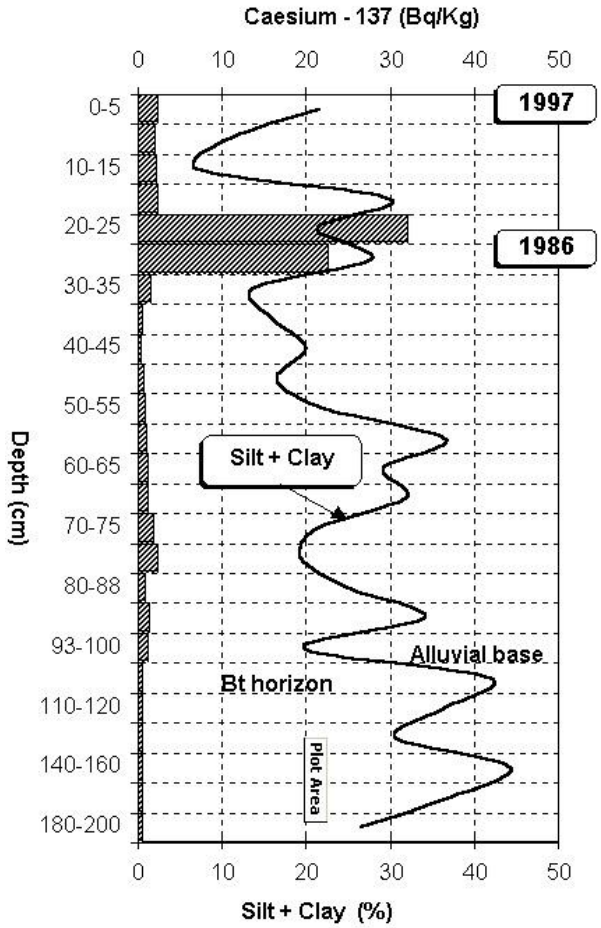

Figure 9 Depth distribution of Caesium-137 and silt+clay content in the alluvial fill of the gully head no.10, Timbru basin, August 31, 1997

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.

Acknowledgements

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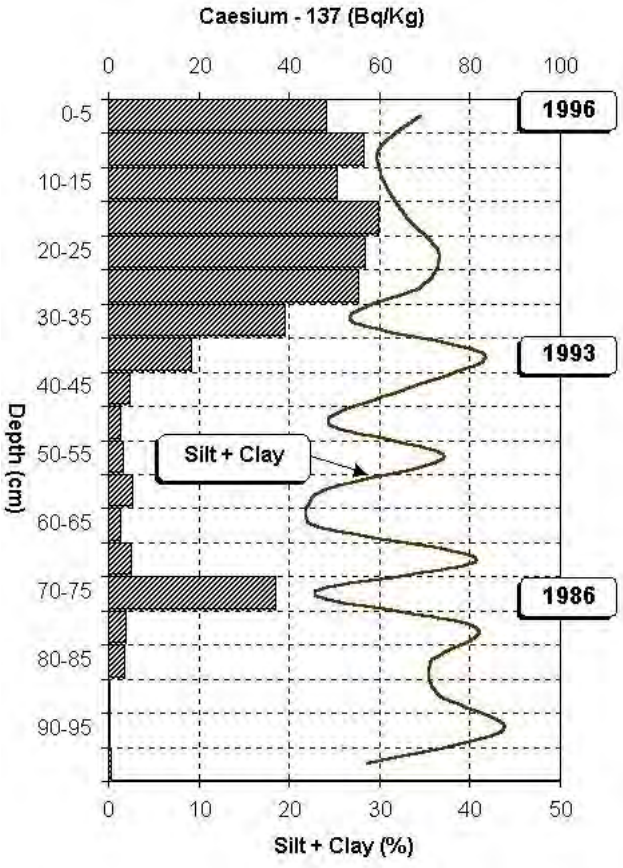

Figure 10 Depth distribution of Caesium-137 and silt+clay content in the Bibiresti reservoir, Upper Racatau basin, Romania (May 13, 1997)

We are indebted to Dr. Felipe Zapata and Dr. Edmundo Garcia Agudo for their continued interest in the project.

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ASSESSMENT OF THE RESERVOIR SEDIMENTATION RATES FROM ^{137}CS MEASUREMENTS IN THE MOLDAVIAN PLATEAU

IONITA Ion (1) MARGINEANU Romulus Mircea (2) HURJUI Cosmin (1)

(1) Central Research Station for Soil Erosion Control Perieni
(2) National Institute for Physics and Nuclear Engineering "Horia Hulubei" Bucharest - Magurele

Abstract: Reservoir sedimentation has been recognized as an important environmental threat in the Moldavian Plateau of Eastern Romania. Measurements of the ^{137}Cs content of reservoir and, sometimes, floodplain sediments have been used to estimate the rate of sedimentation over the past 13-36 years.

The estimated mean sediment accumulation rates in the reservoirs from three geomorphological subunits vary between 2.6 and 7.9 cm/year with an average rate of 4.6 cm/year after April 1986. Strong relationships were established between the individual sedimentation rates and the drainage area within the southern and central part of the Moldavian Plateau.

The shape of the ^{137}Cs depth profile was used as the main approach. Taking into account that the standard pattern is in the form of a cantilever and based on burial magnitude of ^{137}Cs peak derived from Chernobyl two chief patterns of reservoir sedimentation were identified, shallow and deep buried cantilever, respectively.

Keywords: ^{137}Cs, Soil erosion, Sedimentation rates.

Introduction

The hydrological regime of the rivers in Eastern Romania is characterized by big fluctuations including either lack of streamflow or severe floods. The higher amounts of precipitation between 1966 and 1973 induced a marked period of dam planning and construction for multiple purpose use. In the course of time several reservoirs have been impacted by greatly increased sedimentation and loss of capacity in water storage. However, in many cases, it is necessary to mention that because of fishing practice temporarily, after an interval of two-three years the water level used to be brought almost down.

During the past decade a shift in emphasis has taken place regarding the need for more complete and accurate information on reservoir sedimentation. Classical sedimentation surveys involve repeated field measurements and, therefore, this is probably the most costly and time consuming method. The application of radionuclides, particularly ^{137}Cs, for

water erosion and sedimentation studies in Romania has not been attempted so far. Research undertaken on some representative water reservoirs in the Moldavian Plateau was seen as an opportunity to test the potential of ^{137}Cs technique. The use of the fallout radionuclide ^{137}Cs offers considerable possibility of collecting adequate data on reservoir sedimentation and investigating the spatial variability of deposition rates and the patterns involved (Ritchie and McHenry, 1990, Walling and He, 1993, Walling and Quine, 1993, Walling and He, 1997). By dating the sediments within reservoirs it was possible to insight into erosion and sedimentation processes that are impossible to gain with other methods. This paper presents the results obtained on reservoir sedimentation rates in an area subjected to wide range in land degradation by sheet-rill erosion, gullies and landslides.

The study area

The Moldavian Plateau, located in the Eastern Romania and extending about 25,000 square kilometers is considered as the broadest and most typical plateau of Romania (Bacauanu et al., 1980). Clayey-sandy Miocene-Pliocene deposits with a gentle gradient of 7-8 m/km NW-SE has outcropped from sedimentary substratum as a result of erosion. Shallow intercalations of sarmatian sandstone and limestone can sometimes be identified (Jeanrenaud, 1971). As moving from the North to the South a regular, systematic decrease in clay content with increasing in sand percentage can be regarded. This plateau is situated between 32 and 564 m above sea level. The climate is temperate continental with a mean annual temperature of 8-9.8 ^{o}C and precipitation of 460-600 mm. Although the natural vegetation cover was drastically changed by man two natural zones have been distinguished: the forested area that occupies the higher parts of the plateau and the area under silvosteppe (forest-grassland transition) and steppe (short grasslands). Slopes within the plateau are mantled by mollisols and forest soils.

The study area has been focussed mostly on three major units of the Moldavian Plateau:

- The Moldavian Plain, drained mainly by Jijia river occupies the northern part of the plateau, which is rich in clayey Miocene layers. Its average altitude is about 150m.
- The Central Moldavian Plateau that is well known by some structural plateaus bounded by north-looking cuestas. This region encompasses the upper Barlad basin, upstream from its junction with the Racova and Crasna rivers.

- The Tutova Rolling Hills, which are lying in the southern, sandy Pliocene area, being surrounded by the Racova, Barlad and Siret rivers.

Methods

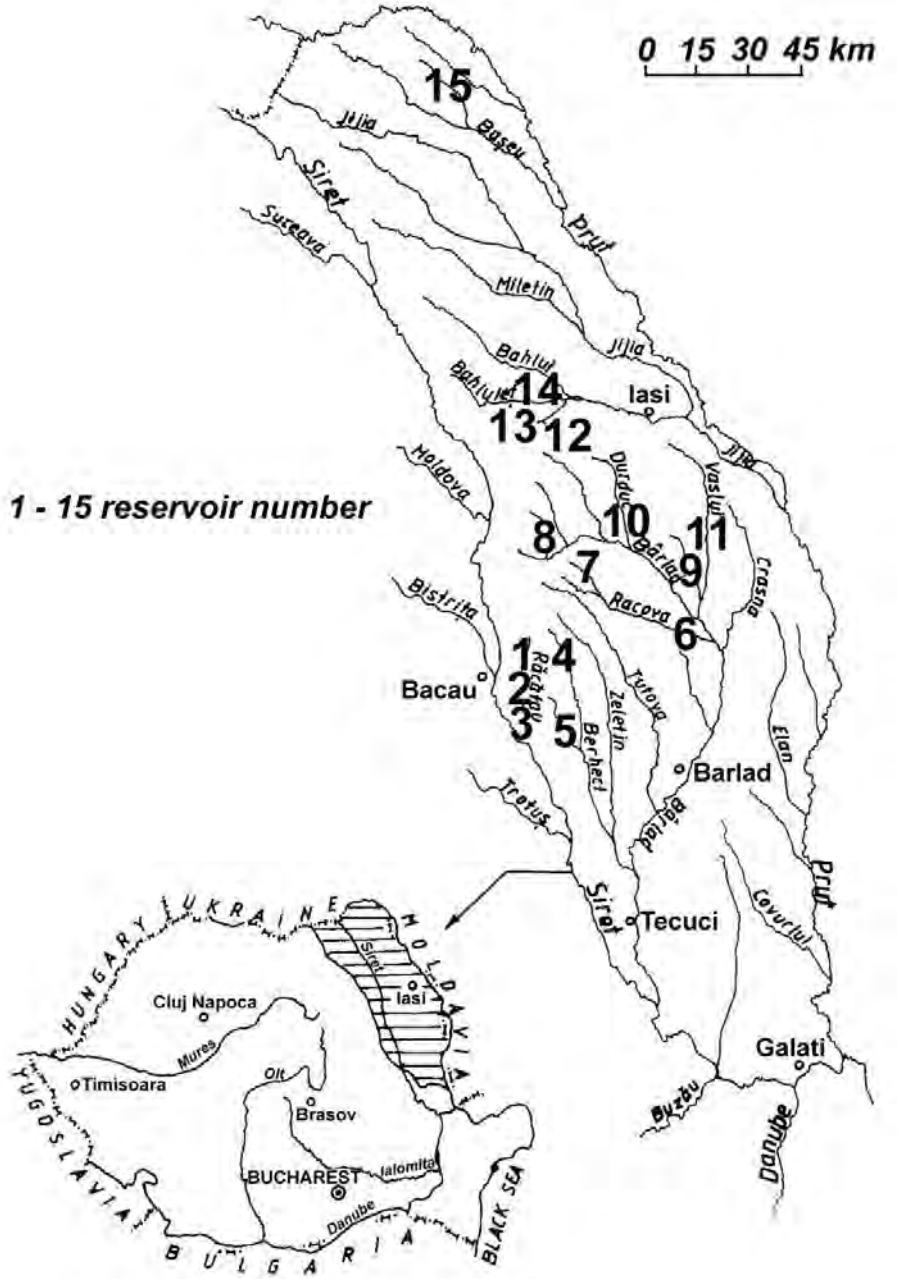
Between autumn 1996 and summer 1999 a number of 15 reservoirs have been gradually selected to estimate the depth of reservoir sedimentation. Figure 1 illustrates both the location of the Moldavian Plateau within Romania and the spatial distribution of reservoirs between the Siret and Prut rivers.

By means of an Eijkelkamp hand auger equipment a lot of holes were firstly drilled in each site to determine the original reservoir floor. Augering was performed both in the present lake area and in the upstream reservoir area already filed with sediments. In the first case, during warm season, drilling was done either from the watertable by means of a small platform or after periodical emptying the lake for fishing. Sometimes, during winter holes were drilled from the ice shell. At least one pit was dug in each reservoir. This representative pit was located as much as possible nearby the present-day lake inlet. Almost 360 sediment samples were collected usually at 50 mm intervals or according to the visible stratigraphy. Samples of reservoir deposits were dried, crushed and sieved. The combined method of sieving and pipetting was used to determine the particle size distribution. Data available at the time of writing include partial analyses for the organic matter content, 105 samples respectively.

Gamma spectrometry was used to determine ^{137}Cs concentration in sediment. The laboratory measurements were made using a Canberra MCA S100 system equipped with a Ge(Li) detector. The field samples were conditioned and measured. The acquisition time ranged from 5000 s to 60000 s per sample. The ^{137}Cs background on study area was determined by collecting spectra up to 200000 s and it is about 0.0015 cps.

Efficiency calibration of the measurement system was performed using the IAEA-375 soil samples as reference material and some reference standards released by the Department of Radioisotope Production of IFIN-HH. The efficiency versus energy of the MCA system was determined using a standard set of radioactive sources. Soil samples were measured in 500 ml Marinelli beakers. The spectra were analyzed with SAMPO 90, a dedicated computer code for high-resolution γ spectrometry. The minimum detectable activity (MDA) for a collecting time of 40000 s is about 0.65 Bq/kg.

Fig. 1 Moldavian Plateau study area showing the location of the reservoirs



Results

Estimation of the regional sedimentation rates

As indicated in Table 1 the catchments of the creeks are ranging from 329 to 50,978 hectares. Most of them are poorly covered by forest but in some cases the woodland is averaging up to 46 % of the drainage area.

Table 1 Data on some reservoirs from the Moldavian Plateau – Romania

No	Reservoir	Operation begining	Basin	Geographical position				Drainage area		
				Latitude		Longitude		Total	Forest land	
				Deg	Min	Deg	Min	ha	ha	%
Tutova Rolling Hills										
1	Bibiresti	1975	Upper Racatau	46	31	27	05	3,912	840	21
2	Horgesti	1983	Middle Racatau	46	27	27	05	10,227	1,692	17
3	Racataul de Jos	1985	Lower Racatau	46	22	27	03	17,553	3,300	19
4	Antohesti	1984	Upper Berheci	46	34	27	14	3,963	412	10
5	Hutu-Gaiceana	1983	Middle Berheci	46	21	27	15	4,665	2,166	46
6	Puscasi	1973	Lower Racova	46	38	27	38	30,845	5,300	17
Central Moldavian Tableland										
7	Pungesti-Garceni	1976	Garcean a Racova	46	43	27	21	3,328	942	28
8	Ras-Craesti	1988	Upper Barlad	46	51	27	10	2,825	1,268	45
9	Moara Domneasca	1964	Feresti-Vaslui	46	44	27	45	6,593	418	6
10	Cazanesti	1975	Durduc-Barlad	46	52	27	29	19,097	7,637	40
11	Solesti	1974	Middle Vaslui	46	47	27	48	42,352	12,445	29
Moldavian Plain										
12	Doroscani	1963	Popesti - Scobalten	47	11	27	16	329	-	-
13	Doroscani	1963	Doroscan Scobalten	47	11	27	16	857	-	-
14	Podu Iloaiei	1966	Bahluiet-Bahlui	47	12	27	15	50,978	5,367	11
15	Ichimeni	1961	Bodeasa -Baseu	48	03	26	52	3,649	-	-

Sediments in the reservoirs containing ^{137}Cs are usually more recent than late 1960s. The ^{137}Cs inputs derived from Chernobyl accident are prevailing towards those derived from testing of nuclear weapons. Among the results available at this time ^{137}Cs depth distribution is of a great interest.

By taking advantage of ^{137}Cs as a tracer it was possible to date a particular alluvial level and to calculate accurately the rate of deposition from the depth of material overlying this level. The results presented in Table 2 indicate that there is a clear regional differentiation in the magnitude of sedimentation rates. However, a mention must be made on the precipitation trend after 1982, which exhibits a marked drought pattern with smaller amounts of rain.

Table 2 Mean annual sedimentation rates past April 1986 for representative reservoirs on Moldavian Plateau using ^{137}Cs measurements

No.	Reservoir	Mean sedimentation rate (cm/year)
Tutova Rolling Hills		**7.9**
1	Bibiresti	6.8
2	Horgesti	7.5
3	Racataul de Jos	9.2
4	Antohesti	5.9
5	Hutu - Gaiceana	6.8
6	Puscasi	11.5
Central Moldavian Tableland		**3.6**
7	Pungesti-Garceni	3.1
8	Ras - Craesti	2.0
9	Moara Domneasca	2.7
10	Cazanesti	3.85
11	Solesti	6.4
Moldavian Plain		**2.4**
12	Doroscani - Popesti	1.5
13	Doroscani	2.3
14	Podu Iloaiei	3.5
15	Ichimeni	2.3
Average		**4.6**

The mean sedimentation rate for the Moldavian Plateau after April 1986 is therefore 4.6 cm/year. The sites showing evidence of highest sediment accumulation rate are located in the southern part of the study

area, averaging 7.9 cm/year. As regards the Central Moldavian Tableland the equivalent value was 3.6 cm/year, which is in a closer agreement with the general average. The highest sediment deposition rate from Tutova Rolling Hills reflects the increasing of mean soil erosion losses to 20-30 t/ha/year in this area as established by Motoc (1983). The sedimentation rate for the northern area, the Moldavian Plain, is 2.4 cm/year being by far the most reduced value. Here, this finding supports the long-term tradition in building small ponds, which represent a particular component of the local environment. Probably, the best interpretation of the regional differentiations in sedimentation rates would be that they are mostly consistent with the main changes in texture range of the underlying layers from clay in North to sand in South.

Strong relationships were defined by plotting the individual sedimentation rates to the corresponding area of the catchment for southern-central part of the study area, as shown in Figure 2 (A and B). In the Moldavian Plain the trend line is almost flat. The results of this broad-based study of sedimentation rates in reservoirs provide, therefore, the clue of a double value in the Tutova Rolling Hills towards the Central Moldavian Plateau and three times greater than the value within the Moldavian Plain. Furthermore, the decrease in sedimentation rate in the reservoirs from the southern to the northern part of the Moldavian Plateau involves a similar pattern on soil erosion rates.

Anyway, these results provided by using of ^{137}Cs measurements would represent the first successful attempt to estimate accurately quantitative rates of sedimentation in the Romanian reservoirs.

Patterns of reservoir sedimentation

Once having established the depth distribution of ^{137}Cs over different reservoirs in the Moldavian Plateau, much work have been conducted for interpretation of the ^{137}Cs profile and to identify the main sedimentation patterns.

The profile characteristics support the assumption that in most undisturbed sites there is a sharp decline in ^{137}Cs activity with increasing depth. Such an asymmetrical distribution of the ^{137}Cs would suggest a standard pattern in the form of a cantilever. If the validity of this assumption is accepted it is possible to define two major types of ^{137}Cs cantilever distribution: shallow and deep buried cantilever. The main criterion in classifying these patterns lies generally in the shape of ^{137}Cs depth profile and particularly in burial magnitude of ^{137}Cs peak derived from Chernobyl.

Shallow buried cantilever

This pattern typifies those areas where the ^{137}Cs - peak concentration exhibits in the upper part of the profile in general between 15 and 50 cm depth. This is especially true in the northern and central part of the Moldavian Plateau where rill-interrill erosion is the main sediment source. Thus, in the Moldavian Plain this is commonly occurring in the top 15-30 cm, indicating that the erosion and sedimentation rates are minimal.

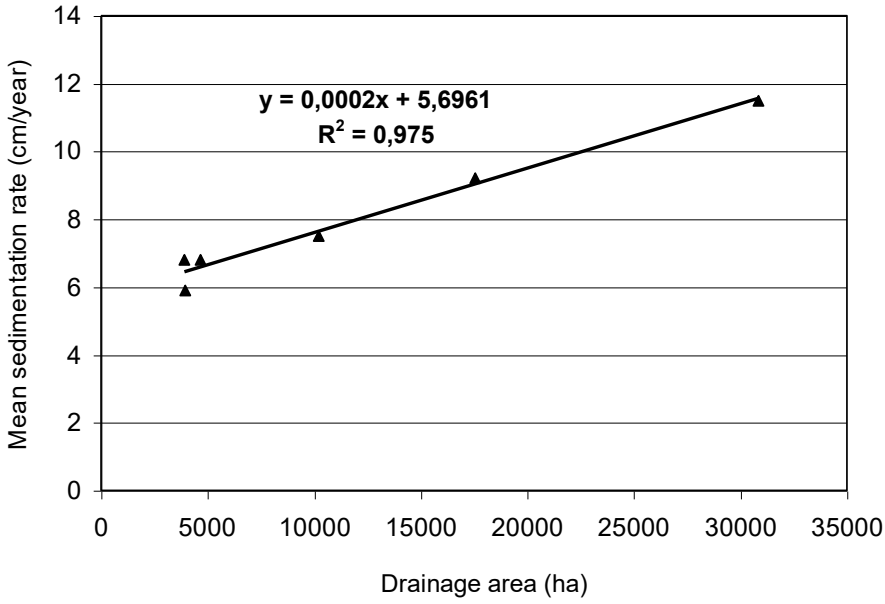
A typical ^{137}Cs depth profile is depicted in Figure 3. The ^{137}Cs concentration in sediments from the upper part is high and uniform. Then, it shows a sharp decrease at a depth of 20 cm and underneath remains essentially low. Moreover, the particle size composition of deposited sediment in this site provides evidence of a sandy texture since the finer part of silt plus clay is averaging near 30 to 40% and the clay fraction does not exceed 10% of the total. Interestingly, this sediment feature produces a short range in particle size distribution and remains essentially constant over the entire study area. Thereby a strong relation between the depth distribution of ^{137}Cs and the proportion of fine particles has not always been noticed. This assumption supports the suggestion cited from other studies by Walling and Quine (1993) that the magnitude of the clay fraction does not limit radiocaesium adsorption. The depth profile of humus at Doroscani reservoir shows that the accumulated sediments have a high but rather uniform matter content varying between 3.1 and 4.8% in the first 65 cm. Figure 4 is associated with the closest study site by Chernobyl which lies 420 km NE of Ichimeni reservoir.

However, the ^{137}Cs concentration of the sediment at the main peak (25-30 cm) is 29.8 Bq/kg which is eight times smaller than the previous location from west of Jassy. Above this peak there is a gradual decline in ^{137}Cs activity indicating the depletion of ^{137}Cs inputs. Even both sites are characterized by resistant soils and geological layers to water erosion, the difference in the magnitude of ^{137}Cs peaks derives from local variation of precipitation. For example, at Popesti-Scobalteni were recorded small rains of 6.5 mm on the 28th of April, 1.5 mm on the 30th of April and 0.1 mm on the 1st of May 1986, while in its northern neighborhood at Podu Iloaiei reservoir during April was no any rainy event. In the latter reservoir this assumption is also emphasized by the low ^{137}Cs activity because its peak does not exceed 42.5 Bq/kg.

In addition, a minor but significant peak occurs at a depth of 110-120 cm, which was assumed to correspond to sediment deposited in 1963. That means the annual siltation rate over the period 1963-1998 was 3.5 cm/year.

Figure 2 The relationship between the mean annual rate of sedimentation in some reservoirs and the drainage area from the Moldavian Plateau, after April 1986

A) **Tutova Rolling Hills**



B) **Central Moldavian Tableland**

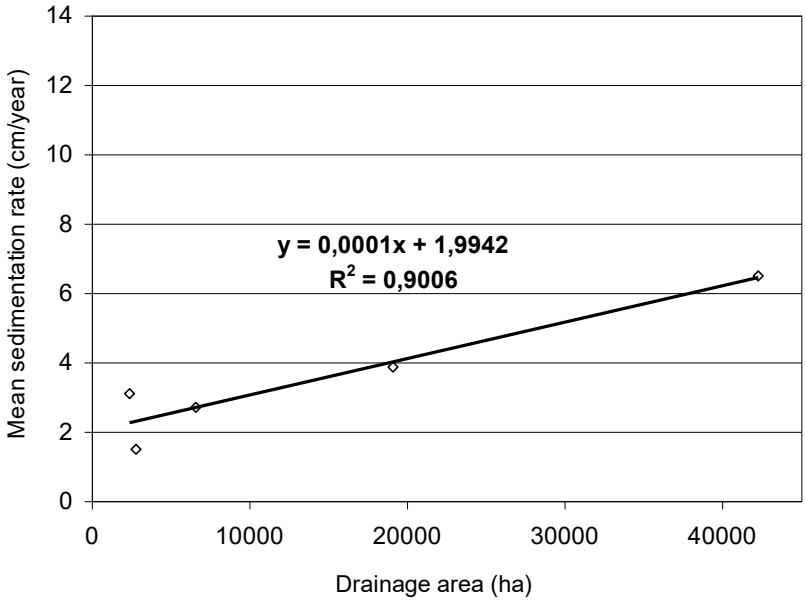


Figure 3 Distribution of Caesium - 137 and the silt+clay content in the Doroscani reservoir from Popesti-Scobalteni basin, Moldavian Plain, Romania (October 7, 1998)

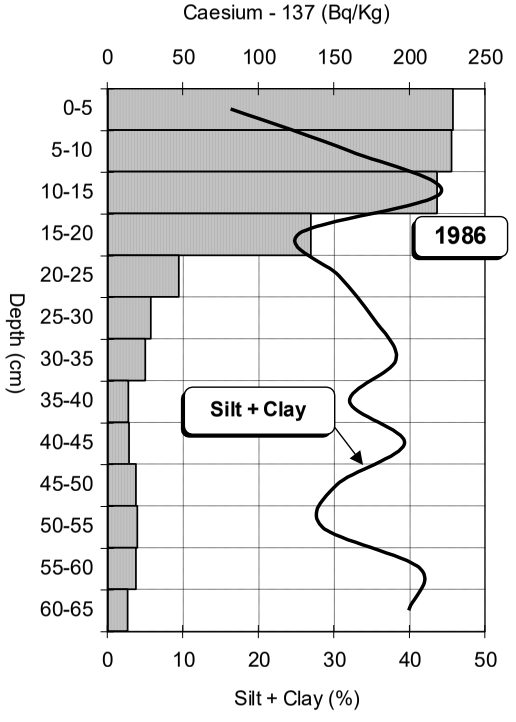
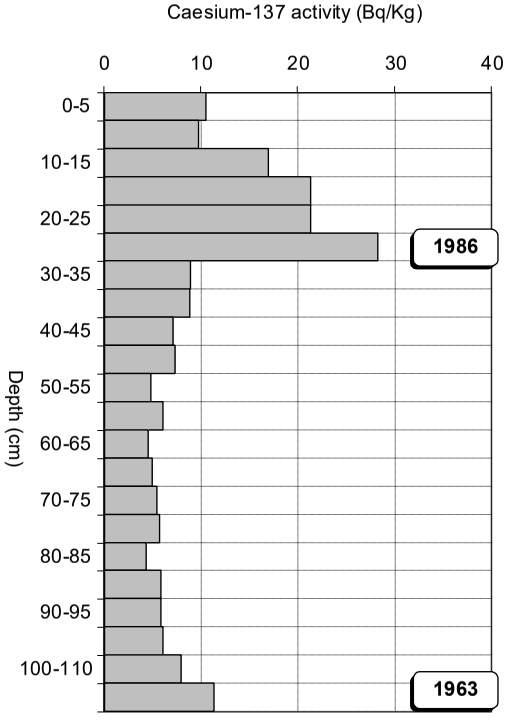


Figure 4 Distribution of Caesium - 137 in the Ichimeni reservoir, Bodeasa basin, Romania (April 14, 1999)



By relating the specific sedimentation rates for two periods, 1963-1985 (3.9 cm/year) and 1986-1998 (2.3 cm/year) is resulting a ratio of 1.7. This higher value of sediment accumulation during the former period can be attributed to the above-average precipitation over late 1960s and early 1970s.

In the reservoirs of the Central Moldavian Plateau the peak of ^{137}Cs concentration usually occurs in the alluvium layers at a depth of 30-50 cm. The distribution of ^{137}Cs by depth for Pungesti-Garceni reservoir from a small basin laying on the southern fringe of that geomorphological subunit is shown on Figure 5. The pattern in general, would be similar of that at Ichimeni in the Northeastern Romania. Because Pungesti reservoir has a shorter operation period of time there are exceptions. Apart from its deeper and higher ^{137}Cs peak there was no significant difference in the magnitude of sediment accumulation before and after 1986. These results from the ratio of 1.2 obtained by relating the mean annual rates of sedimentation tied to the periods 1976-1985 and 1986-1998. Furthermore, at depth of 85-90 cm the floodplain layer reveals a minor ^{137}Cs peak (13.0 Bq/kg) coinciding with the peak in bomb test activity during early 1960s. Based on these data it was possible to estimate the value of 1.1 cm/year as the normal mean aggrading rate on the floodplain over the period 1963-1975. For another small floodplain along the Ras Creek a similar value was estimated over the period 1963-1986.

Figure 6 depicts an entirely different situation associated to Cazanesti reservoir, which is by the same age as Pungesti. It lies in a larger basin Durduc-Upper Barlad of 19,097 hectares where forestland averages 40% of the total. This time there is a fairly significant difference in sediment deposition if comparing mean annual rates over the period 1975-1985 (5.2 cm/year) to 1986-1998 (3.85 cm/year). The ratio of 1.35 supports this assumption. The ^{137}Cs distribution in this profile shows the 1986 peak at a depth of 45-50 cm (34.7 Bq/kg). Taking into account the severe drought over the period 1986-1987 without significant streamflows it is obviously the strong impact of woodland area upon this distribution resulting in both a two years delay of the main ^{137}Cs peak (57.0 Bq/kg at 35-40 cm due to extremely rainy spring 1988) and a very low ^{137}Cs concentration above that peak in the top 30 cm. Also, there is no concordance between the ^{137}Cs and humus depth profiles but in this case the above 1% values of the organic matter content supports the assumption that rill-interrill erosion was the main sediment source. That means the forest succeeded in controlling soil erosion losses under an acceptable level.

To these situations may also be added a short note on two sediment profiles from the Moara Domneasca reservoir which was built in 1964. One of them dug upstream in the lake area filled with sediment indicates the

Figure 5 Distribution of Caesium - 137 and the silt + clay content in the Pungesti reservoir, Garceana basin, Romania (October 16, 1998)

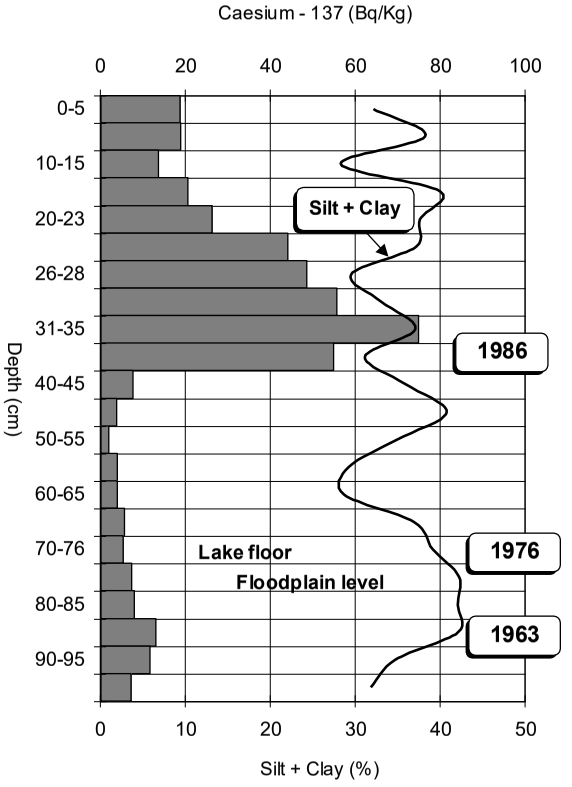
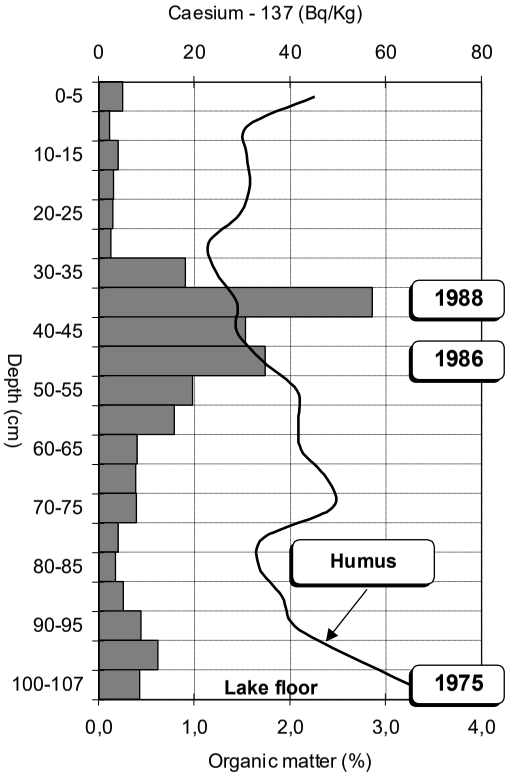


Figure 6 Depth distribution of Caesium - 137 and organic matter content in the Cazanesti reservoir, Durduc basin, Romania (May 5, 1999)



main ^{137}Cs peak of 50.5 Bq/kg at a depth of 44-50 cm. Above it, between 44-25 cm the ^{137}Cs concentration decreases to 7.7 Bq/kg. Than, an increase in ^{137}Cs activity up to 29.3 Bq/kg in the top 25 cm is noticeable. By averaging and relating the sedimentation rates in both pits over the periods 1964-1985 and 1986-1998 a similar ratio of 1.7 with that from Ichimeni was found. This finding is a clue indicating that sediment accumulation was almost double during the former period towards the latter at least in the central and northern part of the Moldavian Plateau.

Deep buried cantilever

This pattern is closely related to those areas where the peak concentration of Chernobyl derived ^{137}Cs is commonly occurring at a depth of 50-100 cm below the sediment surface. The southern part of the Moldavian Plateau, Tutova Rolling Hills, has been recognized as an area facing with severe erosion and sedimentation, which increased burial of the main ^{137}Cs peak.

Figure 7 illustrates some pattern features at the Antohesti reservoir, upper Berheci basin. The proper cantilever is consisting in a normal arm, hanging at a depth of 60 cm (154-192 Bq/kg) and a drastic drop (under 5 Bq/kg) in ^{137}Cs activity with increasing depth. The widely variation in ^{137}Cs concentration in the top 60 cm is a result of combined sediment sources, rill-interrill erosion and gully erosion respectively. Anyway, the higher values are associated to the former erosion process an the lower values to gully erosion. This assumption may be justified by the strong relation between this minor ^{137}Cs peaks and distribution of organic matter content. In addition, in the floodplain layers between 87-120 cm there is no significant ^{137}Cs peak, which can be consistent with nuclear events from 1963. This partial distribution suggests the mean rate of aggradation on that floodplain for the period from 1963 to 1984 may be over 1.65 cm/year. The double value of sedimentation rate estimated in reservoirs from Tutova Rolling Hills towards those from Central Moldavian Plateau would indirectly support the assumption that the aggrading rate on small floodplains in this area was around 2.0 cm/year over the period 1963-1984.

Another sediment profile now dug in the lake area under similar sandy alluvial texture shows a higher ^{137}Cs peak (335.9 Bq/kg) at a depth of 55-60 cm and an increment of 0.5% in humus content corresponding to the same minor peaks.

Furthermore, the depth distribution of ^{137}Cs in the Hutu-Gaiceana reservoir reconfirms the buffer influence of woodland, which averages 46% of a catchment with high relief energy. Above the ^{137}Cs peak (70.4 Bq/kg at

70-75 cm) there is an evident alluvium thickness showing a very low ^{137}Cs activity. Just like in Cazanesti reservoir, Durduc basin, the prevailing forest hampered delivery of sediment with higher radiocaesium concentration. In turn, severe gully erosion and active landslides extended mostly over agricultural land, delivered a big amount of sediment, which is low in ^{137}Cs activity. In this case, the high sediment accumulation indicates that the influence of forest is rather a qualitative one since the woodland is more like a storage for radionuclides and the agricultural land delivers most of the sediment deposited within reservoir.

The highest rate of sediment deposition over the entire study area, averaging 11.5 cm/year was identified on Puscasi reservoir, lower Racova basin, in Tutova Rolling Hills. Actually, Figure 8 depicts a very deep buried cantilever. As implies the name, the ^{137}Cs peak concentration (92.5 Bq/kg) occurs at a depth of 145-150 cm. Above the cantilever arm, between 145 and 95 cm there is a relative constant concentration in ^{137}Cs, around 43.0 Bq/kg. After a sharp decrease in ^{137}Cs activity from 95 to 55 cm, a slight flourishing in ^{137}Cs concentration is obviously in the top 55 cm even it is fluctuant. The wider range ^{137}Cs depth distribution provide evidence of combined sediment sources. The main inputs are connected to the right valleyside of the basin, developed mostly on sandy layers, which represents a broad steep cuesta.

There are exceptions from this pattern resulting from the impact of changes in land management. Such a marked situation was recorded at Bibiresti reservoir in the upper Racatau basin. During 1982-1985 appropriate conservation practices were implemented in this representative basin, mostly used as cropland. After implementing the provisions of the Landed Property Law no. 18/1991 this area was gradually converted in 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 storeys or double cantilever (Figure 9). The first storey clearly occurs below a depth of 70 cm (37.0 Bq/kg) being connected to April 1986, while the second is related to the revival in 1993 of the up-and-down hill farming. The mean siltation rates rose from 5.0 cm/year for the period 1986-1992 to 10.0 cm/year over the period 1993-1996. The ^{137}Cs activity during the former period of time was associated with low ^{137}Cs input (3-5 Bq/kg) indicating fairly soil erosion whereas the latter period is tied to severe rill-interrill erosion and the most significant ^{137}Cs inputs along this profile (up to 59.7 Bq/kg).

Figure 7 Distribution of Caesium - 137 and organic matter content in the Antohesti reservoir on Upper Berheci Basin, Romania - May 14, 1997

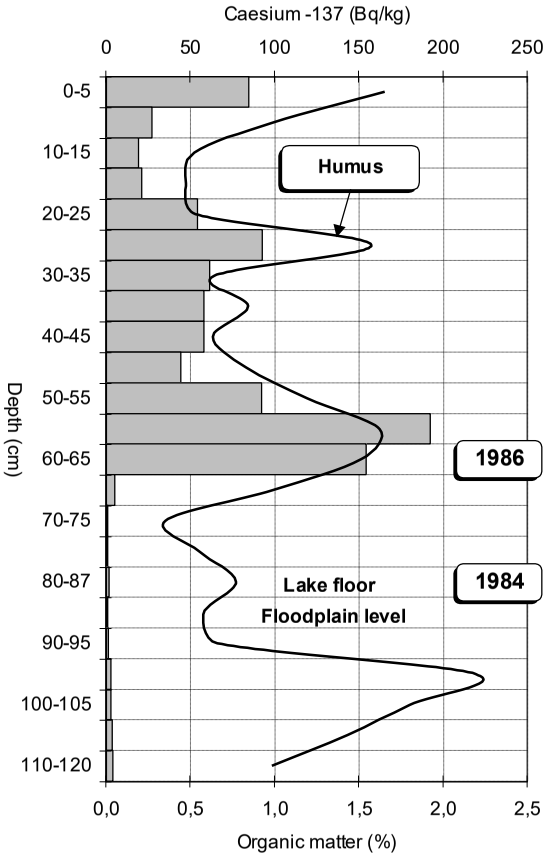
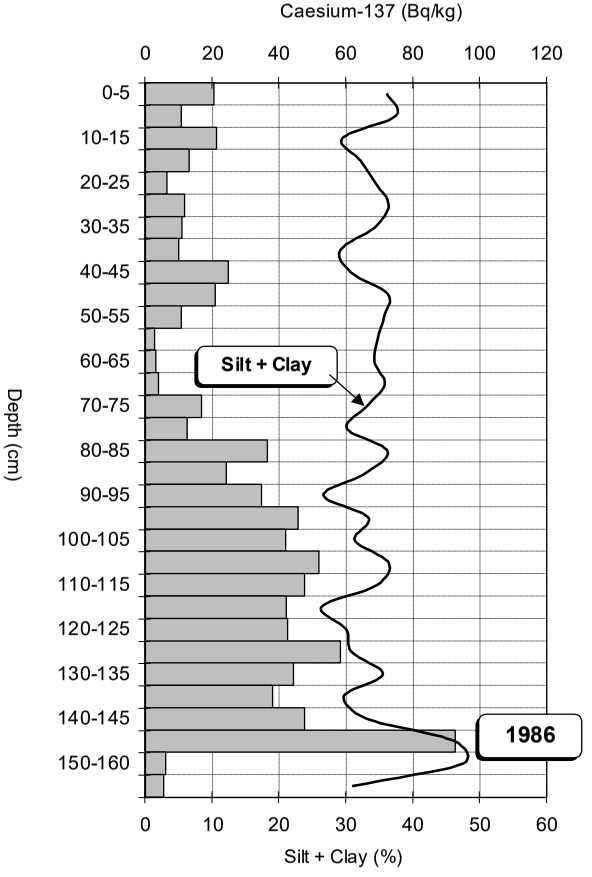


Figure 8 Distribution of Caesium - 137 and silt + clay conten in the Puscasi reservoir on Lower Racova Basin, Romania - June 8, 1998



Therefore, this particular ^{137}Cs depth distribution shows the 86% of the total inventory occurs in the top 40 cm deposited over the period 1993-1996. In fact, all those examples showing such a ^{137}Cs revival in the upper part of the sediment profile provide evidence of the strong impact on the environment induced by the Law no.18/1991, which is not evenly distributed as dating.

Downstream in the middle Racatau basin, on a larger scale this particular pattern was changed as shown in Figure 10. The revival in ^{137}Cs activity in the top 45 cm is noticeable but subsequent in comparison with the major ^{137}Cs peak (ca. 280 Bq/kg) that occurs at a depth of 85 cm. The wide range in the magnitude of the main ^{137}Cs peaks in the Racatau basin is also resulting from spatial variability of precipitation.

Conclusions

Accumulation of ^{137}Cs on reservoirs in the Moldavian Plateau is mainly associated with the Chernobyl inputs and subsequently with ^{137}Cs derived from testing of nuclear weapons.

The estimated mean sedimentation rates in three geomorphological subunits vary between 2.6 and 7.9 cm/year with an average rate of 4.6 cm/year after April 1986. The lowest values are recorded within the reservoirs located in the northern area, the Moldavian Plain. The Central Moldavian Plateau is a transition zone while the Tutova Rolling Hills area has been impacted by greatest sedimentation. This regional differentiation is consistent with the decrease in clay and increase in sand content of substratum layers as moving from the North to the South.

Strong relationships were defined by plotting the individual sedimentation rates to the corresponding catchments within southern and central part of the Moldavian Plateau.

The asymmetrical depth distribution of ^{137}Cs activity in undisturbed sites suggests a standard pattern of reservoir sedimentation in the form of a cantilever. Taking into account the shape of ^{137}Cs depth profile generally and burial magnitude of Chernobyl-derived ^{137}Cs peak particularly, two main types of ^{137}Cs cantilever distribution were established: shallow and deep buried cantilever.

The pattern of shallow buried cantilever typifies those areas where ^{137}Cs peak concentration exhibits in the upper part of the profile commonly at a depth of 15-50 cm. This is especially true in the northern and central part of the Moldavian Plateau where rill-interrill erosion is the main sediment source. The deep buried cantilever is closely related to the Tutova Rolling Hills area, where the peak activity of Chernobyl-derived ^{137}Cs is usually occurring at a depth of 50-100 cm and sometimes deeper. There is a

Figure 9 Depth distribution of Caesium - 137 and silt + clay content in the Bibiresti reservoir, upper Racatau basin, Romania (May 13, 1997)

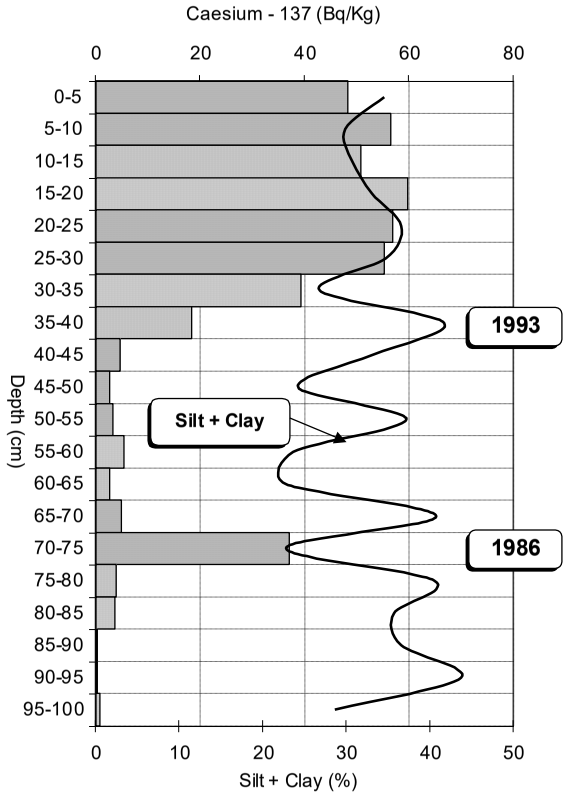
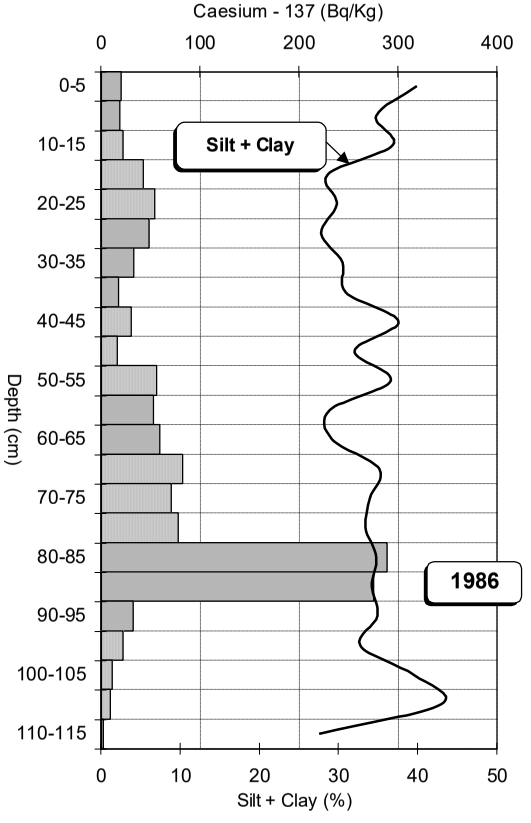


Figure 10 Depth distribution of Caesium - 137 and silt + clay content in the Horgesti reservoir, middle Racatau basin, Romania - June 11, 1998



combination of sediment sources resulting mostly from surface erosion and gullying inputs.

If the sedimentation rates over two distinct periods 1963-1985 and 1986-1998 are compared a ratio of 1.7 can be estimated. This supports the assumption that during the former period with above-average precipitation sediment deposition in reservoirs was almost double.A variable influence of the forest on ^{137}Cs and sediment inputs has been noticed. Main changes in land management, especially arising of the up-and-down hill farming after 1991 caused significant increase in erosion/sedimentation rate in comparison with the previous contour farming.

Acknowledgements

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INVENTORY OF ^{137}CS FROM CHERNOBYL ACCIDENT IN THE MOLDAVIAN TABLELAND OF ROMANIA

MARGINEANU R.[*], IONITA I.[**] BREBAN D.[*], GHEORGHIU D.[*]

[*] National Institute For Physics And Nuclear Engineering, Ifin-Hh Bucharest, Romania
[**] Research Station For Soil Erosion Control, Perieni-Barlad, Romania

Introduction

The Moldavian Plateau located in the Eastern Romania and extending about 25,000 square kilometers is considered as the broadest and most typical plateau of the country.

This plateau is situated between 32 and 564 m above the sea level. The climate is temperate continental with a mean annual temperature of 8-9.8^{o}C and precipitation of 460-500mm. Although man has drastically changed the native vegetation cover, two natural zones are distinguished: the forestry area that occupies the higher parts of the plateau and the area under silvosteppe (forest-grassland transition) and steppe (short grasslands).

The Moldavian Table Land, as the whole Romanian territory, was affected by the radioactive fallout from the Chernobyl accident. The deposition over the Romanian territory from the Chernobyl emissions was extremely non-uniform and great variations were found in small areas, [1,2]. It is well known that the radioactive deposition that has occurred after the Chernobyl accident was characterized by complex meteorological conditions in May 1986 and the direct deposition lasted only few weeks. Consequently, the contamination of the soil surface was very non-uniform. One can not possibly assume that, even for small areas of a few square kilometers, the initial deposition was constant and subsequently the variations observed in inventory were caused by migration with and/or within the soil. Consequently, one should work on the assumption that, generally, the initial deposition remains unknown, practically everywhere in the area of interest. However, in special situation like those arising in the gullyheads, floodplain and reservoirs, the initial deposition due to the Chernobyl accident can be derived from the total inventory of Cs137. In this paper the authors tried to derive the the initial deposition of Cs137 in several reservoirs and gullyheads. The variability of initial deposition in Europe, on small scale, as well as on large scale, is well documentated [3,5,6]

Methods

In each investigated area, a pit was dug from which the samples were taken from surface up to 100-200 cm deep with an increment of 5 cm.

After conditioning, the samples were analyzed in the laboratory, using a Canberra MCA S100 system equipped with a Ge(Li) detector. The detector is housed in 10 cm lead thick shielding. The samples taken in the field were conditioned and subsequently measured. The acquisition time ranged from 5000 s to 60000 s per sample. The background on Cs137 region is about 0.0015 cps and it was determined collecting spectra up to 200000 s.

Efficiency calibration of the measurement system was determined using IAEA-375 soil as reference material in a similar geometry with those for the samples. Also, some reference standards produced in the Department of Isotope Production of IFIN-HH were used for calibration. Soil samples were measured in 500 cm^3 Marinelli beakers. The spectra were analyzed with SAMPO 90, a dedicated computer code for high-resolution γ-ray spectrometry.

The minimum detectable activity for a collecting time of 40000 s is about 0,65 Bq/kg.

Mathematical analyses of Cs137 profile distribution in reservoirs

The Cs137 from sedimented soil originates from the direct fallout and from the redistribution of contaminated soils in the catchment. In these conditions, the initial deposition of Cs137, mixed in the surface soil, was covered by the sedimented soils coming from the basin. Neglecting any downward movement of Cs137 with pore water and assuming that Cs137 input is initailly uniformily distributed at the soil surface, [4], the vertical distribution can be characterised by the one-dimensional diffusion equation:

$$\frac{\partial C(x,t)}{\partial t} = D_n \frac{\partial^2 C(x,t)}{\partial x^2} - \lambda C(x,t) \qquad (1)$$

where: D_n – efective diffusion coefficient ($kg^2\ m^{-4}\ y^{-1}$)

λ - decay constant (y^{-1})

x – accumulated mass of soil per unit area ($kg\ m^{-2}$)

The profile distribution of Cs137 in reservoir sediment was fitted with a sum gaussian functions in order to identify the initial input immediately after Chernobyl accident, the position of the Chernobyl peak within sediment (at the moment of sampling) and the contribution of eroded soil to the total Cs137 inventory in the investigated area. The fitting function used is given by:

$$y = y_0 + \sum_i \frac{A_i}{w_i \sqrt{\pi/2}} e^{-2\frac{(x - x_{ic})^2}{w_i^2}} \qquad (2)$$

In all the investigated areas, the fitting of profile distribution has evidenced the maximum due to Chernobyl and two or three other gaussians which have much larger widths due to the redistribution of Cs137 within the catchment.

Results and disscusions

In the investigated reservoirs, the profile distribution of Cs137 in sedimented soil shows a complex pattern. The eroded soil comes, mainly from arrable field and gullies from the catchment. The depth of Cs137peak due to the Chernobyl deposition varies from 10 cm to 140 cm. The position of the maximum activity of Cs137 within the soil depends on erosion rate in the basin. In addition to the Chernobyl maximum, usually in each depth profile others maxima can be observed. for the resevoirs, these maxima are a consequence of meteorological conditions and changes in land-use in the last decade. The suplimentary Cs137 that occurs above the Chernobyl horizon is a consequence of combined erosion processes (e.g. rill erosion, inter-rill erosion, gully erosion and landslide), [7,8]

In the area, the initial deposition from the Chernobyl accident ranges between 2 kBq/m^2 to 46 kBq/m^2. The highest values of the initial deposition are a result of local and small rain events occurred in the first days of May 1986. The total inventory in reservoirs is generally much higher than the initial deposition, up to 8 times in Doroscani-Scobalteni area, except Hutu-Gaiceana area were the initial deposition and the total inventory are close.
This suggests that in some of the watersheds (as in HG) the fallout was mainly dry and in others that the fallout was wet on the land and dry on the reservoir surface. The data regarding the investigated reservoirs are sumarised in Table 1.

In Antohesti reservoir where two profiles were sampled, one can see that the difference in Cs137 total inventory can be correlated with the size distribution of sedimented soil in these two places. The initial deposition was similar, about 30 kBq/m^2. During the sedimentation process the coarse particles are deposited first and fine particles are deposited later.

As one can see, from Cs137 profile distribution, the sedimentation process in gully heads is complex. There are gully heads for which the maximum Cs137 is in the first 5 cm, but usually, the maximum activity of

Table 1. Chernobyl deposition of Cs-137 in the Romanian Moldavian Tableland

	Reservoir	River Basin	Chernobyl depth (cm)	Sedimentation rate (cm/year)	Chernobyl deposition (kBq/m^2)	Total inventory (kBq/m^2)	Latitude Deg Min	Longitude Deg Min	Geographi-cal Unit
1	Bibiresti	Racatau	69.9	5.8	4.2 ± 1.0	31.5 ±3.5	$46^0$31‟	$27^0$05‟	Tutova Rolling Hills
2	Horgesti	Racatau	82.6	6.9	46 ± 2	105.8 ± 9.5	$46^0$27‟	$27^0$05‟	
3	Racataul de Jos	Racatau	91.0	8.3	8.6 ± 1.8	34.5 ± 4.3	$46^0$22‟	$27^0$03‟	
4a	Antohesti 1 km from the dam	Berheci	57.3	4.8	31 ± 8	132 ± 10	$46^0$34‟	$27^0$14‟	
4b	Antohesti 2.5 km from the dam	Berheci	58.9	4.9	29 ± 3	74 ± 7	$46^0$35‟	$27^0$14‟	
5	Hutu-Gaiceana	Berheci	70.5	5.9	9 ± 1	11.8 ± 2.1	$46^0$21‟	$27^0$15‟	
6	Puscasi	Racova	142.7	11.9	19.9 ± 2	64.2 ± 5.2	$46^0$38‟	$27^0$38‟	
7	Pungesti-Garceni	Racova	30.9	2.6	16.9 ± 6.3	31.5 ± 3.4	$46^0$43‟	$27^0$21‟	Central Moldavian Tableland
8	Ras-Craesti	Barlad	35.0	2.9	2.4 ± 0.5	14.2 ± 1.6	$46^0$51‟	$27^0$10‟	
9	Moara Domneasca	Vaslui	25.5	2.1	8.4 ±1.0	20.4 ± 2.0	$46^0$44‟	$27^0$45‟	
10	Cazanesti	Durduc	38.9	3.2	4.3 ± 1.0	19.5 ± 2.0	$46^0$52‟	$27^0$29‟	
11	Solesti	Vaslui	81.3	6.8	1.8 ± 0.5	8.9 ± 0.8	$46^0$47‟	$27^0$48‟	
12	Popesti	Scobalte ni	9.6	0.8	34 ± 8	79.6 ± 6.1	$47^0$11‟	$27^0$16‟	Moldavian Plain
13	Doroscani	Scobalte ni	23.0	1.9	9.9 ± 1.0	81.3 ± 5.0	$47^0$11‟	$27^0$16‟	
14	Podul Iloaiei	Bahluiet	38.0	3.2	6.5 ± 1.9	15.8 ± 1.4	$47^0$12‟	$27^0$15‟	
15	Ichimeni	Baseu	26.3	2.2	2.0 ± 0.8	14.8 ± 1.6	$48^0$03‟	$26^0$52‟	

Cs137 is deeper, at 10 cm to 25 cm. For some gully heads, the peaks of Cs137 due to the nuclear bomb testing are also visible.

The initial deposition received by the gully heads in 1986 ranges from 1.4 kBq/^{2} to15 kBq/m^2, as presented in Table 2. The initial deposition ranges from 8.4 kBq/m^2 to 12 kBq/m^2 in Gorney Valley. In Timbru Valley, one can see that the initial deposition varies with from 1.2 kBq/^{2} to 5.3 kBq/^{2}. In Roscani-Scranghita gully, one can see three peaks of Cs137. The Chernobyl peak is at 28.1 cm deep, the "1963" peak is at 141 cm and "1959" peak at 173 cm. The last two peaks are correlated with the maxima in fallout due to nuclear test in the years „50 and "60. The initial deposition in Roscani-Scranghita gully was aabout 15 kBq/m^2.

Table 2. Chernobyl deposition of Cs-137 in some gullies from the Romanian Moldavian Tableland

Gully	Cherno-Byl depth (cm)	Sedimen-tation rate (cm/year)	Chernobyl deposition (kBq/m^2)	Total inventory (kBq/m^2)
Scranghita gully head no. 4	28.1	2.3	15.1 ± 1.0	29.3 ± 1.5
Gorney Valley, gully head no. 2	12.1	1.0	8.4 ± 1.0	15.2 ± 1.5
Gorney Valley, gully head no. 3	25	2.1	11.8 ± 1.0	17.4 ± 1.5
Timbru Valley, gully head no. 9	23.2	1.9	1.4 ± 1.0	6.9 ± 1.5
Timbru Valley, gully head no. 10	24.6	2.1	5.3 ± 1.0	8.4 ± 1.5

Conclusions

- Almost all of the Cs-137 found in the sedimented soil in reservoirs and gullies originated from Chernobyl accident.
- The total inventory of the Cs137 in the sediments varies from reservoir to reservoir, with more than one order of magnitude.
- The direct deposition from Chernobyl accident was evaluated.
- The position of maximum of the Cs137 from Chernobyl deposition shows where the surface of bottom sediments were situated in 1986, subsequently being covered with eroded soils from basin.
- Cs137 demonstrates to be very suitable for the assessing of long term erosion and sedimentation processes in the environment.

- The erosion and sedimentation processes contribute to the redistribution of the Cs137 in the environment.
- Considering the specific activity of Cs137 measured in soil and sediment samples, it becomes obvious that the Chernobyl accident has injected measurable amounts of Cs137 in the soil and sediment for the next 100 – 150 years. From this point of view, Cs137 from Chernobyl can be considered a good radioactive tracer for environmental processes.

Aknowledgements

The authors express their gratitude to IAEA-Vienna for its permanently support. The investigation was carried out during 1996 – 2000 in the frame of the IAEA Coordinated Research Program entitled "Soil Erosion and Sedimentation Assessment Studies by Environmental Radionuclides and their Application to Soil Conservation Measures".

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Fig. 1 Moldavian Plateau study area showing the location of the reservoirs

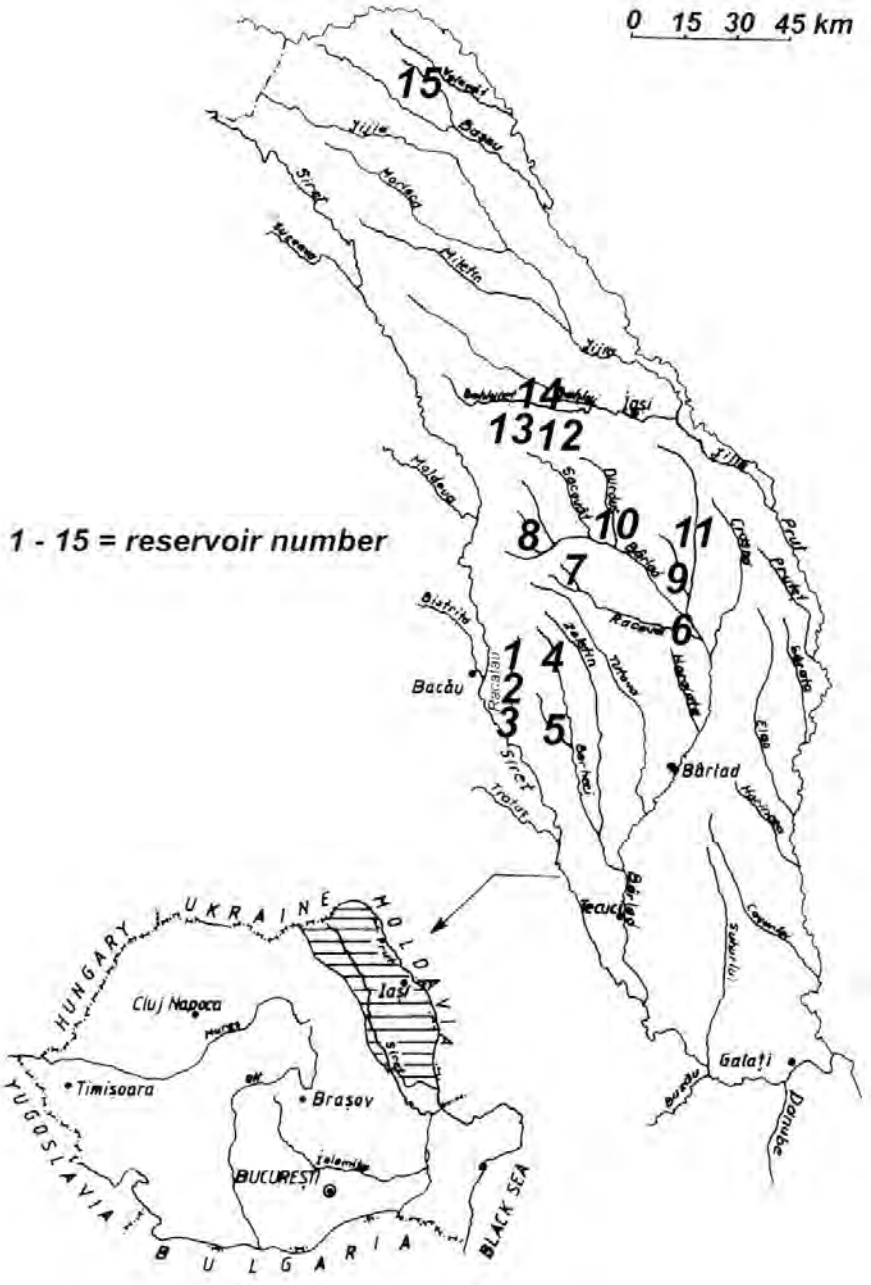


Fig.1 Antohesti reservoir, Profile distribution of Cs137, sampling site no.1

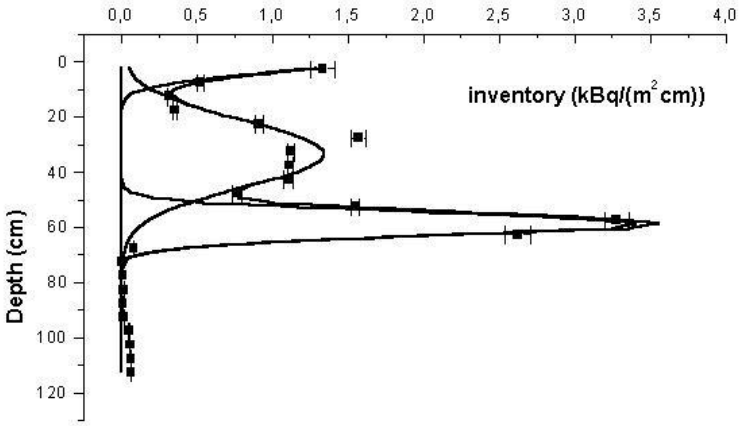
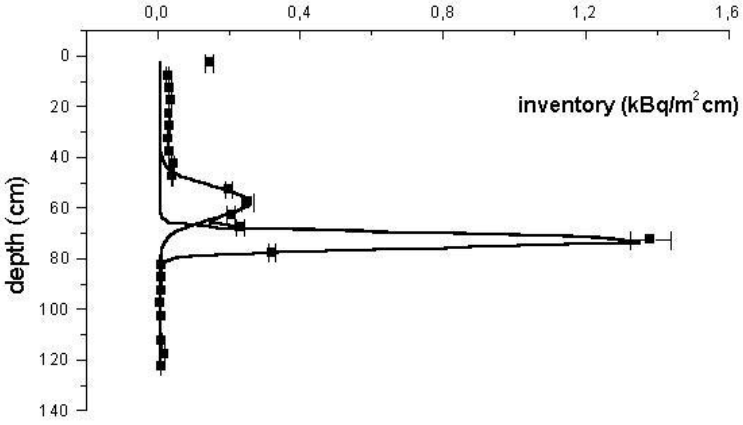


Fig.2 Depth profile of Cs137 in Hutu Gaiceana reservoir



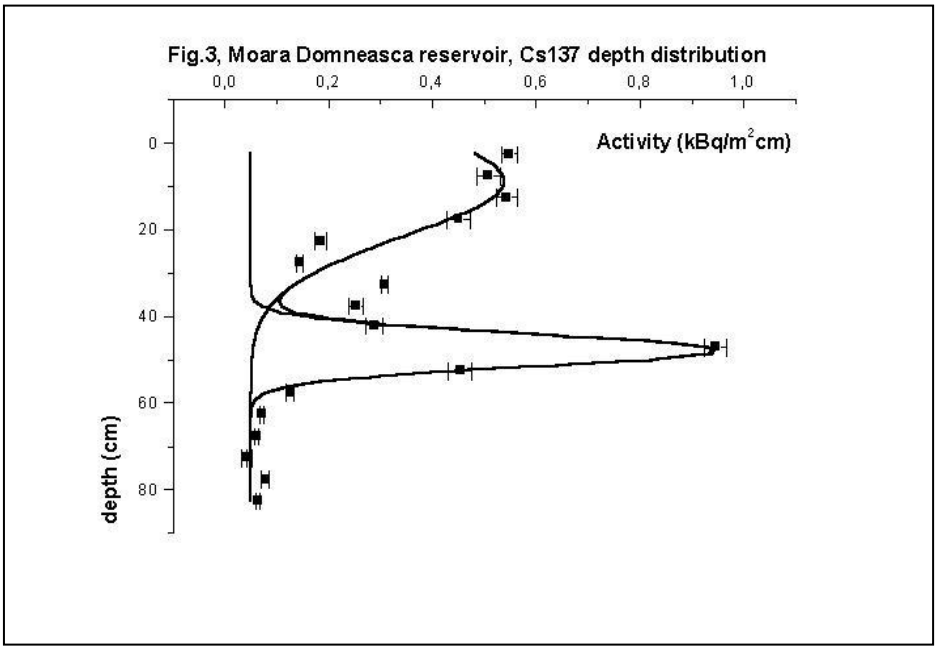


Fig.3, Moara Domneasca reservoir, Cs137 depth distribution
0,0
0,2
0,4
0,6
0,8
1,0
Activity (kBq/m2cm)
0
20
40
60
80
depth (cm)

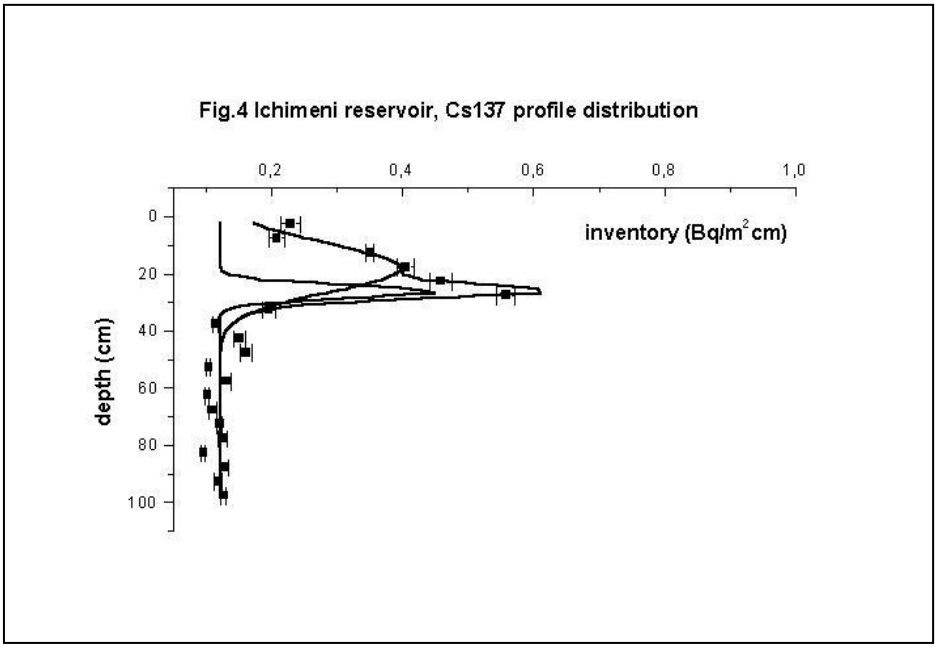


Fig.4 Ichimeni reservoir, Cs137 profile distribution
0,2
0,4
0,6
0,8
1,0
inventory (Bq/m2cm)
0
20
40
60
80
100
depth (cm)

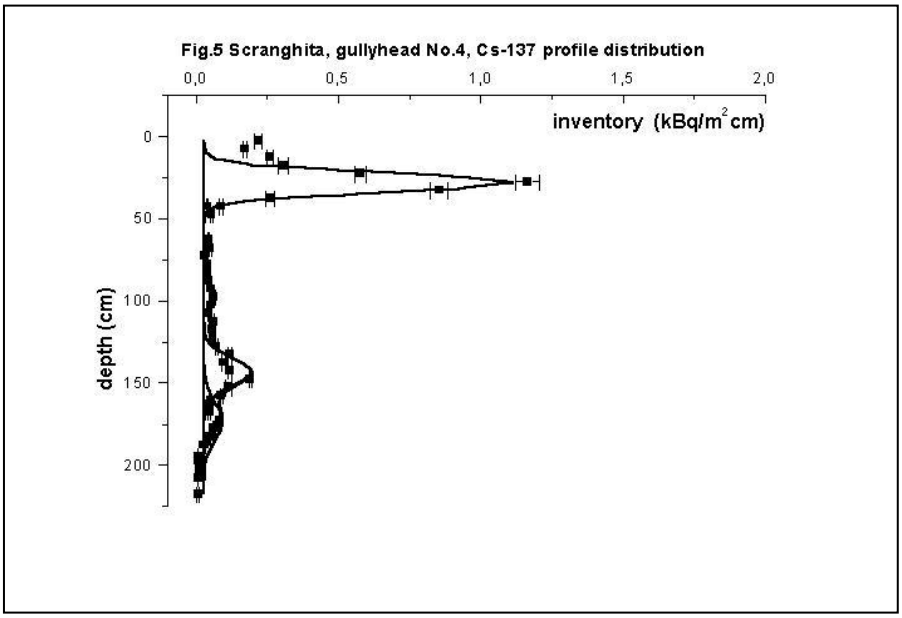


Fig.5 Scranghita, gullyhead No.4, Cs-137 profile distribution
0,0
0,5
1,0
1,5
2,0
inventory (kBq/m2 cm)
0
50
100
150
200
depth (cm)

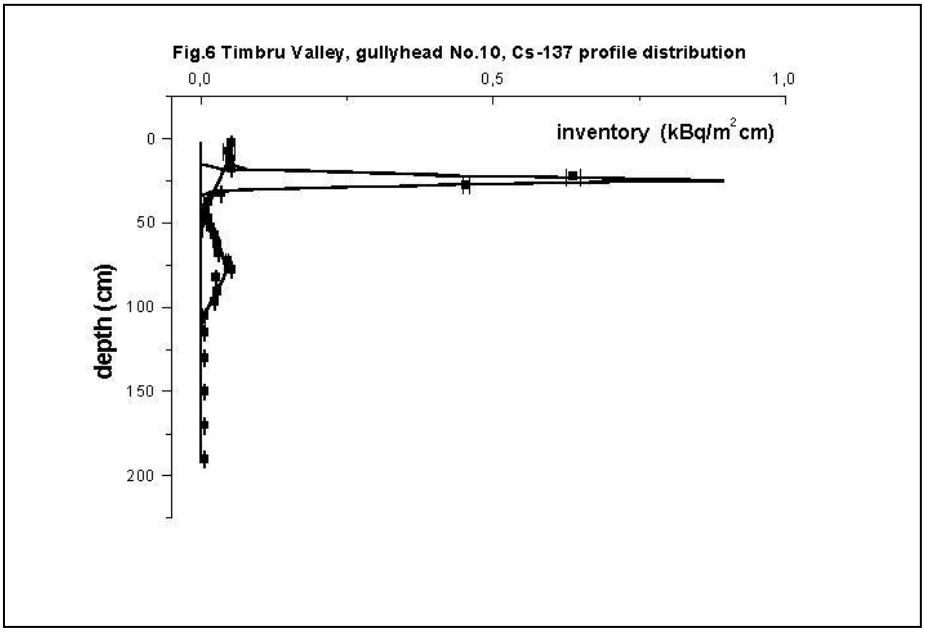


Fig.6 Timbru Valley, gullyhead No.10, Cs-137 profile distribution
0,0
0,5
1,0
inventory (kBq/m2 cm)
0
50
100
150
200
depth (cm)

DEVELOPMENT OF THE SOIL EROSION CONTROL IN ROMANIA

NISTOR DUMITRU and IONITA ION

Abstract: About 43% (6.4 million hectares) of the total Romanian agricultural land is located on slopes of less 5 percent and it is subjected to soil erosion and associated processes.

In terms of sediment yield from agricultural land estimates amount to 106.6 million tons/yr. Cropland, pastures and unproductive land enter this value with 82 percent. Sediment derived from rill-interrill erosion and gully erosion averages 73 percent of this amount.

Until 1960, the traditional cropland farming was consisting in up-and-down hill small plots and there was no significant concern on soil erosion control.

Then, as a result of the collection of much research data and many years of experience, conservation practices have been getting considerable attention, progressively. Consequently, by 1990 about 2.2 million hectares representing 30 percent of the total agricultural land with erosion potential was under conservation practices.

The new landed property law no. 18/1991 includes two provisions, which are not of a nature to create conditions for the extension of conservation measures. Over last decade, the traditional farming by up-and-down hill small plots is on the screen again and caused much of the decline in the environmental quality.

This paper tries to present the main characteristics of soil erosion control in Romania.

Key words: Soil erosion, Conservation practices.

Introduction

Soil erosion is of greatest interest among the processes affecting soil quality and productivity. Accelerated population growth and the unwise land use and management, especially since World War I, have led to dramatic degradation of the environment.

The territory of Romania, which lies in the South - Eastern Europe, encompasses 237,500 square kilometers. Romania has a variety of landscapes resulting from its wide range of major relief forms which are very well proportioned: 36 percent Carpathian Mountains and Subcarpathians, 34 percent hills and tablelands, and 30 percent plains. Within its boundaries live 23.5 millions people.

Hot summers and cold winters, variability in the distribution of rainfall, fluctuating length of growing season typify Romanian continental-temperate climate. There is a crossing of three main climatic influences as follow: Mediterranean climate, central European climate under Atlantic air masses, and east European climate by excessive continental nuance.

Average annual precipitation varies from about 360 mm at the lower elevations within the Danube Delta to 1450 mm in the mountain area between 2000-2543 meters elevation. The mean annual temperature is about 10 ^{0}C. The extreme values of temperature were recorded as follows: the minimum of -38.5 ^{0}C on January 25, 1942, in the central Romania near Brasov, and the maximum of +44.5 ^{0}C on August 10, 1951 in the south-east area, near Braila city.

For the Romanian agriculture the main soil classes are mollisols (chernozems, gray wooden soils) and argiluvisols (reddish-brown soils, brown argoloiluvials, brown-luvic soils and luvisols).

The principal feature of the old traditional agriculture in Romania consists primarily of an up-and-down hill farming system under small plots that speeds the erosion rates. However, in limited areas there were a few concerns for controlling soil erosion such as periodical conversion of cropland to grasses, agroterracing and contour tillage.

Since 1960, by improving our basic understanding of the relationship between soil erosion and properties as well as of the hydrologic processes and best management practices it was possible to improve and implement erosion control practices on about one third of the land subjected to soil erosion.

From 1990, the decline in extension of conservation practices is attributed to a particular government policy and the cropping picture of the old traditional agriculture is on the screen again.

Materials and Methods

Various studies were conducted to meet different needs for action: describing properties of the eroded soils, understanding fundamental processes of hydrology, improving and implementing best management practices.

Research plots were constructed in some locations to determine soil and water losses caused by water erosion. Those plots that were set-up in 1970 at Perieni-Barlad are still in use. Long-term field measurements regarding erosion/deposition rates are of value.

Also, a lot of information is included in this paper by reviewing of literature.

Results

3.1. Extend and types of water erosion

Because of its natural conditions, Romania presents the most varied forms created by water erosion among the Central and Eastern European

countries. The wind erosion is affecting only small areas located in the South.

According to the 1980 Inventory of the Institute for Geodesy, Photogrammetry, Mapping and Land Planning, the agricultural land from Romania averaged about 63 percent of the total, as shown in Table 1.

Table 1. Land - use stratification in Romania

Land -use	Surface	
	Million ha	**%**
Arable (Cropland)	9.833	41.4
Pastures	4.467	18.8
Vineyards	0.306	1.3
Orchards	0.357	1.5
Agricultural total	**14.963**	**63.0**
Forestry vegetation	6.568	27.7
Water and marsh	0.796	3.3
Roads and railroads	0.375	1.6
Yards, constructions	0.655	2.8
Unproductive (Abandoned)	0.393	1.6
Non agricultural total	**8.787**	**37.0**
General total	**23.750**	**100.0**

Data from Table 2 illustrate that among agricultural land most of the pastures (grazingland) orchards and the vineyards are laying out on sloping land, especially. Forests are concentrated on mountain area, mostly.

Even the arable land is located on "gentler" slopes this land use is a major source for soil losses because the high percentage of row crops (corn, dry beans, sunflower, potatoes) determined high erosion rates. The non-adequate management of the pastureland had an unfavorable influence, too.

Nationwide, the rate of erosion presents a distinct interest, too. For the entire territory of Romania Motoc M. published a study in 1983. Figure1 shows division into zones of the total erosion in tones/ha/year. The peak erosion rate is 30-45 t/ha/year and occurred in the Curvature Subcarpathians. Then, follow with high values of 20-30 t/ha/year the Meridional Subcarpathians, the Getic Plateau, the Moldavian Plateau, and the western part of the Transilvanian Plateau. As regards the classes of the erosion intensity it is noticed that the classes with moderate and high rates of erosion (9 - 30 t/ha/year) are predominating.

Table 2 - Use of the sloping land with erosion potential

Land use	Area		Mean slope of land (%)
	Over 5% slope (million ha)	Percentage of the total	
Agricultural, from which:	6.367	42.6	
Arable (Cropland)	2.572	26.0	17.0
Pastureland	3.360	75.0	21.8
Wine plantations	0.169	55.0	16.0
Fruit plantations	0.266	75.0	18.0
Forestland	5.748	87.5	40.4

A special attention was given to the sediment sources. Tables 3 and 4 show the contribution of the land use and the type of erosion processes to the total erosion.

Table 3 - Total erosion by land-use

No	Land-use	Total erosion			
		million t/yr	%		
1	Cropland (Arable land)	28.0	26.2	24.7	22.3
2	Pastures (Grazing land)	45.0	42.2	39.6	35.7
3	Vineyards	1.7	1.6	1.5	1.2
4	Orchards	2.1	2.0	1.8	1.7
5	Unproductive (Abandoned land)	29.8	28.0	26.4	23.6
	Agricultural land total	106.6	100.0	-	-
	Woodland - total	6.7	-	6.0	5.3
	Total	113.3	-	100.0	-
	Bankrivers and localities erosion	12.7	-	-	10.2
	General total	**126.0**	**-**	**-**	**100.0**

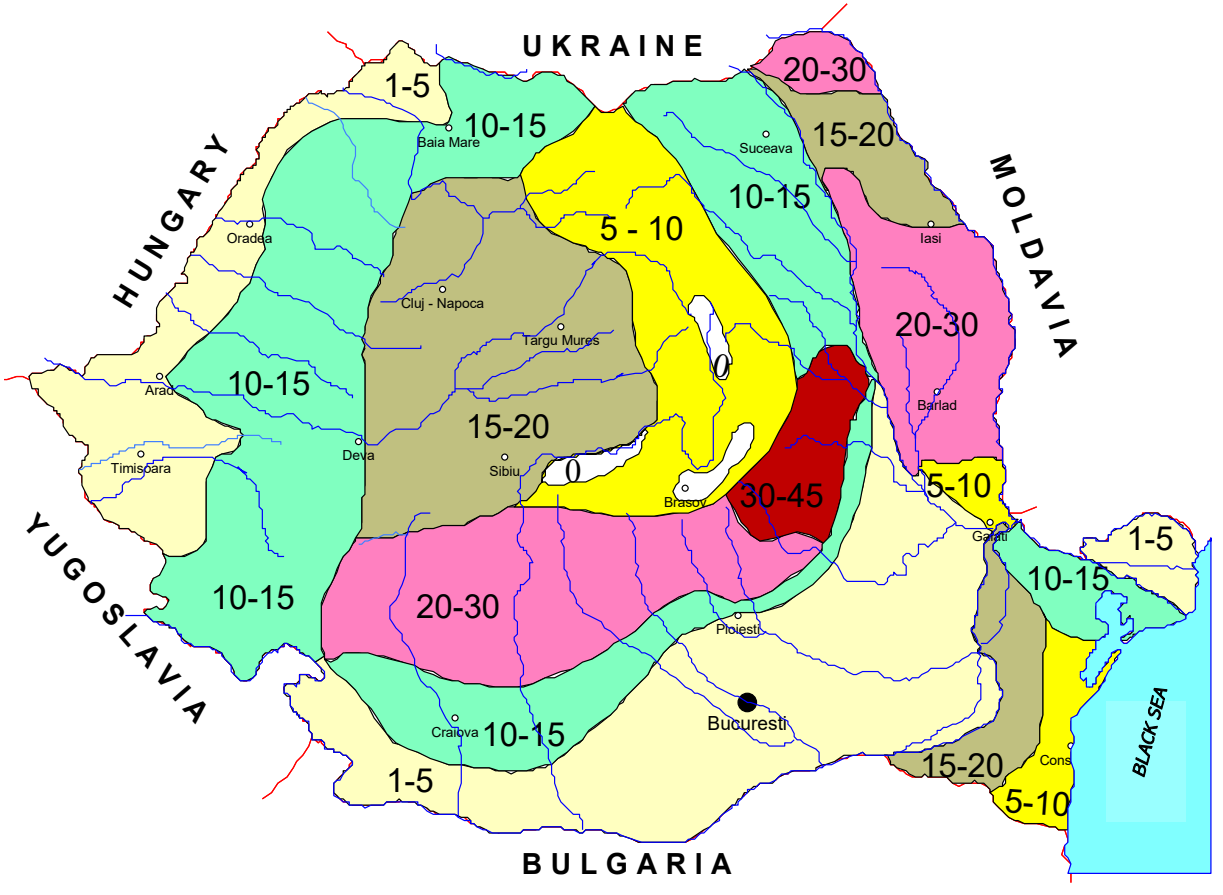


Figure 1 Total erosion on the agricultural land in Romania - tons/ha/year (after Motoc M., 1983)

Table 4 - Total erosion by types of water erosion

No	Type of erosion	Total erosion		
		million t/yr	%	
1	Surface erosion	61.8	54.5	49.0
2	Gully erosion	29.8	26.4	23.6
3	Landslides	15.0	13.1	11.9
4	Gully erosion and landslides on woodland	6.7	6.0	5.3
	Total	113.3	100.0	-
	Bankrivers and localities erosion	12.7	-	10.2
	General total	**126.0**	**-**	**100.0**

These data reflect different input levels to the gross erosion. In terms of the physical soil losses from agricultural land estimates run as high as 106.6 million tons per year. Of this amount, an estimated 102.8 million tons enter the total erosion from grazingland, unproductive land and cropland. The reduced value from vineyards and orchards is due to that over the last 30 years the plantations were set up based on conservation treatments.

By the other hand, surface erosion (sheet and rill) and gully erosion are the most important contributors to gross erosion, whereas landslides have a subsequent input.

3.2. Results obtained on study of the eroded soils

Research on soil erosion in Romania has been conducted in recent years, namely after the Second World War. Erosion surveying started in 1947 in Buzau county (Motoc M., 1952) and reached a climax in 1977 when Florea N. et al. released the map of soil erosion in Romania at 1:500,000 scale. Those maps served to the designing of conservation practices. Besides, the form and intensity of erosion several other factors were included so that these special surveying maps actually represent the suggested GIS layers as practised at present.

The work of Luca Al. (1971) shows the influence of the eroded soil properties on wheat yields. Applying regression equations allows assessment of the yield level depending on the organic matter, nitrogen, phosphorus content and available water capacity. Motoc M. (1983) established a general rating curve for assessing the wheat yield over the rate

of annual erosion and an equation to estimate the long - term crop losses as well. These data are of interest to define some local parameters of EPIC model.

3.3. Understanding fundamental processes

In this category hydrological studies on dispersed overland flow, rillflow, and concentrated ephemeral streamflow that causes gully formation are included. Runoff plots were set-up under different conditions in some agricultural research stations. By processing long-term data Motoc M. (1960, 1983) elaborated a proper quantitative model to evaluate the soil loss through sheet-rill erosion. It is by the same type as Wischmeier's model and it was for the first time used in an European Country in the designing of erosion control practices. The Hi_{15} indicator proposed by Stanescu P. et al. (1969), where H is amount of precipitation and i15 the intensity of the rainstorm nucleus on a 15-minute duration was of value in running this model. That index for rainfall aggressiveness is easier to be calculated and has similar performance as the rainfall erosion index proposed by Wischmeier W.H. (1959) for the United States.

Data collected at Perieni Research Station over 25-year period allowed to Motoc M. and Ionita I. (1983) to establish a rainfall and vegetation index for singly storms occurring at short intervals. Field research carried out by Motoc M. and Ouatu O. (1985) on rill development shows the two types of flow patterns: one during rill formation and the other one stable when turbidity is reduced by 8-10 times. Stanescu P. (1979) also elaborated a model for estimating the sediment concentration of overland flow.

Motoc M., Ionita I. and Nistor D., (1998) estimated the erosion and climatic risk at the wheat and maize crops in the Moldavian Plateau related to sheet-rill erosion. Figure 2 illustrates the distribution of soil loss from 1970 to 1994 under the check plot of continuous fallow. Within this erosion cycle there are obviously to erosion peaks as follows: the first in 1975 and the latter around 1988.

As to the concentrated flows and gully development, it is of particular interest research carried out by Ionita I. (1998) in the Moldavian Plateau. Long-term field measurements allowed establishing the patterns of gully evolution and indicating the gully head advance, the areal gully growth, and quantifying material delivered by gullies. The decreasing trend of gullying over the period 1960-1990 is generally as the rainfall pattern but it was subsequently influenced by the increasing effect of conservation practices.

Within approach the concern shifted from descriptive to quantitative models to assess soil loss by gullying (Motoc. M. et al., 1979; Radoane Maria et al., 1995; Ionita I., 1998).

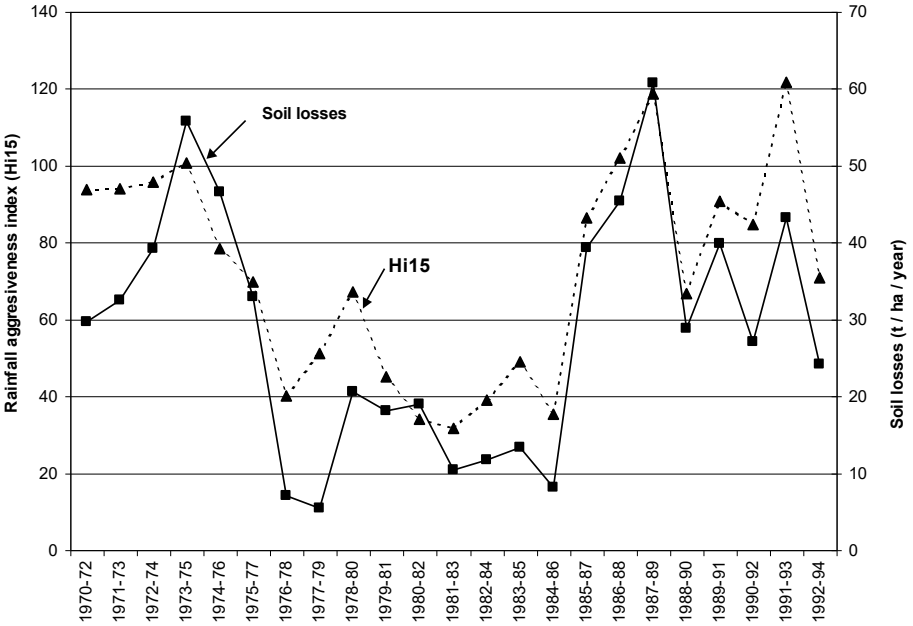


Figure 2 Rainfall aggressiveness and soil losses under continuous fallow for the period 1970-1994 (moving average by three years)

Mihaiu et al. (1979) studied the development of gullies under control structures and Pujina D. (1997) focussed the attention on landslide processes and the appropriate control methods. Significant contributions on land treatments at basin scale with agricultural use are attributed to Baloiu V. (1980).

Over the last decades, valuable research on quantitative geomorphology came out (Balteanu D., 1983; Ichim I. and Radoane Maria, 1986; Radoane Maria et al., 1999; etc.).

3.4. Implementing conservation practices

The strategy of soil conservation in Romania had in view that the vegetation is generally the most effective means of water erosion control while the constructions are an auxiliary component.

As a result of many of experience and the collection of much research data, the following erosion control practices were recommended for contouring, strip cropping, buffer strip cropping, terracing, using crop

residues, establishing permanent vegetation in eroded areas, stabilising gullies with suitable structure, subsurface drainage, land modelling, etc. Of this practices it should be mentioned the bench terraces for vineyards and orchards.

The bench terraces, which reduce land slope, were first time constructed at Perieni Research Station by adapting the method used in the United States. The design of a terrace system involves the proper spacing and location of terraces. On the basis of construction most of them were built from the upper side only (Havreliuc A. and Ouatu O., 1971). Later, during 1980s they wee constructed from the lower side, especially (Roman I. et al., 1988). The two major types of bench terraces are level terrace and the graded terrace. Both types are alike on that they are used to control water and reduce erosion. They differ in that the level terrace is used to conserve moisture in semiarid regions or in areas having permeable soils, whereas the gradient terrace is used for the orderly disposed of surplus water.

Terraces by steps, concurrently constructed with the primary very deep ploughing, as those from Valea Calugareasca and Bilcesti were implemented in all Romanian wine and fruit plantations (Mihalache L., 1972; Mihaiu et al. 1985).

In 1954, the Control Research Station for Soil Erosion Control (CRSSEC) was set-up at Perieni, near Barlad city, in the Moldavian Plateau of Eastern Romania. Its major purposes were to enhance the study of erosion processes, to elaborate prescriptions for land planning, to implement conservation tillage and practices and to be fully effective in applying technical training. Through the time, the territory of CRSSEC Perieni of 2,160 ha encompassed three types of small watersheds as representative scale models for soil and water conservation on sloping land. Shifting analysis toward crop yields over the time, Table 5 is indicating a remarkable increase of yield levels after implementing conservation measures.

In the implementing of conservation practices the Designing Section for Soil Erosion Control within the Institute for Studies and Designing of Land Reclamations - Bucharest and every county office for land treatments were deeply involved. Noticeable results on the designing of erosion control practices have been reported in the following counties: Arges, Bacau, Brasov, Buzau, Cluj, Constanta, Salaj, Suceava, Vaslui and Vrancea.

Table 5 - Crop yields in Gheltag watershed from Perieni Station.

Crop	Crop yields - kg/ha			
	Before land treatment	After implementing conservation practices		
		Strip cropping	Buffer strip cropping	Terraces
Wheat	800-1500	3150-5740	3210-5712	3591-5575
Corn	800-1200	6340-8500	6240-8114	6112-8014
Peas	400- 800		1350-2325	1120-1450

The Department for Land Reclamations of the Ministry for Agriculture including the county offices was very efficient in controlling soil erosion. Also, from 1960 to 1990 many graduated individuals with different farming organisations provided a valuable contribution in implementing conservation practices.

Discussion

Until 1960, the traditional system on sloping agricultural land in Romania consisted in up-and-down hill farming. Some 85 percent of this land was excessively split in small plots, each of less than one hectare in size. The tillage operations were made by animal traction, by hand and there was no any input of chemical fertiliser. If adding the local natural conditions a high risk of erosion was resulting. Excepting local areas there was no concern about soil erosion threat and a minimum awareness of conservation practices.

After the Second World War despite some complicating factors, scientists have approached the problem of assessing damage to soil productivity from erosion.

Since 1960, the awareness of soil erosion and adopting conservation practices has been progressively increased because it was the "right thing to do". The area under those small plots was turned into co-operative farms. About 15 percent of the agricultural land, which belonged to proper farmers regarding the ownership size, was changed in state farms. Practising conservation involves changes, all of which have costs. Nationwide, the first important objective was to perform ploughing on or nearly on the contour as one of the oldest and simplest conservation tillage. Then, based on the experience gained by CRSSEC Perieni, in each hilly county was set-up a representative farm under conservation practices. The total area of those particular units amounted to 65,000 hectares.

By the end of 1999 as much 2.2 million hectares, representing 30 percent of the agricultural land with erosion potential, were adequately protected against erosion. In some regions, the approach of best management practices resulted in appropriate erosion control at basin scale such as: Arges, Middle Olt, Bistrita, Barlad, and partly Mures, Buzau, Putna, Milcov basins. Annual expenditure in conservation projects was state investment as unreimbursable funding.

It should be mentioned that over the period 1960-1975 the main concern was focussed on dam structures within drainage network, especially on gullies. Between 1975-1990 the priority was given to implement proper conservation practices on slopes.

The new landed property law no. 18/1991 includes two provisions which are not of a nature to create conditions for the extension of conservation measures. One of these stipulates that the land reallotment has to be usually done on the old sites. This means in most cases that the plots will be up-and-down the hill led out. The second is referring to the successors' right up to the fourth degree! That enables an increasing rate of land splitting which is higher than that before the Second World War and the allotment of about 2 million people who never had a connection with agriculture. Moreover, right now it was just promulgated another law, no.1/2000, which has in view the forestland splitting on a large area for private ownership.

The major effect of the above-mentioned laws is revival of the old traditional agricultural system. So, the up-and-down hill farming is on the screen again. Ownership boundary lines interfere with conservation tillage and practices. It is not surprising that small plot layout is a significant obstacle to voluntary erosion control. Another problem for the last decade is that the state ceased funding for soil erosion control and this investment does not represent a priority for landowners.

Figure 3 can provide an evidence of the strong impact of Law no.18/1991 on agricultural practices and soil erosion/deposition (Ionita I. and Margineanu R., 1999).

During 1982-1985 appropriate conservation practices were implemented in the upper Racatau basin, mostly used as cropland. After 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 Caesium-137 that shows two peaks. The first pick 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-and-down hill farming. The mean

deposition rates rose from 5.0 cm/yr. for the period 1986-1992 to 10.0 cm/yr. over the period 1993-1996.

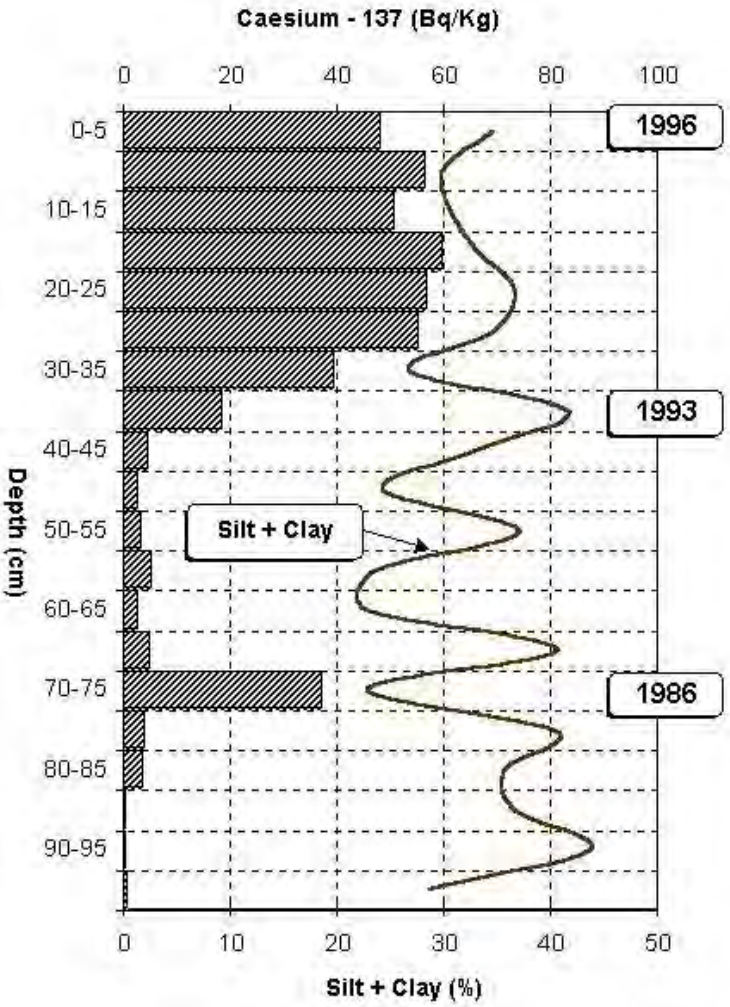


Figure 3 Depth distribution of Caesium-137 and silt+clay content in the Bibiresti reservoir, Upper Racatau basin, Romania - May 13, 1997

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.

Therefore, it might be concluded that activity of real soil erosion control in Romania extended over 30-year period, from 1960 to 1990.

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CONSERVATION TILLAGE ON SLOPING LAND IN ROMANIA

NISTOR DOINA, NISTOR DUMITRU AND HURJUI COSMIN

Abstract: This paper aims to provide a contribution to improving corn farming on slopes by new tillage methods. The basics of these methods is to leave sufficient crop residue on the soil surface to significantly reduce soil erosion and, which involve less energy than conventional tillage.

Over the period 1992-1998 different tillage treatments were considered. During 7-year experiment the influence of soil protecting methods on bulk density, penetration resistance, available water reserve, soil and water losses, nutrient losses and corn yield was studied, as well.

In comparison with the unprotected variant (moldboard) the others (chisel and no-till) have slightly influenced the bulk density.

As regards soil compaction, the vegetation conditions for corn either get worse, when ploughing is converted by chiselling or it has to give up at moldboard.

The available water reserve on 0-100 cm depth was influenced during July, a critical month for corn, by the widely range in soil tillage and the amounts of crop residues on the surface.

Partial soil tillage and leaving about 50 percent of wheat stubble (chisel) on the soil surface resulted in decreasing soil losses by 28 percent. Direct corn planting in wheat stubble reduced soil losses up to 68 percent versus conventional farming.

Key words:
Conservation tillage, conventional tillage, bulk density, penetration resistance, soil and water losses, corn yield.

1. Introduction

Soil erosion represents on long-term the most severe threat for mankind and the environment. The amount of sediments with a high percent of nutrients, delivered from the agricultural land and carried by rivers in seas and oceans, increased from 9 billion tons/yr before intensive soil cultivation to 24 billion tons/yr (*, **, Motoc M. et al., 1975). Erosion has played, and continuous to play, a major role in gradual impairing the soil productivity and has a strong impact on dam structures, roads, economic objectives and others. Damages from sedimentation tend to be cumulative.

So far as known, of a total agricultural area of 14.96 million hectares in Romania, around 6.37 million hectares (43%) are susceptible to water erosion of varying degree and associated processes. Of this area, nearly 2.6 million hectares are used for cropland (arableland). The average amount of the annual total erosion is 126 million tons of which 106.6 million tons are delivered by agricultural lands. Surface erosion (sheet-rill-erosion) is the

main contributor to the total erosion because the annual rate of such induced soil loss is estimated to 61.8 million tons (Motoc M., 1983).

2. Materials and Methods

Over the period 1992 -1999 the following factors were considered:
Factor A: keeping the soil surface under mulch

a_o = unprotected (stubble incorporated by ploughing, conventional);

a_1 = partly protected (chisel);

a_2 = protected under wheat stubble (no-till).

Factor B: seedbed preparation

b_o = by rotary tiller (broadcast tillage);

b_1 = direct planting (strip tillage)

The experimental site lies on mollisols (cambic chernozem), moderately eroded, and the slope is 10-12 percents. Within the cultivated topsoil the nutrient content is as follows: 2.33% organic matter, 0.105% total nitrogen, 0.039% total phosphorus and 80.2 ppm of the same layer is around 23%.

The study was initiated inside a three-year crop rotation of peas-winter wheat -corn. Under plots planted to wheat and peas the conventional tillage was applied. An amount of 75-80 kg phosphorous a.s./ha and 110-120 kg nitrogen a.s./ha has been used by chemical fertiliser. The experiment was set up according to the split-plots method in four repetitions.

3. Results

3.1. Influence of the soil - protecting methods on bulk density

The bulk is a relative independent feature that offers information to characterise the physical status of the soil that can not be usually inferred from other features. A hand auger Eijkelkamp equipment for sampling in soil was used to determine the bulk density. Measurements were performed after corn planting in 1995, 1996 and 1997 during early May. By analysing data included Tables 1, 2 and 3 it is possible to find that the rate of the bulk density occurred. That difference was statistically assured. Bulk density is one of the main indicators of soil tilth and a major contributing factor in the formation of many others soil characteristics. High values of the water storage capacity, the permeability, the aeration and increasing mechanical resistance to the penetration of roots into soil.

Table 1. Influence of the soil - protecting methods on bulk density over the period May 1995 - May 1997

Base tillage	Bulk density g/cu.cm	Difference	%	Significance
Unprotected (Plowed, check plot)	1.47	-	100.0	-
Partly protected (chisel)	1.50	0.024	101.6	**
Protected in wheat stubble (No-till)	1.53	0.057	103.9	***

LD 5% = 0.008; LD 1% = 0.013; LD 0.1% = 0.038

Table 2. Influence of the seedbed preparation methods on bulk density over the period May 1995 - May 1997

Seedbed preparation	Bulk density g/cu.cm	Difference	%	Significance
Rotary tiller (broadcast)	1.49	-	-	-
Planted in stubble (strip)	1.51	0.021	101.4	***

LD 5% = 0.009; LD 1% = 0.014; LD 0.1% = 0.022

Table 3. Influence of the seedbed preparation methods depending of the type of base tillage on bulk density over the period May 1995 - May 1997

Base tillage	Seedbed preparation	Bulk density g/cu.cm	Difference	%	Signifi-cance.
Unprotected (Plowed, check plot)	Rotary tiller (broadcast)	1.47	-	100.0	-
	Planted in stubble (strip)	1.48	0.055	100.4	-
Partly protected (chisel)	Rotary tiller (broadcast)	1.49	-	100.0	-
	Planted in stubble (strip)	1.51	0.021	101.4	*
Protected in wheat stubble (No-till)	Rotary tiller (broadcast)	1.51	-	100.0	-
	Planted in stubble (strip)	1.55	0.037	102.4	**

LD 5% = 0.015; LD 1% = 0.023; LD 0.1% = 0.038;

3.2. Influence of the soil-protecting methods on penetration resistance

In order to asses the state of soil compaction depending of the tillage measurement on the tillage measurements on penetration resistance were carried out under the plots planted in corn at a depth of 0-30 cm over the period 1995-1997 both in May at the beginning of the crop stage and in July as a critical period. Different implements of tillage had significant and very significant influenced the penetration resistance as shown in Tables 4, 5, 6, 7, 8 and 9. Renunciation at ploughing led to the increase of cone resistance from 606 Kpa to 1,010 Kpa. It should be mentioned that according to the data provided by Canarache A. (1990)) there is no any limitation on the growth of corn root system for values of the penetration resistance under 2,500 Kpa.

Direct planting through wheat stubble by use of proper drill has caused in the tilled resistance by 23.5 percent, statistical assured. As a general conclusion it is possible to assess that as the penetration resistance increases gradually, so likewise the rate of soil tillage decreases. However, this augment is not of a nature to deteriorate the growing conditions of the corn root system.

The values of penetration resistance are 2-3 times as great during July as those recorded in May.

Table 4. Influence of the soil - protecting methods on penetration resistance over the period May 1995 - May 1997

Base tillage	Penetration resistance (Kpa)	Difference	%	Significance
Unprotected (Plowed, check plot)	606	-	100.0	-
Partly protected (chisel)	747	+141	123.3	**
Protected in wheat stubble (No-till)	1010	+405	166.8	***

LD 5% = 55; LD 1% = 90; LD 0.1% = 232

Table 5. Influence of the seedbed preparation methods on penetration resistance over the period May 1995 - May 1997

Seedbed preparation	Penetration resistance (Kpa)	Difference	%	Significance
Rotary tiller (broadcast)	705	-	100.0	-
Planted in stubble (strip)	870	+165	123.5	***

LD 5% = 54; LD 1% = 81; LD 0.1% = 131

Table 6. Influence of the seedbed preparation methods depending of the type of base tillage on penetration resistance over the period May 1995 - May 1997

Base tillage	Seedbed preparation	Penetr. Resist. (Kpa)	Difference	%	Signif icance
Unprotected (Plowed, check plot)	Rotary tiller (broadcast)	590	-	100.0	-
	Planted in stubble (strip)	621	+31	105.2	-
Partly protected (chisel)	Rotary tiller (broadcast)	679	-	100.0	-
	Planted in stubble (strip)	814	+135	119.8	*
Protected in wheat stubble (No-till)	Rotary tiller (broadcast)	845	-	100.0	-
	Planted in stubble (strip)	1176	+331	139.1	***

LD 5% = 93; LD 1% = 141; LD 0.1% = 227

Table 7. Influence of the soil - protecting methods on penetration resistance for the period July 1995 - July 1997

Base tillage	Penetration resistance (Kpa)	Difference	%	Significance
Unprotected (Plowed, check plot)	2015	-	100.0	-
Partly protected (chisel)	2169	+154	107.6	**
Protected in wheat stubble (No-till)	2788	+773	138.4	***

LD 5% = 755; LD 1% = 1083; LD 0.1% = 1249

Table 8. Influence of the seedbed preparation methods on penetration resistance over the period July 1995 - July 1997

Seedbed preparation	Penetration resistance (Kpa)	Difference	%	Significance
Rotary tiller (broadcast)	2372	-	100.0	-
Planted in stubble (strip)	2276	-95	96.0	***

LD 5% = 252; LD 1% = 381; LD 0.1% = 612

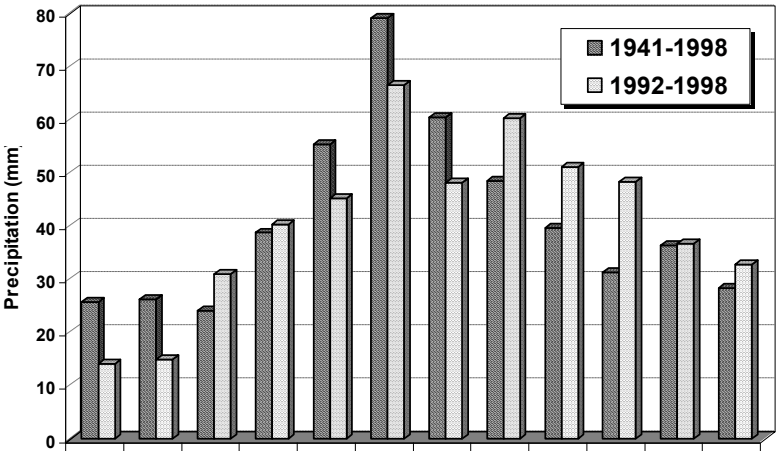
Table 9. Influence of the seedbed preparation methods depending of the type of base tillage on penetration resistance for the period July 1995 - July 1997

Base tillage	Seedbed preparation	Penetr. Resist. (Kpa)	Difference	%	Signifi-cance
Unprotected (Plowed, check plot)	Rotary tiller (broadcast)	2042	-	100.0	-
	Planted in stubble (strip)	1988	-54	97.4	-
Partly protected (chisel)	Rotary tiller (broadcast)	2129	-	100.0	-
	Planted in stubble (strip)	2209	+79	103.7	-
Protected in wheat stubble (No-till)	Rotary tiller (broadcast)	2944	-	100.0	-
	Planted in stubble (strip)	2633	-311	89.4	-

LD 5% = 436; LD 1% = 660; LD 0.1% = 1060

3.3. Influence of the soil-protecting methods on the available water capacity

Over the experimental period 1992-1998, during active growing season for corn, the mean monthly precipitation did not exceed the multiannual values as illustrated in Figure 1.



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1941-1998	25,6	26,1	24,0	38,7	55,3	79,1	60,4	48,4	39,5	31,3	36,4	28,4
1992-1998	14,0	14,9	31,0	40,2	45,2	66,5	48,1	60,2	51,0	48,3	36,6	32,6

Figure 1. Normal monthly total precipitation

In comparison with mean multiannual values the highest difference occurred in July, the most critical month for water requirements by corn, as shown in Table 10.

Table 10. Influence of the soil-protecting methods on the available water capacity at a depth of 0-100 cm, in July, over the period 1993-1998

Base tillage	Available water capacity (cu.m/ha)					
	1993	1994	1995	1997	1998	Average
Unprotected (Plowed, check plot)	395	743	733	477	-42	461
Partly protected (chisel)	272	652	665	324	-115	359
Protected in wheat stubble (No-till)	230	621	547	174	-283	258

In July 1998, the available reserve at a depth of 0-100 cm lowered below the coefficient of withering and had a strong impact on the level of corn yield.

As an average for the entire experimental period the value of available water reserve under the plowed plot in July exceeded by 102 cu.m/ha the chisel and 203 cu.m/ha the no-till plot, respectively. Those differences between tillage implements did not provide some assured statistical differences on corn yield (Moldenhauer W.C. et al., 1983, Hatfield J.L. et al., 1994).

3.4. Influence of tillage on water and soil losses

An experimental site consisting in standards runoff plots under different protecting methods entered into operation in Tarina catchement. Six plots are used, all with a tillage history, fully instrumented for measuring runoff and soil loss. The plots are 50 m by 8m (400 sq.m) and allow mechanical operation of the tillage. Seeding and tillage are perpendicular to the 13 percent slope.

Based on long-term data, illustrated in Table 11, it might be concluded that tillage leaving a protective cover of previous crop residue on the surface represent a new opportunity to control soil erosion (Triplett G.B. et al., 1976, Unger P.W., 1994).

Table 11. Influence of tillage on soil losses (1992-1996)

Base tillage	Erosion (t/ha)					
	1992	1993	1994	1995	1996	Average
Continuous fallow	18.2	26.2	-	19.4	23.3	18.4
Unprotected (Plowed, check plot)	4.7	17.1	0.8	8.0	13.8	8.9
Partly protected (chisel)	3.3	24.4	-	0.6	3.7	6.4
Protected in wheat stubble (No-till)	2.7	7.2	-	0.8	2.1	2.6

Substitution of ploughing (conventional tillage) by chisel planting, without turning over the surface around 50 percent of previous crop residue, resulted in soil losses under the tolerable limit of 6-8 t/ha, annually.

By renunciation to ploughing shifting to a particular drill for direct corn planting in wheat stubble soil losses were reduced by 70-80 percent. Results obtained within this experimental site allowed estimating the runoff ratios for each new treatment under corn as shown in Table 12. Thus, values of the runoff ratios ranged from 0.28 under conventional tillage and 0.16 where no-till was used. These date are of interest to design

of the conservation practices, assessing and predicting soil erosion, as well.

3.5. Influence of the soil-protecting methods on nutrient losses

Within the above mentioned, experimental site the nutrient losses have been determined for the first time in Romania under non-conventional tillage. Also, a great concern was focused to establish the rate of nutrients losses through water and soil, respectively (see Table 13). In average, over the period of study, the organic matter varied between 58.9 kg/ha under no-till plot and 407.0 kg/ha in the check plot-continuous fallow. In comparison with the chisel planting reduces the organic matter loss by over 30 percent and direct corn planting in wheat stubble reduces that value by 75 percent.

Nitrogen losses, in average, ranged from 3.2 to 20.3 kg/ha. In the plot under chiselling the losses were lowered by 50 percent and in no-till plot by 77 percent that of those occurred conventional tillage. About 80-95% of the average nitrogen losses is associated to sediment transport and the rest of minor importance through runoff.

The available phosphorous losses were low, generally, and ranged from 0.9 to 5.2kg/ha. If compared with the conventional tillage outputs, the no-till treatment resulted in reducing these losses by 80 percent. Of these, over 80 are associated with the sediment transport.

As regards potassium losses the situation is almost similar with that of phosphorous excepting the higher contribution through runoff of 20-40 percent, in the formation of these losses.

3.6. Influence of the soil-protecting methods on corn yield

By analysing the average corn yields for the period 1992-1998 it is possible to notice that there were not occurred significant differences between tillage treatments, as shown in Table 14. The highest yield of 5,030 kg/ha was obtained under chisel planting that confirms the existing world results, especially from U.S.A.

In most experimental years, there was a tiny difference between the two treatment methods of seedbed preparation. Table 15 illustrates that during the 7- year period an average variation of 320 kg/ha in the favour of the broad tillage occurred but this was not significant. It is of a great interest to underline the protection offered by the undisturbed wheat stubble between corn rows to the sloping land.

4. Discussion

- Results obtained during the 7-year experimental period were influenced by the climatic conditions, especially the rainfall, and changes induced by the studied factors, as well.
- In comparison with the conventional tillage (unprotected by crop residue), the other tillage treatments (chisel and no- till) have influenced the bulk density to a small extent. The explanation results from both the soil properties, where the experiments carried out, and the freeze-thaw impact on soil profile.
- Penetration resistance is an appropriate indicator for describing the conditions offered by tilled layer to the growth of the corn root system. During crop stage, the penetration resistance tends to increase, correlated with the momentary moisture, bulk density and clay content of the soil.
- Partial processing of the soil and leaving about 50 percent of wheat stubble on the surface (chisel) resulted in reducing soil losses by 28 percent. Direct corn planting in stubble wheat reduced soil loss by 68 percent than in conventional tillage.
- The corresponding runoff ratios are as follows: 0.28 under continuous fallow, 0.26 in conventional tillage, 0.19 under chisel and 0.16 for no-till.
- Conservation tillage systems also reduce nutrient losses. Of these, over 93 percent at organic matter, over 83 percent at phosphorous and over 60 percent at potassium are lost through eroded soil.
- Corn yield was not influenced significantly by the different soil-protecting methods.

Results obtained during a 7-year period confirm that conservation tillage systems represent a viable and promising alternative for soil conservation and protection of the Romania environment.

Table 12. Influence of tillage on runoff over the period 1992-1996

Tillage	Annual rainfall and runoff (cu.m/ha)												Runoff ratio
	1992		1993		1994		1995		1996		Average		
	Rain*	Runoff	Rain*	Runoff	Rain*	Runoff	Rain*	Runoff	Rain*	Runoff	Rain*	Runoff	
Continuous fallow	563	160.5	1595	369	-	-	788	154.0	1175	476.0	824.2	231.9	0.28
Unprotected (Plowed, Check)	563	197	1595	384	309	32.5	609	115.2	1175	401.7	850.2	226.1	0.26
Partly protected (chisel)	337	52.0	1125	379	-	-	268	17.0	942	120.2	534.3	101.6	0.19
Protected in wheat stubble (No-till)	337	61.0	793	180	-	-	268	22.0	753	78.5	430.2	68.4	0.16

* Rainfall that caused runoff

Table 13. Influence of tillage on the mean nutrient losses for the period 1992-1996

Tillage	Humus kg/ha	Nitrogen loss			P_2O_5 loss			K_2O loss		
		Total Kg/ha	Water %	Soil %	Total Kg/ha	Water %	Soil %	Total Kg/ha	Water %	Soil %
Continuous fallow	407.0	20.3	4.6	95.4	5.2	10.2	89.8	4.7	20.8	79.2
Unprotected (Plowed, Check)	231.6	13.4	19.1	80.9	4.5	13.7	86.3	3.8	43.3	56.7
Partly protected (chisel)	148.6	6.8	8.7	91.3	1.6	10.5	89.5	1.6	32.2	67.8
Protected in wheat stubble (No-till)	58.9	3.2	10.2	89.8	0.9	15.3	84.7	0.7	38.3	61.7

Table 14. Influence of base tillage on corn yield (1992-1998)

Base tillage	Corn yield (kg/ha)							Average		Differ.	Sign.
	1992	1993	1994	1995	1996	1997	1998	Kg/ha	%	Kg/ha	
Unprotected (Plowed, Check)	4630	7220	3030	1340	6170	6910	4750	4860	100.0	-	-
Partly protected (chisel)	4490	6780	3030	2430	6530	7270	4700	5030	103.5	+170	-
Protected in wheat stubble (No-till)	4010	6050	2640	3250	6680	7230	4420	4320	88.9	- 540	-

LD 5% = 1050 kg/ha

Table 15. Influence of seedbed preparation methods on corn yield (1992-1998)

Seedbed preparation	Corn yield (kg/ha)							Average		Differ.	Sign.
	1992	1993	1994	1995	1996	1997	1998	Kg/ha	%	Kg/ha	
Rotary tiller (broadcast)	4510	7080	3080	2420	7400	7120	4060	5090	100.0	-	-
Planted in stubble (strip)	4240	6290	2720	2260	5520	7150	5190	4770	93.7	-320	-

LD 5% = 630 kg/ha

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THE USE OF SOME GIS TECHNIQUES TO STUDY GULLIES AND LANDSLIDES DISTRIBUTION IN EASTERN ROMANIA

COSMIN HURJUI, DOREL PUJINA

Abstract: Previously made inventories of classical gullies and landslides in the Moldavian Plateau (25,000 sq. km) have been considered as dependent (dychotomous) variables in a graphical multivariate analysis. The maps of multiannual temperatures, precipitation, geology, human encroachment by deforestation and hillslopes orientation were taken into account as independent variables.

Several GIS techniques like crossclasification (crosstabulation) of images, overlay, regression, multiple (logistic) regression have been performed in order to estimate the influence of some independent variable on gullies and landslides areal distribution.

Keywords: gullies, landslides, GIS techniques

Introduction

Land degradation phenomena, gullies and landslides, are important sources of concern in Eastern Romania, because of their role in siltation of rivers and reservoirs and because of their economical consequences, especially in agriculture. The Moldavian Plateau as referred here comprises an area of about 25,000 square kilometers, between Siret and Prut rivers, both of them tributaries from the left to the Danube.

Usually classical gullies and landslides were considered as case studies in order to assess causes of initiation and trends of development. The first important geomorphological inventory of gullies (about 9000 gullies), based on a gridding method, was done by Maria Radoane, N. Radoane and I. Ichim (1992, 1995) (Figure 1). Landslides in certain watersheds of the Central Moldavian Plateau and Barlad Tableland, mainly on the territory of Vaslui County (about 1000 landslides in a 5,300 sq. km territory), were surveyed by Savopol L. (1974), Ivanciu A. (1982) and Pujina D. (1992). Both gullies inventory and the landslides survey have been realized in a classical manner, "manually" using topographical map sheets at a scale of 1:25,000, without any help of computers. On each topographic sheet a 1 km^2 square grid was drawn. For each case the following variables were taken into consideration: number of gullies, length, maximum width and maximum depth, gully orientation, slope, length, and relief energy of gullied hillslopes, as well as the distance from gully head to water divide.

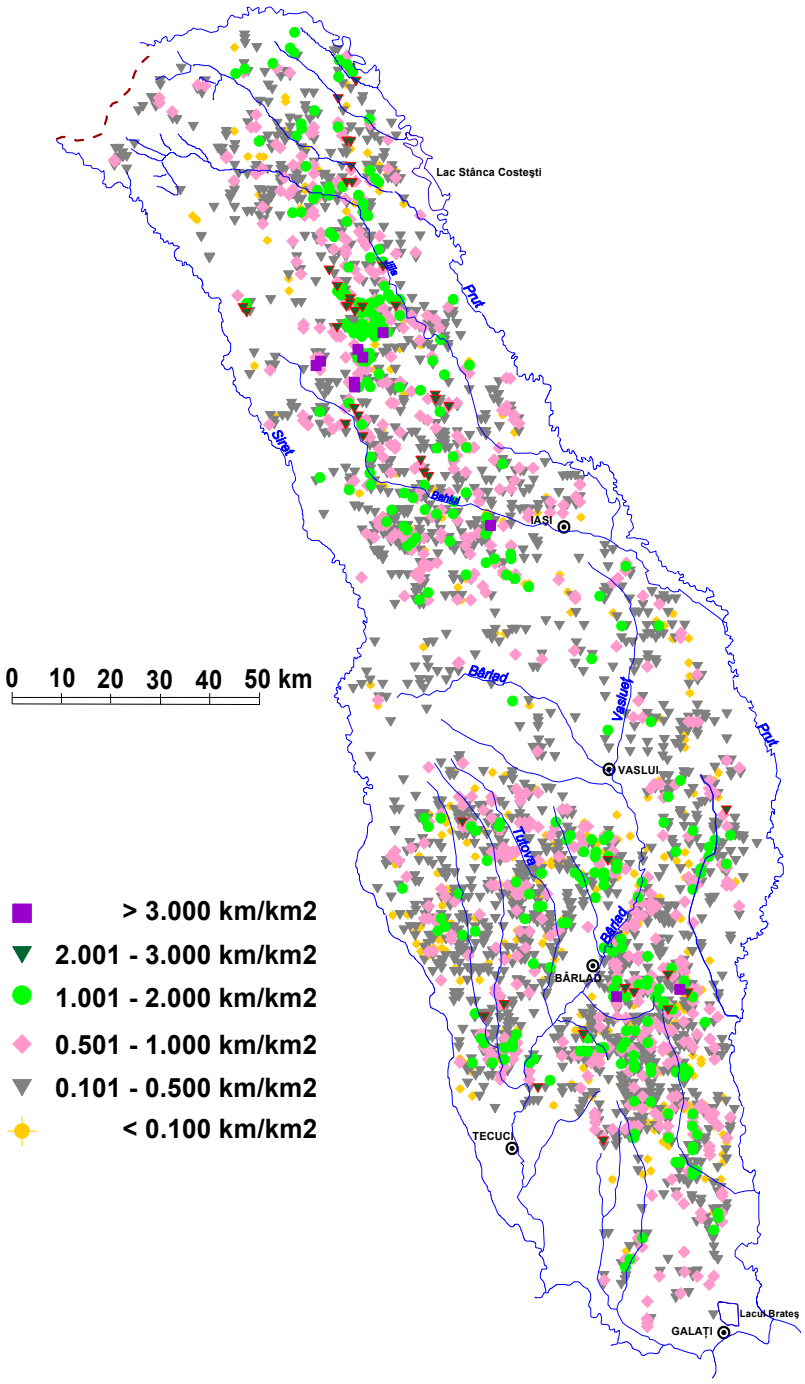

Fig. 1 Distribution of gullies in the Moldavian Plateau – Eastern Romania (After Maria Radoane, Radoane N., Ichim I., 1992 and 1995)

The study area is characterized by weakly consolidated bedrock belonging to Sarmatian (in most cases) and Pliocene (in the Southern region). From the north to the south there occur the geological complexes of Buglovian - Basarabian (*marls and clays*), of Chersonian (*clays, marls and sands*), of Meotian (*clays and sands with interlayers of limestones*), of Pontian and Romanian (*sands and gravels*). The overall geological structure is that of a monocline with layers having the general slope of 5 - 8 m/km, from NW-SE. Thin loessial deposits of maximum 10 meters cover as a venere this structure, sometimes being present only as witnesses of erosion. Soil horizons have metrical thickness in the valley fills, sometimes cut by valley floor gullies. The depth of gullies is temporarily limited by the depth of two lithological layers with special resistance to penetration and cohesion properties: one is the soil horizon B_t and the other is a green sandy clay (Hurjui C., 2000). In some areas of Barlad Tableland (Vaslui County) the green sandy clay has a regional significance.

Some of the main conclusions of the mentioned authors are as follows:

- The number of gullies per km^2 is between 2 and 4, with a maximum of 20 gullies per km^2; average density is between 0.1 to 1 km per km^2, with a maximum length value of over 3 km per km^2.
- The main dimensions of gullies in the Moldavian Plateau are: L = 170 m, D = 3.5 m and B = 12 m.
- The areas with the highest susceptibility of gully initiation in Moldavia are at the intersection of following factors: hillslope orientation towards NW and SE, respectively (hillslopes of consequent valleys), slope inclination between 20 to 30 %, slope length between 300 and 500 m and a dominantly sandy lithology.

With such dimensions and areas of 7140 sq. m one may note that gullies practically cannot be seen on maps with scales of 1M, like we use in this approach. That is why Figure 2 shows the distribution of gullies by density of pixels of 1 sq. km. Usually, gullies cover only 1 – 2 % of the area in Figure 2, and situations are extremely rare when they cover areas like 1 pixel of 1 sq. km.

The situation is different in the case of landslides from Vaslui County, when they are visible at their original scale even on plans of 1M. Pujina D. and Hurjui C. have analyzed landslides in many watersheds within a perimeter of about 5300 sq. km, that covers approximately Vaslui County, the central and south-central area of the Moldavian Plateau. A data base containing data about landslides since 1830, rain, thunder and earthquakes was updated. Pujina D. has mainly described the variability of landslides by

Fig. 2 Distribution of gullies in the
Moldavian Plateau – Eastern Romania

the time series technique and the matrix cube. The conclusions that are important for this approach are:

- The great majority of landslides phenomena (82.5 %) took place between 150 – 300 m altitude, with a preference for areas upper than the weighted average of the region, of 257 m.

- The weighted relief energy of the perimeter is of 196 m. In comparison with that figure, the landslides were more frequent on hillslopes with 150 – 300 m relief.

- In the north eastern part of the territory, the landslides were developed mainly on hillsides with slopes between 15 – 35 %.

Method

Both maps showing the distribution of gullies in Eastern Romania are exaggerated at this scale, but they suggest that gullies are grouped in three main areas: a northern one on Jijia and Bahlui watersheds and two in the south, one superimposed on Tutova Rolling Hills (SW) and the other on Falciu Rolling Hills (SE). The original maps resulted both from the gullies and the landslides inventory were digitized at their original scale, of 1:25,000 and 1:10,000, respectively. A digital elevation model at the scale of 1M was constructed by interpolating corresponding digitized contours. Other thematical maps like those of precipitation, temperatures, geological maps and map sheets of areas under forest at three moments were digitized too. We assume that if the "clouds" of great density of gullies are more or less similar in shape and dimensions with the spots at the same location in other thematical maps showing what we can consider independent variables, then the respective independent variable has a stronger or a weaker influence on distribution of the dychotomous dependent variable. In order to compare such independent variables with the distribution of gullies map, we gathered together many thematical maps from different sources, at the same scale and projection and the techniques of regression and multiple (logistic) regression were applied. This assumption is confirmed by the well known strong negative relationship between elevation and temperature, illustrated by the comparison between areas with the same elevation in the DEM and curves of the same temperature (Figures 3 and 4).

Results

The climatic factors of precipitation and temperature are among the main variables of the "landschaft", together with geology and relief. Overlaying the distribution of gullies map on precipitation (multiannual sum in mm of precipitation) and on maps of temperatures digitized from Clima RSR-IMH Atlas, 1969, (multiannual average values of temperatures) (Figures 3 and 5), the following results have been obtained (Table 1 and 2):

In both cases, over 90 % of the area belongs to two categories, 500-600 mm of precipitation and 8-9 ^{o}C. By the same time, 89.3 % of the total of 9184 gullies, and 97 % respectively belongs to the same two classes. Having a to small number of classes, we cannot consider the apparent strong parabolic relationship between precipitation, temperature and corresponding numbers of gullies ($y = -0.2236x^2 + 244.17x - 61573$ with $R^2 = 0.94$

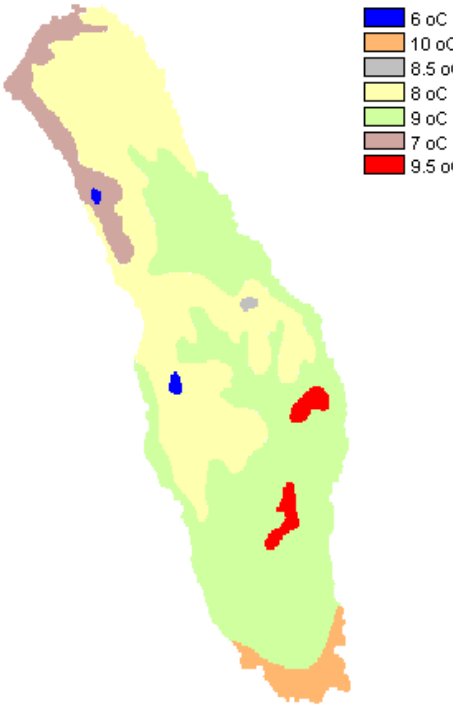

Fig. 3 Temperatures distribution in Eastern Romania, between Prut and Siret rivers (From Clima RSR-IMH Atlas, 1969)

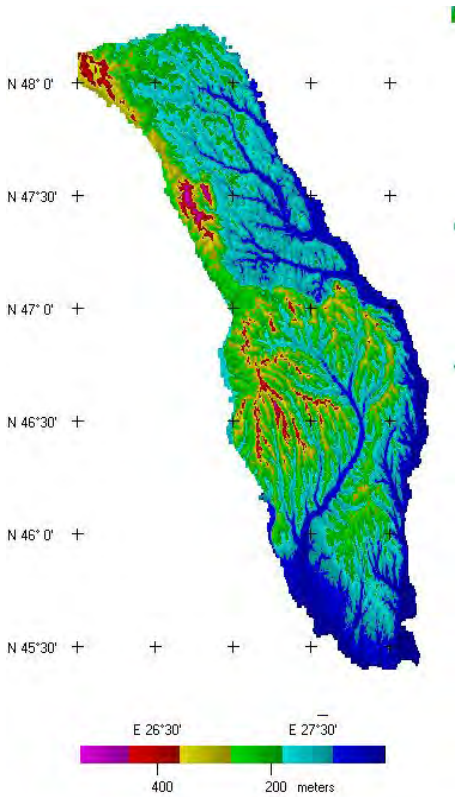

Fig. 4 Digital elevation model of Eastern Romania, between Prut and Siret rivers (from NIMA 2000)

Table 1 and 2

Precipitation (mm)	Gullies count	%
400	60	0.7
500	5389	51.0
600	3657	38.3
700	42	0.5

Temperature (°C)	Gullies count	%
7	167	1.8
8	2194	24.0
9	6650	73.0
10	137	1.5

for precipitation/gullies for example), but the squared R's indicate that precipitation has a stronger influence on gullies distribution than temperature. Actually, the hydrothermal coefficient (Zachar, 1982), calculated by Radoane Maria (1995) from the formula HTK = $(\sum R/\sum t)\cdot 10$, where $\sum R$ is the total annual precipitation and $\sum t$ is the daily summation of air temperatures above 10 °C, for the territory of Moldavia showed values

ranging from 1.5 in the east up to 2.5 in the northwest. This means that the whole area has a great susceptibility to gully erosion.

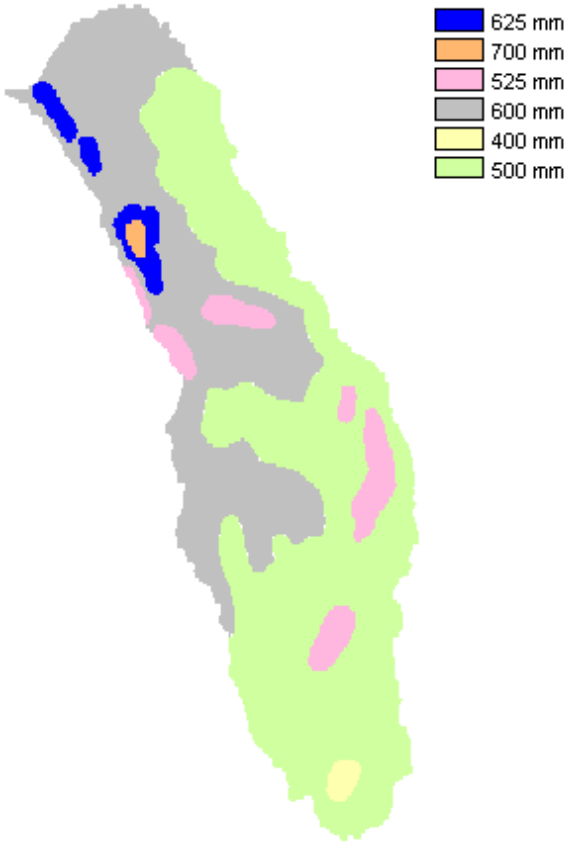

Fig. 5 Precipitation distribution in Eastern Romania, between Prut and Siret rivers (From Clima RSR-IMH Atlas, 1969)

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he territory of Eastern Romania was in the past heavily forested (an "official" figure promoted is of 75 %). Today, agriculture is the dominant land use and forests are only covering 17%. Overlaying maps from different sources of areas under forest at three moments, we have obtained the map in Figure 6. Note that all three maps are approximate for several reasons: the quality of historical documents regarding the period of antiquity, the scale of the present approach in which only great compact forests are shown and the fact that the difference between 1972 and the present days is not so great. However, they allowed us to learn the trends in the evolution of

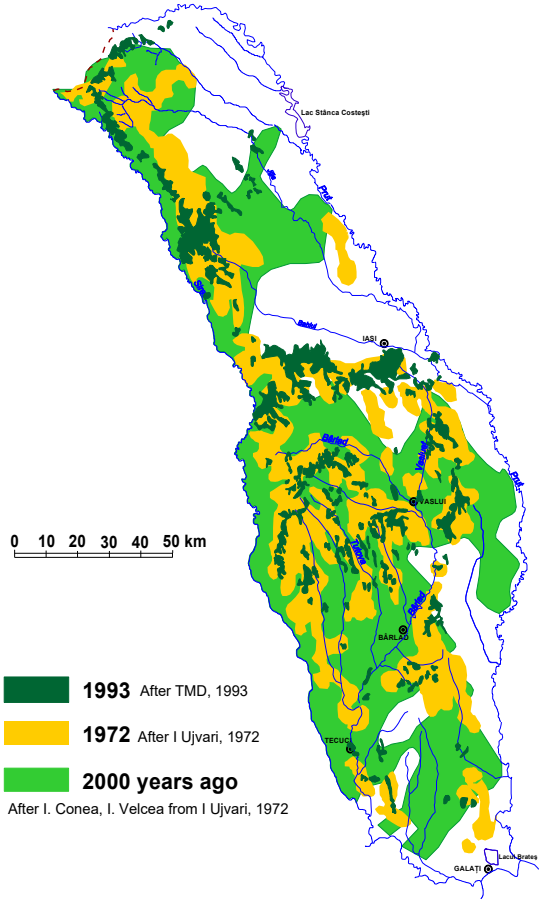

Fig. 6 Evolution of areas under forest in the Moldavian Plateau – Eastern Romania, between antiquity and 1993

forested areas over a long period of time. Our inquiry into forest change processes in the area revealed that the main trend was of changing forests to agricultural land, beginning from the lower elevations and going to the top of the hills. These processes took place from east to west in the northern part of the region, and from the edge of existing forests to their center in the south and south-central part.

Our expectations for gullies and landslides to appear mainly on deforested areas have been deceived. Only 3095 gullies (33.7 %) are located on deforested land and regression techniques yields only weak parameters of the relationship.

Another important variable from which we would expect to have a strong influence on gullies distribution is geology. Some opinion exists that there is a relationship between regional geological structure of the area

expressed as three grain size distribution indices characterizing three great domains of the same age and geomorphology of gullies. Due to this geological structure newer deposits (from Buglovian – Volhynian to Romanian and Pleistocene – Holocene) appear from north to the south. Northern – older deposits are assumed to be more clayey and the southern, predominantly sandy. We emphasize the fact that geological structure should better be expressed in terms of geostatistics in order to characterize such great areas.

In our approach, we have taken into account only the most recent deposits, the most erodable ones. From two geological maps only deposits of Pontian, Dacian, Romanian age, and thin loessial Pleistocene deposits were extracted (Figure 7). Initially, we have assumed that the pattern of

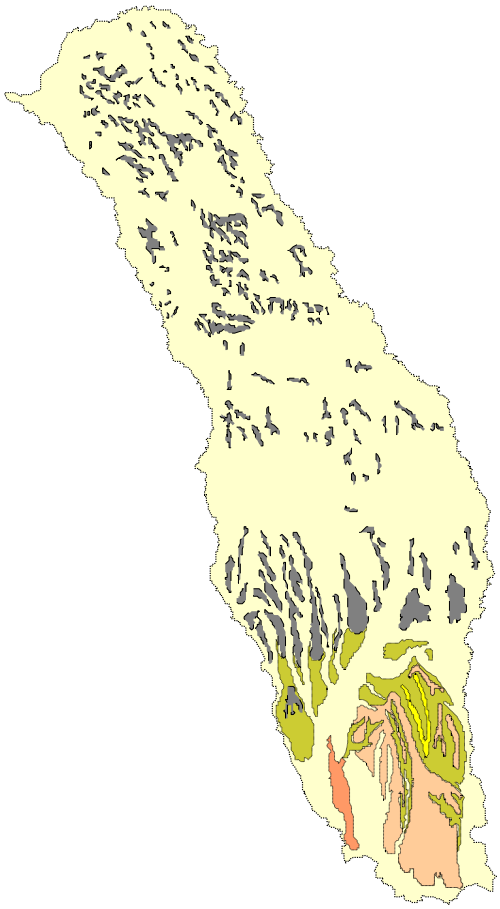

Fig. 7 Deposits of Pontian, Dacian, Romanian age (south) and loessial Pleistocene extracted from the geological map of Eastern Romania

these geological layers is the most likely to be superimposed on the map of distribution of gullies in the Moldavian Plateau, because such deposits together with soil horizons are firstly eroded. Experience also shown that, for this particular region, the evolution of gullies deeper than 3.5 m is limited, at least temporarily, by two lithological layers (Hurjui C., 2000). Once again, only 2847 (31 %) gullies have been developed on deposits this young. A possible explanation is that most of the gullies are not located on the top of the hills occupied by loessial witnesses of erosion.

Being a combination of vertical incision and gravitational bank processes, gullies seems to have a different pattern of their distribution in Eastern Romania, firstly on valley floors and secondarily on hillsides, in comparison with landslides, which are mainly located on hillsides.

Many geomorphologists stated that hillslope orientation is one of the most important variables influencing gullies and landslides distribution.

Hillslopes with northeastern orientation are considered by Radoane M. as the most susceptible of gullying. In Figure 8 we have chosen hilslopes with western, eastern and northern orientations. The "zebra" maps were constructed by means of HILLSHADING module in a GIS package of software and by switching the color to black for the sunlit hillsides.

Westerly looking hilslopes are among the most susceptible to be affected by landslides. 4776 (52 %) gullies are located on easterly looking hillslopes (60 % NE after Radoane M.).

Because the overall geological structure is a SE balanced monocline, the north oriented hillslopes map illustrates the cuesta fronts. Actually, the influence of hillslopes orientation on gullies and landslides distribution must be considered as a geological variable, as well.

For the same reason, many valleys are assymetrical with westerly oriented hillslopes relatively more affected by landslides. 5.61 % of the entire surface of the perimeter (5,300 sq. km) is affected by landslides (Figure 9). The greatest one, Lunca, has 585 hectares, is developed in Basarabian – Chersonian deposits in the northern region of the territory, in Vasluiet watershed. The study perimeter has only 648 km^2 of forests (12.86 %). In some northern watersheds a much higher density of landslides occurs because of the existance of Basarabian marls and Chersonian lacustrine clays.

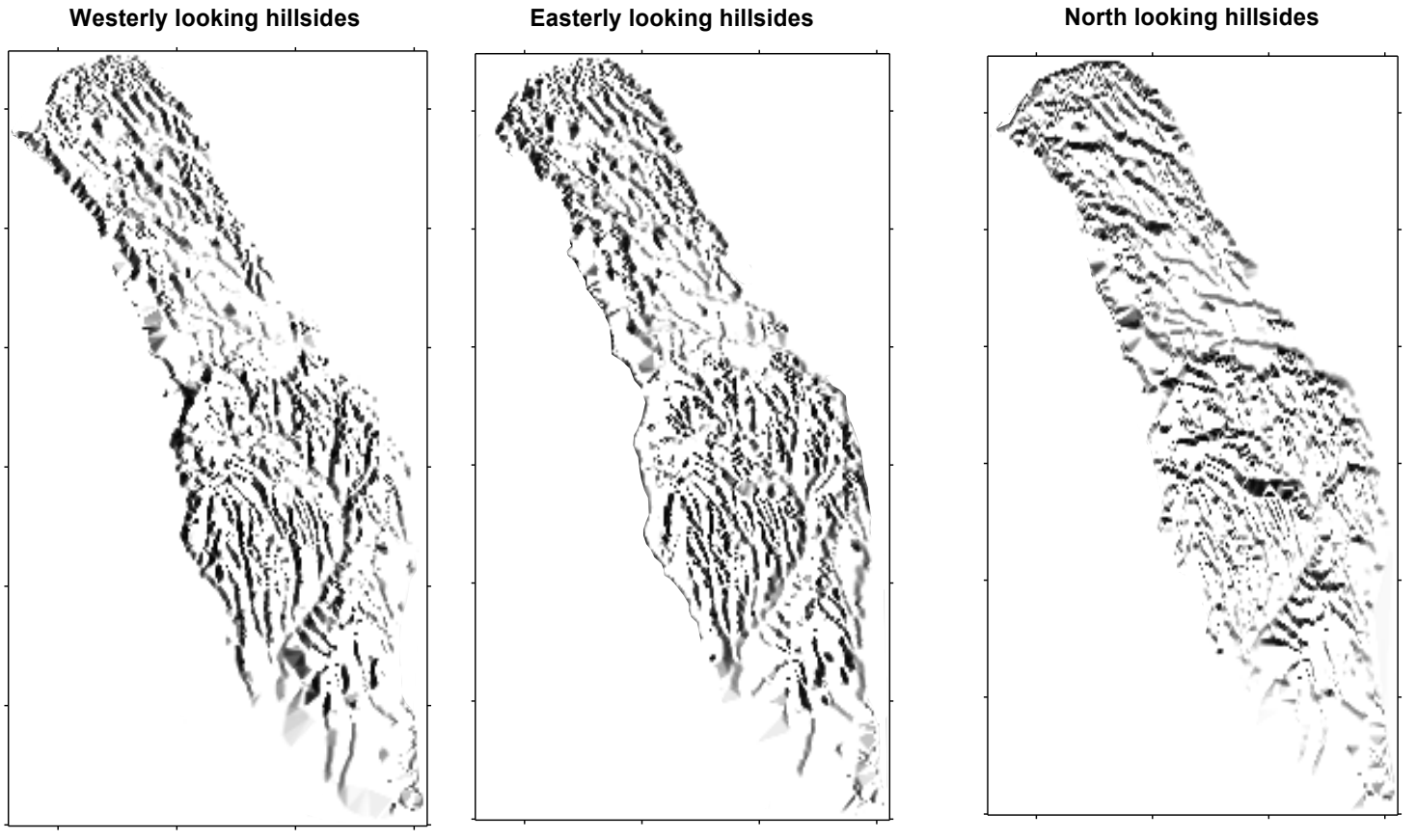

Fig. 8 Zebra maps of Eastern Romania showing hillsides orientation

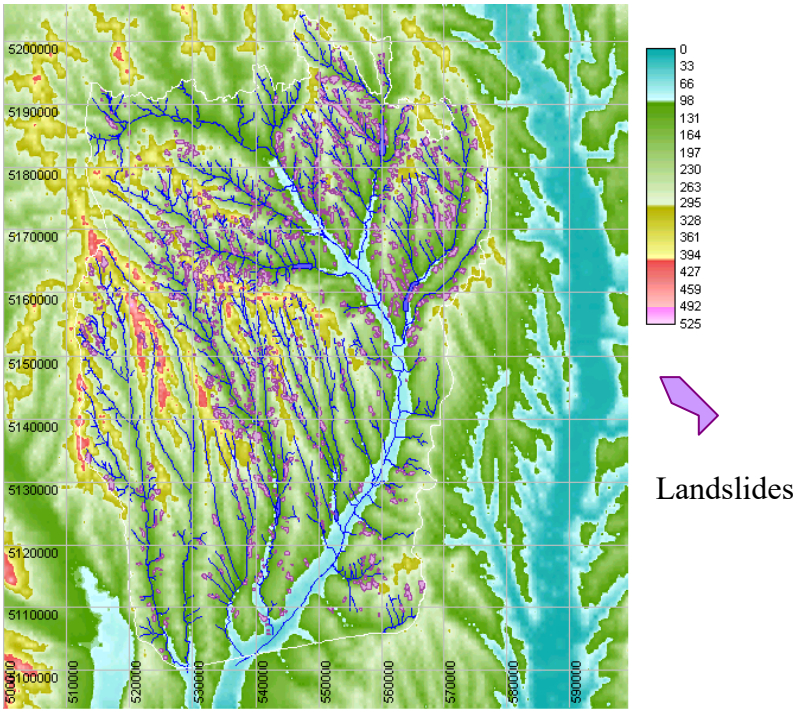

Fig. 9 Landslides map of Vaslui County (Barlad Tableland), Eastern Romania *The thin square grid is 10x10 km*

Conclusions

Several GIS techniques like crossclasification (crosstabulation) of images, overlay, regression, multiple (logistic) regression applied to some variables like multiannual temperatures, precipitation, geology, human encroachment by deforestation and hillslopes orientation were used to estimate their influence on gullies and landslides areal distribution. Over 9,000 gullies in a perimeter of 25,000 sq. km and 1,000 landslides in a perimeter of 5,300 sq. km were taken into account.

The climatic factors of precipitation and temperatures and hillslope orientation, as an expression of the overall geological structure of a SE balanced monocline, have proven to have the most important influence on areal distribution of gullies and landslides in Eastern Romania.

Surprisingly, human encraochment by deforestation over a long period of time (since antiquity till present days) and by changing of land use from

forest to agricultural land did not have the expected impact on land degradation by gullies and landslides.

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