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Application of ^{137}Cs for measuring soil erosion/deposition rates in Romania

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ABSTRACT

Two methods of monitoring soil redistribution along agroterraces were explored in Tarina basin of the Moldavian Plateau: the classical method of annual or periodic field measurements and the ^{137}C technique. Results obtained by both methods indicate that the aggradation rate of the agroterrace edge averages 5.0-6.0 cm/yr, but the ^{137}C technique is more efficient because it requires only one field visit. Much of the downward movement of soil in these agroterraces can be related to contour ploughing, although some erosion/deposition undoubtedly occurs.

The future of using ^{137}C as a tracer of erosion and sedimentation within discontinuous gullies is promising. Some results obtained in the Moldavian Plateau near Barlad support this assumption. A field study, based on a depth - incremental sampling method, was undertaken in two small basins, Roscani and Timbru. Depth distribution of ^{137}Cs from recent sediments deposited along the floor of discontinuous gullies allowed the establishment of a mean sedimentation rate of 4.4 cm/yr over the period 1963-1996, and 2.5 cm/yr after 1986 for short gullies. In the case of long gullies, after the Chernobyl nuclear accident this value is to 4.9 cm/year. Furthermore, it was possible to estimate: the age of the gullies (23-48 years), the mean gully head advance (0.9 m/yr), the mean total mass of sediment deposited/eroded within the gully system (up to 124 t/yr) and the main sediment source (the active gully head and banks).

Conservation practices and tillage were first implemented during 1982-1983 in the upper Racatau basin of 3,912 hectares. Significant changes in land management practices resulted from the application of the Landed Property Law no. 18/1991. The marked shifting from contour to up and down hill farming created a doubling in the amount of soil erosion and deposition. Depth distribution of ^{137}Cs in recent sediments of the Bibiresti reservoir indicates a mean sedimentation rate of 5.0 cm/yr over the period 1986-1992 and 10.0 cm/yr for the period 1993-1996.

Keywords: ^{137}Cs. Agroterraces. Gully erosion. Sediment deposition.

INTRODUCTION

Soil erosion and deposition are major problems in many parts of Romania leading to concern about sustainable agriculture and the quality of the environment. Many methods have been used to reduce soil loss from agricultural fields. There has been increased interest in the use of contour ploughing and stripcropping system in controlling soil loss by sheet-rill erosion.

Through time, along the boundary between two strips an agroterrace was increasing in height. The first objective of this study was to measure soil redistribution at such locations.

Gully erosion, which is associated with concentrated flow, represents another major sediment source. Most work involving gully development has focussed on estimating erosion rates by means of conventional methods. Since the discontinuous gullies exhibit both erosion and sedimentation, the use of ^{137}Cs technique is of value because it can be used to measure soil loss and deposition. It can be applied on a large scale and can be employed as a new approach for the measurement of gully erosion.

Significant changes in land management practices from small agricultural basins are revealed by the depth distribution of ^{137}Cs in recently deposited sediments.

STUDY SITE AND METHODS

The study site was located on the southern part of the Moldavian Plateau, Romania mainly near Perieni-Barlad. The small watersheds of Tarina, Roscani, Upper Racatau Valleys on the Tutova Rolling Hills were studied.

Two methods of monitoring soil redistribution along agroterraces were explored in Tarina basin: the classical method of annual or periodic field measurements, combined with soil profiles and the ^{137}Cs technique. Two investigation types on the evolution of discontinuous gullies were carried out:

a) Data were collected by ^{137}Cs measurements during one field visit and by long-term engineering surveys in Roscani basin (51.6 ha), located at 46º 19' N and 27º 36' E.

b) Data were collected during one field visit within Timbru basin of 45.1 ha (46º 07' N and 27º 41' E) by combining both ^{137}Cs technique and conventional methods.

Depth distribution of ^{137}Cs concentration, based on an incremental sampling method from recent sediments deposited in the Bibiresti reservoir - Upper Racatau basin (3,912 ha) has been used to determine the response of erosion/sedimentation rates to changes in land management practices.

Particle size distribution and organic matter content of soil samples were also usually measured. Gamma spectroscopy analyses for ^{137}Cs were made using the Canberra MCA S100 system equipped with a Ge (Li) detector.

RESULTS AND DISCUSSION

Soil redistribution data

During late 1960s and 1970s a contour stripcropping system was implemented at Central Research Station for Soil Erosion Control (CRSSEC) Perieni in Tarina basin. A topographic survey was carried out in the summer of 1984. In addition, several soil profiles were dug in order to establish the level of the C horizon. These classical data showed that after 17 years along the boundary between different contour strips agroterraces were formed. The height of their steep backslope ranged between 41.1 to 99.5 cm. The former value was associated with those strips sometimes cultivated with perennial grasses and the latter belongs to those strips which were ploughed every year. The average depth of cultivation is 20-25 cm. A maximum rate of rise of the agroterrace edge by 5.8 cm/yr was found (Ionita et al., 1985). Much of the downward movement of the soil on these agroterraces can be mostly related to contour ploughing, although some erosion/deposition by water undoubtedly occurred (Figure1).

Figure 1. Increase in elevation of an agroterrace by ploughing, Crang basin, Romania, August 1998.

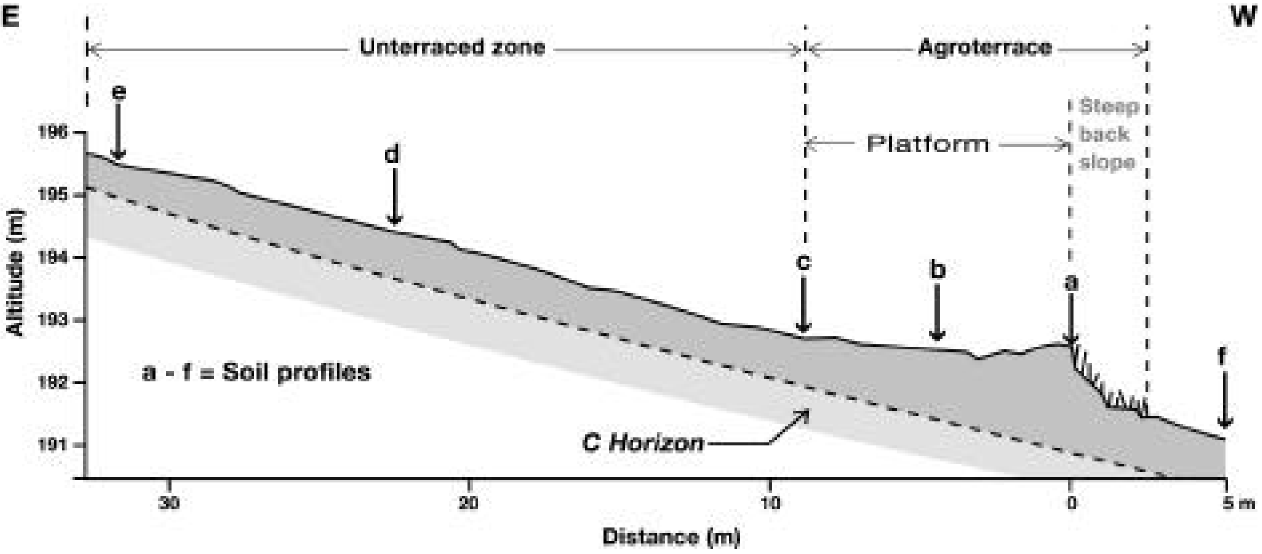


Figure 2. Cross section through an agroterrace on the left valleyside of Tarina Valley, Moldavian Plateau - Romania, 1999.

In 1999, a representative transect on the left valleyside of Tarina Valley was studied. It has an average slope of 12% and six sites (designated a, b, c, d, e, f) were selected for sampling at 10 cm intervals to determine the depth distribution of ^{137}Cs (Figure 2). The ^{137}Cs activity in these six soil profiles may be interpreted as follows:

- A significant ^{137}Cs gain occurs on the lower half of the agroterrace platform, on 4-5 m width (Figure 3 a-b);
- The mean rate of rise of the agroterrace edge is 5.0-5.4 cm/yr. This rate is also equal to the height of the steep backslope divided by the age of agroterrace: 120 cm/22 years = 5.45cm/yr. Results obtained of both methods and validate the prior finding.

- Some ^{137}Cs loss and gain (Figure 3 c-f) mainly upslope the edge indicates either runoff pulsations on a short reach, or the influence of contour ploughing on soil disturbing.

Gully erosion data

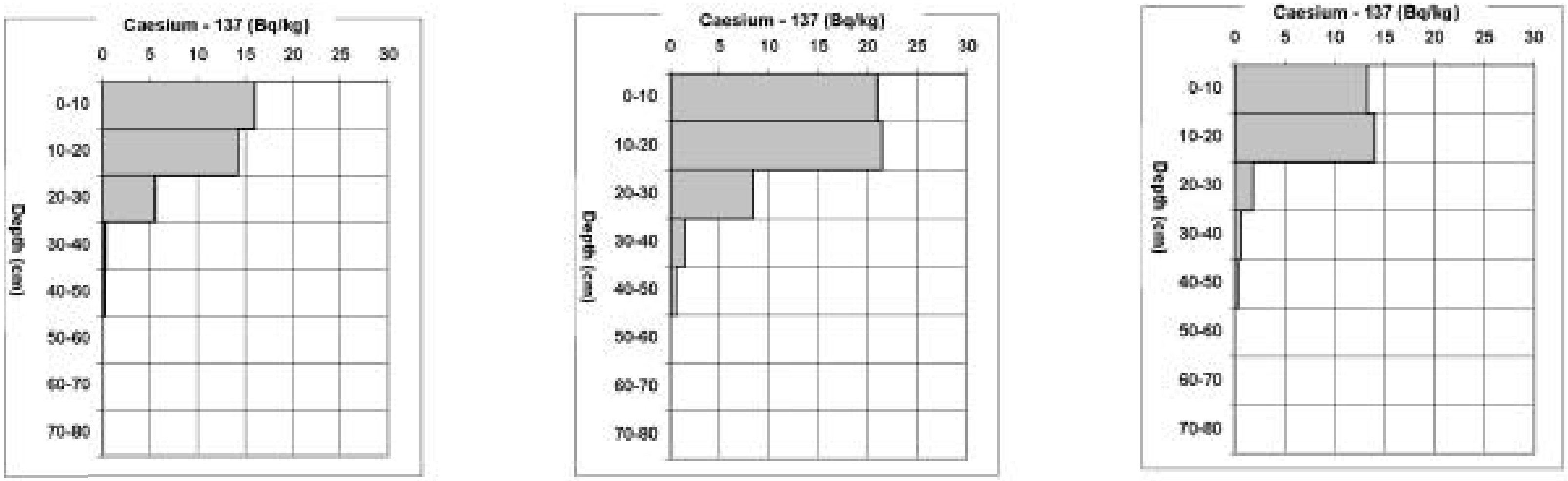
Leopold and Miller (1956) classified gullies as discontinuous or continuous. A discontinuous gully system is characterized by a vertical headcut, a channel immediately below the headcut which often is slightly deeper than it is wide, and a decreasing depth of the channel downstream. Where the plane of the gully floor intersects the more steeply sloping plane of the original valley floor, the gully walls have decreased to zero in height and a fan occurs. Heede (1967) stated that discontinuous gullies may occur singly or in a system of chains in which one gully follows the next downslope.

According to Ionita's approach (1997), deposition begins upstream of the point where the gully walls decrease to zero in height and this is the key factor that controls the decreasing depth of the channel. The floor of most discontinuous gullies is mantled with recent sediment and, therefore, the apex (root) of the alluvial fan migrates towards the nearby headcut. Moreover, the width of the gully floor gets progressively broader downstream and its plane configuration has the shape of a short or long diffusor.

Until 1996, data collected on discontinuous gullies were from conventional surveying methods. The ^{137}Cs technique was then used in small watersheds as Roscani and Timbru. To understand the development of discontinuous gullies two cases were investigated.

Firstly, a combination of long-term classical measurements with recent ^{137}Cs data, as a mutual check, were used in the Roscani basin.

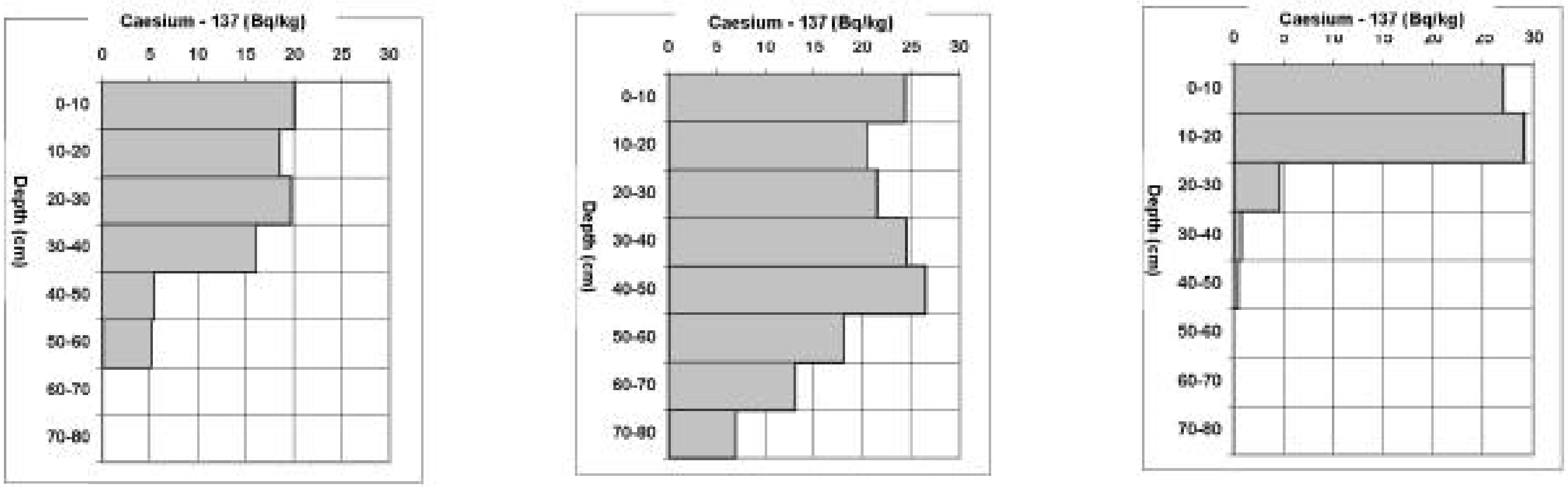
Figure 4 illustrates the advance of three gully heads over the period 1979-1996, averaging 1.0 m/yr in the gully no. 4 and 0.5-0.6 m/yr for all others.



e - 31,5 m upward the edge

d - 22,5 m upward the edge

c - Agroterrace hinge



b - Agroterrace centre

a - Agroterrace edge

f - 5 m downward the edge

Figure 3. Depth incremental Caesium-137 profiles from disturbed sites, Tarina basin - Romania, 1999.

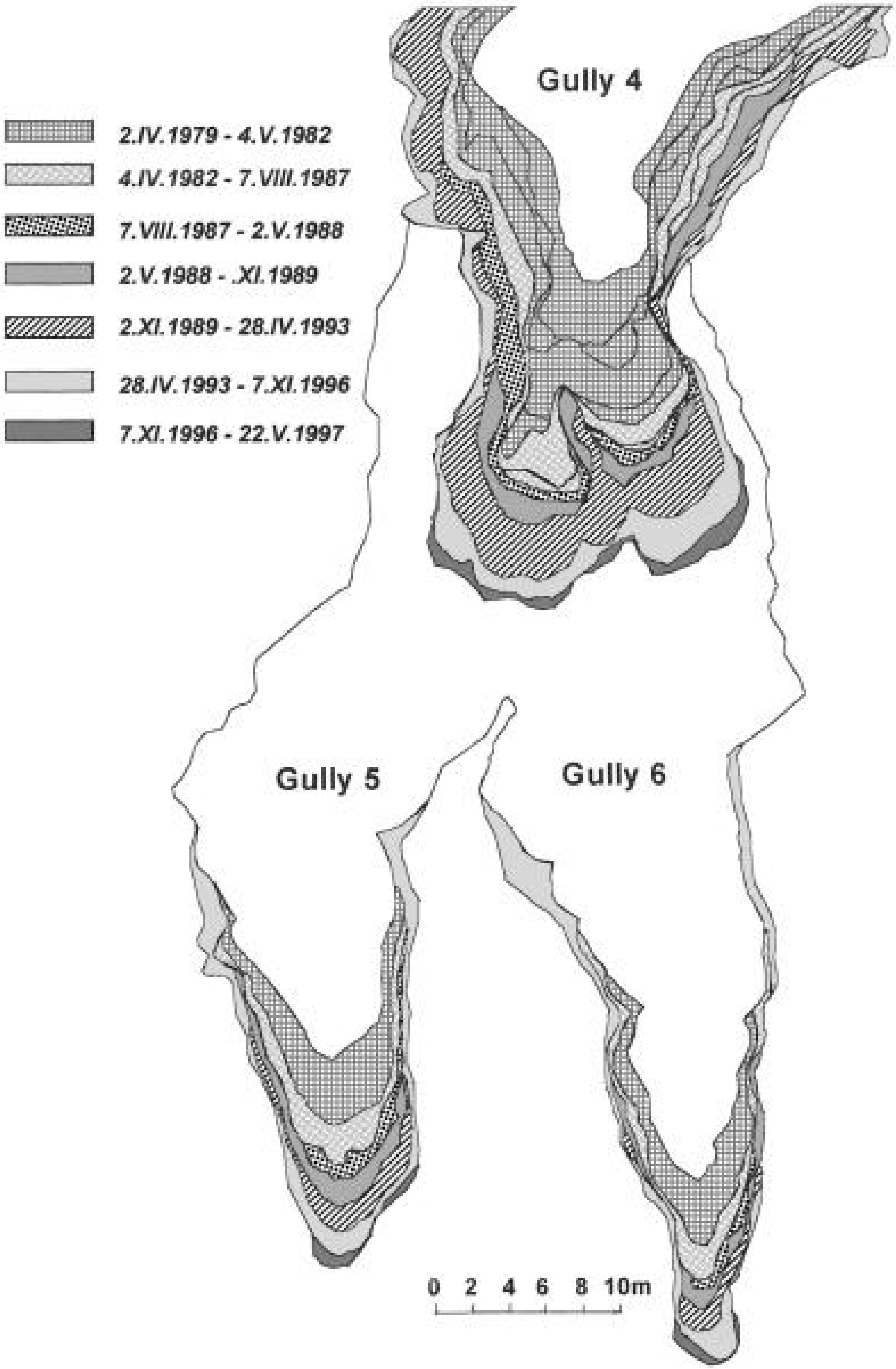


Figure 4. Measured advance of discontinuous gully heads, Roscani Valley, Moldavian Plateau, Romania (1979-1997).

Soil samples for ^{137}Cs analysis were collected from the gully head no. 4, which actually represents the outlet from the gully no. 6, and from the floor of gully no. 4 at its mid length. Figure 5 indicates a remarkably close association of the aggradation rate with the major world nuclear events. According to this graph there are three obvious ^{137}Cs peaks:

- The major one (56.9 Bq/kg) at 30-35 cm depth due to Chernobyl accident on April '86;
- The second peak (9.2 Bq/kg) between 145-150 cm depth coincides with the climax in bomb activity during the early 1960s, especially in 1963;
- The third peak (3.9 Bq/kg) at 170-175 cm depth is related to the commencement of ^{137}Cs fallout in 1959.

Thus, over a period of 43 years (1954-1996) the mean aggradation rate on the floor (short diffusor) of gully no. 6 was 4.4 cm/yr. Further, a ratio of 1.7 is obtained when dividing the mean aggrading rate of 5.0 cm/yr over the period 1963-1985 by the rate value of 2.9cm/yr, associated with the period 1986-1996. Then, the age of that gully is equal to the total thickness of alluvial sediments divided by the mean siltation rate = (210 cm/4.4 cm/yr) = 48 years. By plotting gully length versus gully age, the average gully head advance can be calculated: 43 m/48 years = 0.90 m/yr. This finding agrees with the conventional value obtained for the period 1960-1996 (Ionita, 1997).

Because the gully floor area is 236 square meters, the volume of sediment deposited during 11 years (1986-1996) is 82.6 cubic meters (236(0.35). For the same period an average total deposited mass of 11.3 t/yr [(82.6(1.5) / 11] results.

From the "classical data", the average annual erosion rate was estimated at 9.8 t/yr (5.3m^2/yr = the areal gully growth, 1.2 m = average gully depth in the active area and 1.5t/m^3 = bulk density).

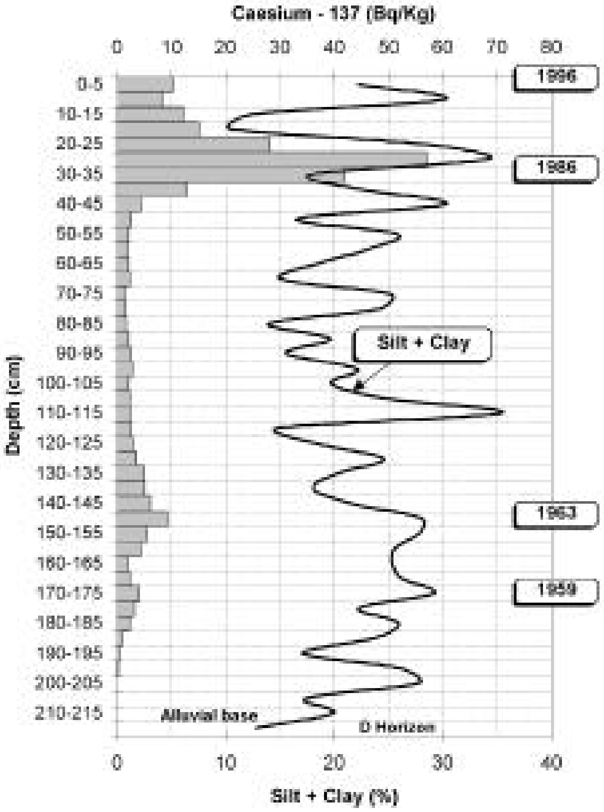


Figure 5. Distribution of Caesium -137 and silt+clay content in the alluvial fill from the gully head no.4, Roscani Valley, Romania - December 12, 1996.

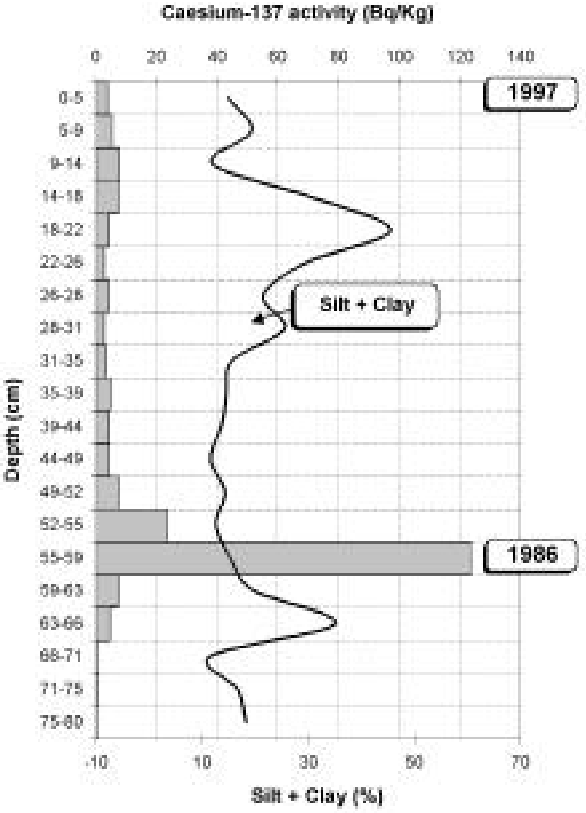


Figure 6. Depth distribution of Caesium -137 and silt+clay content within the alluvial fill of the gully floor no.4, Roscani Valley, Romania - October 10, 1997.

In addition to these data, the sediment concentration above the gully head during streamflows was observed to exhibit low values. Therefore, these findings support the assumption that the main sediment source within the discontinuous gullies is their actively eroding area (the gully head and partly the banks). This conclusion is supported by the depth distribution of ^{137}Cs in the alluvial fill (long diffusor) of the gully no. 4 (Figure 6).

The low ^{137}Cs activity in the top 52 cm (under 8 Bq/kg) indicates a sediment source, namely the gully head area. In this case, the mean sediment deposition along the gully floor is 122 t/yr [(1649 m^2(0.59 m (1.5 t/m^3) / 12 years]. This mass value is similar to the weight of eroded sediment originating in the active area (86t/yr delivered by gully head plus 34 t/yr from gully banks as calculated from classical measurements).

These last two figures can be compared with the period after the Chernobyl accident. The mean past 1986 aggradation rate along short diffusor of gully no.6 was 2.9cm/yr (2.7-3.1cm/yr) but was almost double (4.9 cm/yr) on the long diffusor of gully no.4. A wide range in the magnitude of ^{137}Cs peak was observed. For example, on the floor of gully no. 4 the ^{137}Cs peak is 123.3 Bq/kg located at 55-59 cm depth in a layer where the silt+clay fraction is 15%. This value is double in comparison with the peak value from the outlet of the gully no. 6. (56.9 Bq/kg) inside a layer with 34% silt+clay content. These distributions raised so many questions and answers. The year 1986 was extremely dry. There was no variation in precipitation on very short reaches and, also, no significant streamflow occurred. Anyhow, the soil texture is a counterargument for a logical explanation. These marked differences could support the assumption that the ^{137}Cs fallout input was not uniform. As mostly illustrated in the latter figure there is no strong relationship between the finer particles, silt+clay, commonly found in alluvial sediment and ^{137}Cs concentration. Moreover, grain size composition for both sites is predominantly sandy because the average clay content is around 5% and silt+clay fraction is about 22%.

Figure 7. Gully head no.8 cut in the alluvial fill of the gully floor no.7 in the Timbru basin, Moldavian Plateau, Romania, April 27, 1995.

If the validity of the 1.7 ratio, calculated on short diffusor is acceptable for long diffusor too, then it is clear that over the period 1963-1985 the mean aggradation rate would be 8.3cm/yr (4.9(1.7). This means that the 1963 ^{137}Cs peak would exhibit at around 250 cm depth, but the total alluvial thickness of 280 cm indicate a higher mean value of aggradation (over 9.5cm/yr) since the 1963 ^{137}Cs peak has not been intercepted. So, the mean aggradation rate on the long diffusor was double over the period 1963-1985 compared with 1986-1997.

The second case study involves an investigation of gully erosion/deposition on three successive gullies in Timbru basin of the Falciu Hills. They are typical short diffusors, as illustrated in Figure 7.

Field data were obtained during one visit by both surveying classical method and ^{137}Cs technique. The length of the gullies ranges between 13.6 to 31.7 m and the height of each headcut does not exceed 1.50 m. Most of sediment outcropping in the gully headcuts consists of recent sandy alluvium.

The depth distribution of ^{137}Cs from the gully head no.8, which in fact represents the outlet of the upstream gully no. 7, when compared with that from gully head no. 4 of the Roscani Valley, shows marked similarity (Figure 8). The mean aggradation rate over the period 1963-1996 is the same 4.4 cm/yr. This means the head of gully no.7 was located here, at the sampling point, around 1960 (163 cm/4.4 cm/yr = 37 years) and explains the lack of a clear third ^{137}Cs peak at the alluvial base. The same distribution of ^{137}Cs concentration in the top 30cm along the gully floor no.9 suggests a comparative mean sedimentation rate to gully no.7 (Figure 9). In turn, its smaller thickness of alluvium indicates a younger gully, which was formed 23 years ago (100 cm / 4.4 cm/yr) and, therefore, does not exhibit both 1963 and 1959 ^{137}Cs subsequent peaks.

By this approach, it was calculated that the mean gully head advance was 0.60 to 0.85m/yr. After Chernobyl accident, the mean rate of aggradation of the studied gullies was 2.33cm/year. Given that the average area of the siltated gully floor is 51.9 m^2 the associated annual volume of sediment runs to 1.21 m^3/yr (51.9(0.0233) and the annual deposited mass is 1.82t/yr (1.21(1.5).

The magnitude of the major ^{137}Cs peak also varies widely in the Timbru basin. Furthermore, there is no obvious correlation between the main ^{137}Cs concentration peaks, higher organic matter content and silt + clay fraction.

The foregoing discussion demonstrates the value of ^{137}Cs technique, and the erosion/sedimentation data, obtainable using the approach. Without doubt the ^{137}Cs technique provides a sound basis and is an useful guide to further research. The future of using ^{137}Cs as a tracer of erosion and deposition within discontinuous gullies is promising. It is clear that two dominant fluvial processes, erosion and sedimentation, act simultaneously to develop most of the discontinuous gullies.

Land management data

During 1982-1985 appropriate conservation practices were implemented in the upper Racatau basin, mostly used as cropland. After the implementation of the Landed Property Law no. 18/1991, the area was gradually converted to an up-and-down hill farming system and the rate of soil erosion and sedimentation doubled.

This finding is supported by the depth distribution of ^{137}Cs, which illustrates that under these circumstances the shape of the ^{137}Cs profile is in the form of a two layers or double cantilever (Figure 10). The first layer clearly occurs below a depth of 70 cm (37.0 Bq/kg) and is connected to the Chernobyl accident of April 1986, while the second is related to the revival in 1993 of the up-

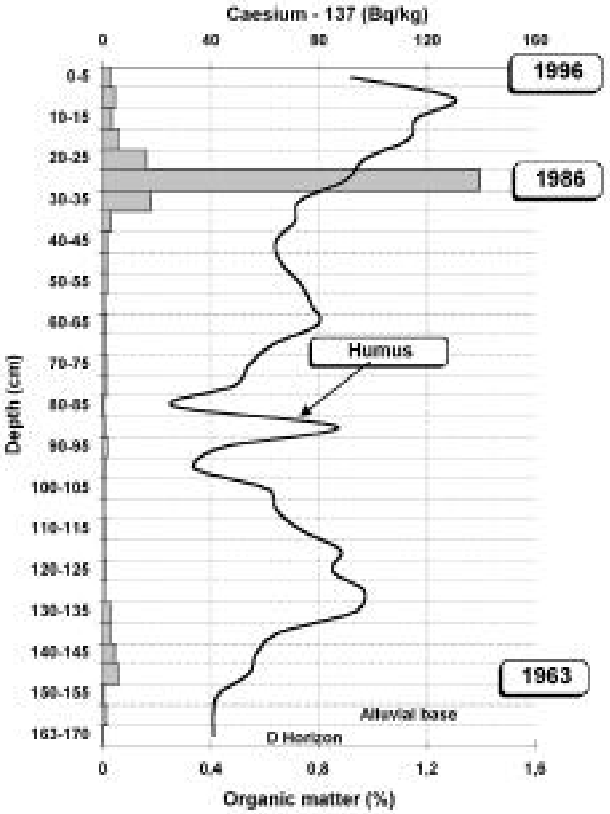


Figure 8. Distribution of Caesium -137 and organic matter content in the alluvial fill from the gully head no.8 Timbru Valley, December 13, 1996.

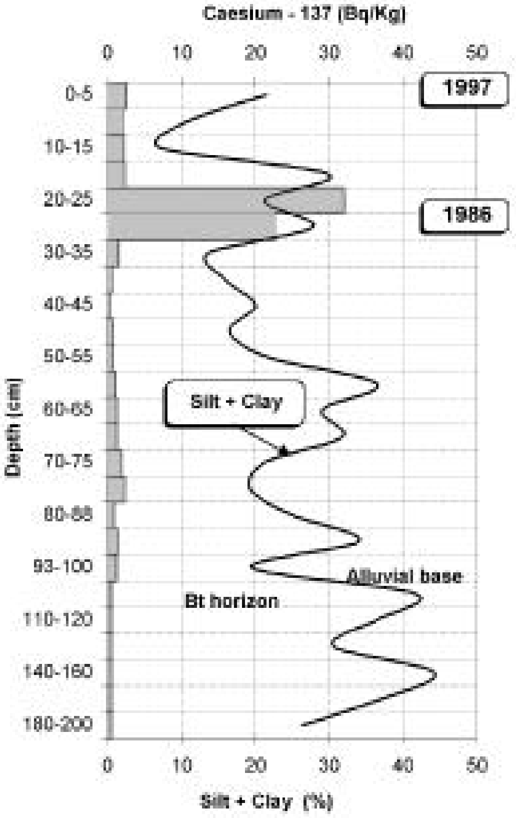


Figure 9. Depth distribution of Caesium-137 and silt+clay content in the alluvial fill of the gully head no.10, Timbru basin, August 31, 1997.

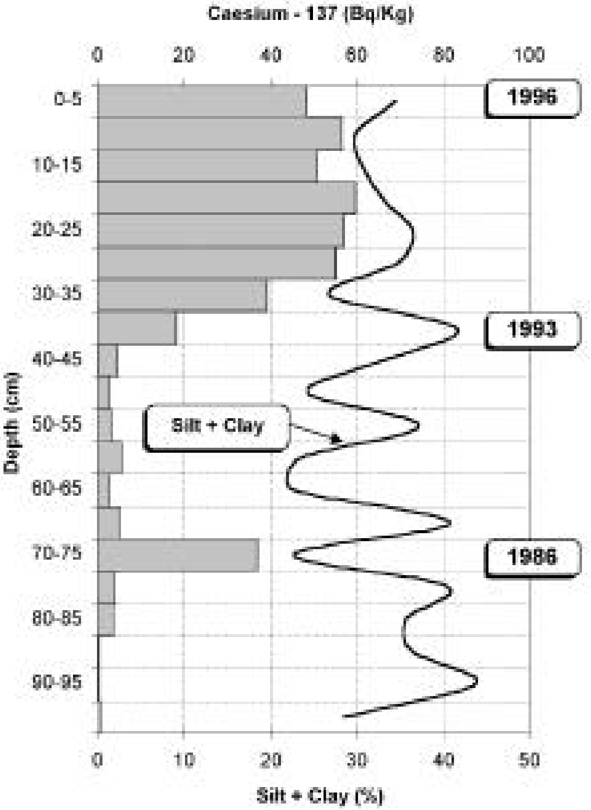


Figure 10. Depth distribution of Caesium-137 and silt+clay content in the Bibiresti reservoir, Upper Racatau basin, Romania (May 13, 1997).

and-down hill farming. The mean siltation rates rose from 5.0 cm/yr for the period 1986-1992 to 10.0 cm/yr over the period 1993-1996.

The ^{137}Cs activity during the former period was associated with low ^{137}Cs input (3-5 Bq/kg) indicating fairly low rates of soil erosion, whereas the latter period had severe rill-interrill erosion with the most significant ^{137}Cs inputs along this profile (up to 59.7 Bq/kg). Therefore, this particular ^{137}Cs depth distribution shows that 86% of the total inventory occurs in the top 40 cm, representing the period 1993-1996.

All sites with such a ^{137}Cs concentration in the upper part of the sediment profile provide evidence of the strong impact of Law no.18/1991 on agricultural practices and soil erosion/deposition.

It should be mentioned that more information on reservoir sedimentation rates is available in other paper of this special issue.

CONCLUSIONS

Soil deposition on agroterraces along the boundary between contour stripcrops has been estimated by ^{137}Cs technique at 5.0-5.4 cm/yr.

This study points out the importance of understanding the development of discontinuous gullies by using ^{137}Cs technique and provides estimates of long term erosion and sedimentation rates.

Depth distribution of ^{137}Cs in recent sedimentary deposits in a small reservoir produced evidence of a sharp increase in erosion/deposition rates after the contour farming system was converted to a traditional up-and-down slope system.

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