55	288.9	4.0	1.3	0
Feb	9.66	9.46	10.56	10.70	280.3	21.2	7.2	2
Mar	12.55	12.80	13.80	14.59	268.3	12.2	3.5	0
Apr	15.88	16.66	17.50	18.88	71.3	4.4	1.5	0
May	19.93	20.70	21.86	23.13	141.8	28.0	4.7	1
Jun	23.60	24.66	26.06	27.40	101.3	14.0	3.9	0
Jul	26.26	28.30	28.83	31.28	8.0	2.4	1.1	0
Aug	25.52	29.55	29.18	32.37	25.7	10.0	3.4	0
Sep	24.34	25.33	25.68	29.18	247.8	100.0	18.0	3
Oct	19.47	20.07	20.47	21.8	111.3	12.4	4.1	0
Nov	14.27	13.80	15.06	15.03	69.2	8.8	3.6	0
Dec	11.43	10.30	12.10	11.30	157.2	33.2	3.7	1
Mean	17.66	18.33	19.26	20.43	Total = 1771.1		4.6	7

I_{30} = 30-minute maximum rain intensity.

Table 2. Summary of the measured soil properties in both natural and disturbed plots over 55 months (December 1988–June 1993)

	Sample size	Average	Standard error	$P(z)$†
Natural (N)				
Stable aggregates (%)	30	80.75	0.469	
Bulk density (t/m^3)	30	1.57	0.008	
Total organic carbon (%)	30	4.14	0.056	
Water content at −50 kPa (g/g)	30	0.32	0.003	
Water content at −1500 kPa (g/g)	30	0.14	0.001	
Saturated hydraulic conductivity (cm/h)	19	11.26	2.868	
Disturbed (D)				
Stable aggregates (%)	30	70.02	1.724	
Bulk density (t/m^3)	30	1.60	0.009	
Total organic carbon (%)	30	3.14	0.105	
Water content at −50 kPa (g/g)	30	0.31	0.003	
Water content at −1500 kPa (g/g)	30	0.14	0.002	
Saturated hydraulic conductivity (cm/h)	19	6.75	2.030	
Differences (N–D)				
Stable aggregates (%)	30	10.73	1.797	< 0.01
Bulk density (t/m^3)	30	0.03	0.009	< 0.01
Total organic carbon (%)	30	−1.00	0.112	< 0.01
Water content at −50 kPa (g/g)	30	−0.01	0.005	0.133
Water content at −1500 kPa (g/g)	30	−0.00	0.002	0.294
Saturated hydraulic conductivity (cm/h)	19	−4.51	2.494	0.235

† $P(z)$ Probability values for Wilcoxon signed-rank test on paired differences.

extreme temperatures. The greatest differences between the plots occurred in December (11.4 °C in plot N and 10.3 °C in plot D) and August (25.5 °C in plot N and 29.5 °C in plot D). The maximum temperatures in plot D from July to September were about 3 °C higher than in plot N. It is known that an increase in soil temperature increases the mineralization of stored soil organic matter (Smith, 1979).

Total rainfall during the 55 months of the field study was 1771 mm (Table 1). The mean value of I_{30} (30-minutes maximum intensity) was very low (4.6 mm/h) and only seven events occurred with an I_{30} higher than 15 mm/h. Thus, the rainfall aggressiveness might be considered as having a minor effect on the physical degradation of the soil surface.

Total organic carbon

Table 2 presents summary statistics for the analysed soil parameters of plots N and D and their paired differences using the Wilcoxon signed-rank test (Wilcoxon, 1945). The overall mean %OC was 4.14 in plot N and 3.14 in plot D ($P < 0.01$). At the start of the experiment the mean value of OC in plot D was 4.0% and 55 months later it had fallen by 35% to 2.6%, while no changes were observed for plot N. Significant differences between the stored OC content of the plots were observed as early as the sixth month after vegetation removal (Fig. 1). A significant negative correlation ($r = -0.84$; $P < 0.01$) was found between OC and the cumulative time in plot D. The model that best represented the decrease was a linear equation (Fig. 1).

The amount of organic matter in soils is affected by several factors, the most significant being the amounts of organic carbon fixed through photosynthetic reactions (Tate, 1987). Among these factors, the very high rate of decline in the soil OC content under the environmental conditions of the experiment might be attributable to two effects induced by the removal of vegetation: (i) the lack of plant residue returned to the soil; and (ii) the increase in soil temperature during the warmer season in plot D. These results agree with those reported by Parton *et al.* (1987), who pointed out the important role played by roots and other plant residues when returned to the soil. As regards soil temperature, Scott *et al.* (1994) showed a decrease in total soil carbon between

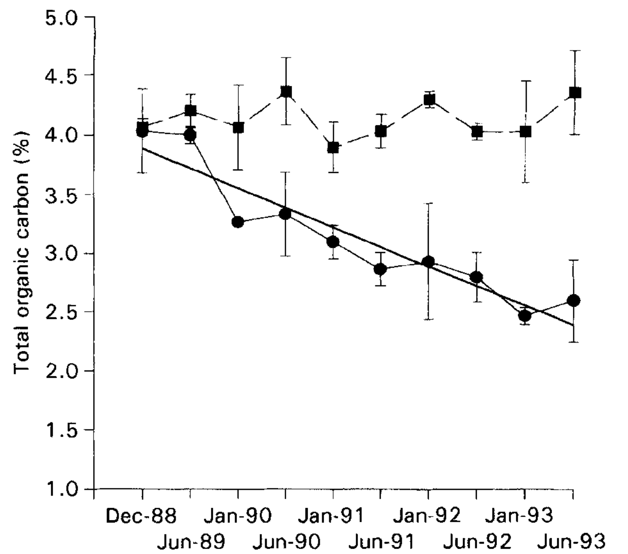

Fig. 1. Change in total organic carbon in natural (■) and disturbed plots (●). Bars represent standard deviation ($n = 3$). The solid line is the regression equation that best fits the experimental data ($y = 3.91 - 0.028x$, $R^2 = 0.88$), x = time after vegetation removal in months.

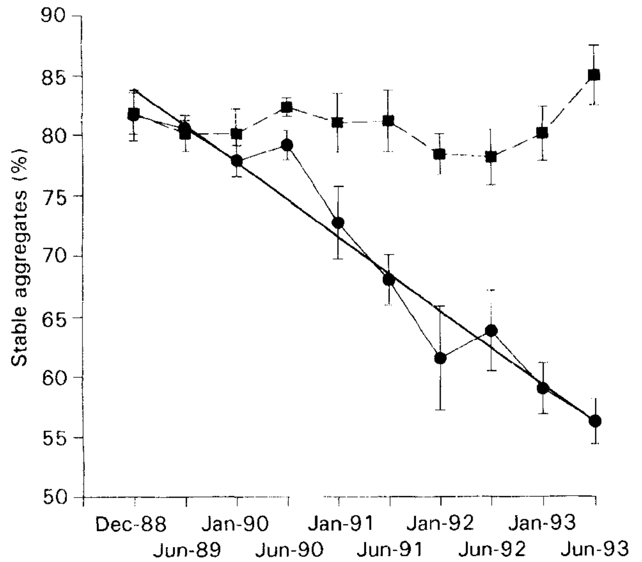

Fig. 2. Change in aggregate stability in natural (■) and disturbed plots (●). Bars represent standard deviation ($n = 3$). The solid line is the regression equation that best fits the experimental data ($y = 84.36 - 0.51x$, $R^2 = 0.94$), x = time after vegetation removal in months.

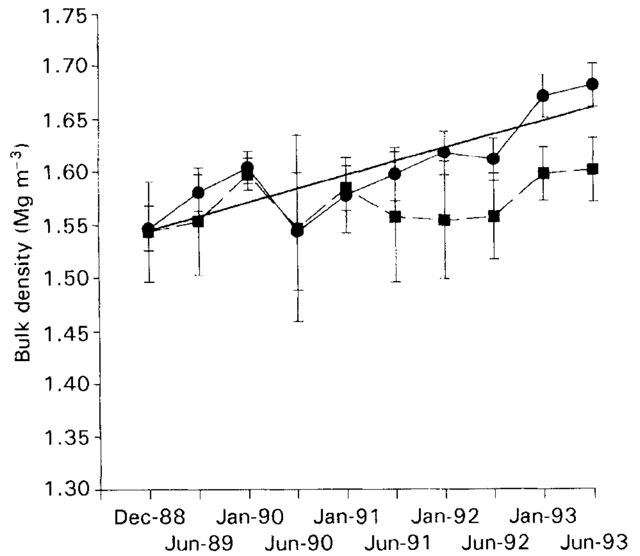

Fig. 3. Change in bulk density in natural (■) and disturbed plots (●). Bars represent standard deviation ($n = 3$). The solid line is the regression equation that best fits the experimental data ($y = 1.54 - 0.0021x$, $R^2 = 0.71$), x = time after vegetation removal in months.

May and August as a result of increase in soil temperature. West *et al.* (1994), using the Century Model (Parton *et al.*, 1987), predicted that the steady state soil organic matter content would decrease by 12.4% as a result of a 2 °C increase in mean annual temperature.

Stable aggregates

The overall mean PSA showed a significant difference ($P < 0.001$) between plots N and D (80.7% in plot N and 70.0% in plot D, Table 2). At the beginning of the experiment the value of the PSA in plot D was 81.6%, decreasing to 56.3% by the last sampling. Significant differences in the PSA between the plots during the first year were found (Fig. 2). The PSA showed a highly significant correlation ($P < 0.001$) with cumulative time in plot D; this decrease was best represented by a linear equation (Fig. 2).

A significant positive correlation was found in plot D between the PSA and OC ($r = -0.775$; $P < 0.001$) and a negative correlation ($r = 0.791$, $P < 0.001$) between PSA and BD. Significant correlations between organic carbon and soil structure have also been reported by several authors (Lal & Fausey, 1993; Giusquiani *et al.*, 1995). In addition, the probable reduction in microbiological activity and root exudation after vegetation removal will have contributed to the structural degradation (Lynch & Bragg, 1985; Diaz *et al.*, 1994).

Bulk density

Significantly higher BD ($P < 0.01$) was found in plot D compared with plot N (Table 2). The overall mean BD 1.60 t/m^3 in plot D and 1.57 t/m^3 in plot N. The BD of plot D for the first and the last sampling dates was 1.55 t/m^3 and 1.68 t/m^3, respectively (Fig. 3).

The analysis of temporal variability showed a significant tendency ($P < 0.05$) for BD to increase slowly in plot D. No such tendency occurred in plot N. Figure 3 shows the model that best represented the increase in BD during the monitoring period.

Increases in BD may be attributed to: (i) the effect of raindrop impact on the bare soil (Barber & Romero, 1994; Mwendera & Feyen, 1994); and (ii) the reduction of biological activity (Scott *et al.*, 1994). In this experiment the impact of rainfall energy was very low: total precipitation was 1771 mm (< 350 mm per year) and only seven events occurred where $I_{30} > 15$ mm/h (Table 1). Thus, any soil compaction was probably mainly due to the loss of structural stability caused by decreases in organic carbon. This hypothesis was corroborated by the strong correlations observed between BD and PSA and between PSA and OC.

Water holding capacity and saturated hydraulic conductivity

Changes in water holding capacity and saturated hydraulic conductivity resulting from removal of vegetation were not statistically significant. Lack of significance may have been due to low sensitivity in the methods used and, in the case of hydraulic conductivity, large spatial variation (Table 2).

CONCLUSIONS

On the basis of this study, we can conclude that soil degradation processes after vegetation removal in semiarid zones can be quantified in a short time period (55 months). Vital soil properties such as structural stability, organic carbon content or bulk density tended to deteriorate without any symptom of recovery. Under these circumstances the process appears to be irreversible.

ACKNOWLEDGEMENTS

This research was supported with funds from the Commission of the European Communities, STEP Programm, contract Nos. EV4V–0112–C(AM) & PL900247. We also wish to acknowledge the advice of Dr M. Stocking (UEA, Norwich) during the experimental procedure. The experimental plots are included in the FAO Network on Erosion-Induced Loss in Soil Productivity.

REFERENCES

ALBALADEJO, J. 1990. Impact of the degradation processes on soil quality in arid mediterranean environment. In: *Strategies to Combat Desertification in Mediterranean Europe* (eds J.L. Rubio & R.J. Rickson), Commission of the European Communities, Luxembourg, pp. 193–215.

BARBER, R.G. & ROMERO, D. 1994. Effects of bulldozer and chain clearing on soil properties and crop yields. *Soil Science Society of America Journal* 58, 1768–1775.

BENITO, E., GÓMEZ-ULLA, A. & DÍAZ FIERROS, F. 1986. Descripción de un simulador de lluvia para estudios de erodibilidad del suelo y estabilidad de los agregados al agua. *Anales de Edafologia y Agrobiologia* 45, 1115–1126.

BURKE, W., GABRIELS, D. & BOUMA, J. (eds). 1986. *Soil Structure Assessment*. A.A. Balkema, Rotterdam.

COLOMBO, B. & BACCANTI, M. 1989. A new method for the automatic and selective determination of total organic carbon in sediments, soils, composts, etc. *Paper to the 11th International Symposium on Microchemical Technics. Wiesbaden.*

DIAZ, E., ROLDAN, A., LAX, A. & ALBALADEJO, J. 1994. Formation of stable aggregates in degraded soils by amendment with urban refuse and peat. *Geoderma* 63, 277–288.

GIUSQUIANI, P.L., PAGLIAI, M., GIGLIOTTI, G., BUSINELLI, D. & BENETTI, A. 1995. Urban waste compost: effects on physical, chemical and biochemical soil properties. *Journal of Environmental Quality* 24, 175–182.

LAL, R. & STEWART. B.A. 1990. Soil degradation. Need for action: research and development priorities. *Advances in Soil Science* 11, 331–336.

LAL, R. & FAUSEY, N.R. 1993. Drainage and tillage effects on a Crosby-Kokomo soil association in Ohio. IV. Soil physical properties. *Soil Technology* 6, 123–135.

LOPEZ BERMUDEZ, F. 1993. La erosion del suelo en el riesgo de desertificacion de España. In: *Medio Ambiente y Desarrollo antes y despues de Rio-92*, Fundacion Marcelino Botin, Santander, pp. 119–147.

LOPEZ BERMUDEZ, F. & ALBALADEJO, J. 1990. Factores ambientales de la degradación del suelo en el area Mediterranea. In: *Soil Degradation and Rehabilitation in Mediterranean Environmental Conditions* (eds J. Albaladejo *et al.*), CSIC, Murcia, pp. 15–45.

LYNCH, J.M. & BRAGG, E. 1985. Microorganisms and soil aggregate stability. *Advances in Soil Science* 2, 133–171.

MARTINEZ FERNANDEZ, J. 1990. Estudio de las características hidrodinámicas de los suelos: El método del recipiente de tensión hídrica. *I Reunión Nacional de Geomorfología*, Sociedad Española de Geomorfología, Teruel, pp. 699–708.

MILTON, S.J., DEAN, W.R.J., DUPLESSIS, M.A. & SIEGFRIED, W.R. 1994. A conceptual model of arid rangeland degradation. *BioScience* 44, 70–76.

MORGAN, R.P.C. 1986. *Soil Erosion and Conservation*. Longman Scientific & Technical, London.

MWENDERA, E.J. & FEYEN, J. 1994. Effects of tillage and rainfall on soil surface roughness and properties. *Soil Technology* 7, 93–103.

PARTON, W.J., SCHIMEL, D.S. COLE, C.V. & OJIMA, D.S. 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Science Society of America Journal* 51, 1173–1179.

PEREZ TREJO, F. 1994. *Desertification and land degradation in the European Mediterranean*-EUR 14850. Office for Official Publications of the European Communities, Luxembourg.

SCOTT, H.D., MAUROMOUSTAKOS, A., HANDAYANI, I.P. & MILLER, D.M. 1994. Temporal variability of selected properties of loessial soil as affected by cropping. *Soil Science Society of America Journal* 58, 1531–1538.

SMITH, O.L. 1979. Application of a model of the decomposition of soil organic matter. *Soil Biology and Biochemistry* 11, 607–618.

SOIL SURVEY STAFF. 1994. *Keys to soil taxonomy: 6th edition*. Soil Conservation Service, US Government Printing Office, Washington, DC.

STAKMAN, W.P., VALK, G.A. & VAN DER HARST, G.G. 1969. *Determination of soil moisture retention curves. I. Sand Box apparatus - Range pF 0 to 2.7*, 3rd rev. ed., Institute for Land and Water Management Research, Wageningen.

TATE, R.L. 1987. *Soil Organic Matter. Biological and Ecological Effects*. Wiley-Interscience, New York.

WEST, N.E., STARK, J.M. *et al.* 1994. Effects of climatic change on the edaphic features of arid and semiarid lands of western North America. *Arid Soil Research and Rehabilitation* 8, 307–351.

WHITFORD, W.G. 1992. Effects of climate change on soil biotic communities and soil processes. In: *Global Warming and Biological Diversity* (eds R.L. Peters & T.E. Lovejoy), Yale University Press, New Haven, Conneticut, pp. 124–136.

WILCOXON, F. 1945. Individual comparisons by ranking methods. *Biometrics Bulletin* 1, 80–83.

Received 2 October 1996, accepted after revision 3 September 1997