USE OF CS – 137 IN SOIL EROSION AND SILTATION ASSESSMENT IN ROMANIA

Ion Ionita, Romulus-Mircea Margineanu

1. Introduction

Soil erosion and sedimentation processes are a serious threat since Romania has as much as 15 million hectares in agricultural fields. About 43 % (6.4 million ha) of it is sloping land with erosion potential.

This study was conducted in small watersheds on Moldavian Tableland, located in Eastern Romania. The field samples were analyzed at the Institute of Physics and Nuclear Engineering (IPNE), Magurele - Bucharest for measuring Cs – 137 activity and at Central Research Station for Soil Erosion Control (CRSSEC) Perieni - Barlad to determine other physical and chemical soil properties.

The main objectives are as follows:

- Measure water, soil and humus losses during rainy events under erosion plots;
- Measure Cs -137 specific activity in the same site;
- Establish relationships between soil and Cs – 137 losses;
- Evaluate siltation rates due to the floor aggrading of the discontinuous gullies by means of Caesium 137 inventory;
- Determine siltation rates on small reservoirs using Cs – 137 as a tracer.

2. Results obtained

2. 1. Surface erosion data

Field measurements on water, soil, 137 – Cs and humus losses have been conducted at Perieni Research Station in a small watershed, Tarina Valley. This basin is located in Tutova Rolling Hills which is a major geomorphological subunit of the Moldavian Tableland. Several plots are used, all with a cropping history, fully instrumented for measuring runoff and soil loss. They are cultivated with different crops as follows: corn, dry beans, winter wheat, bromegrass. The check plot is used as permanent fallow which is always free of weeds. The plots are laying out on loamy textured mollisoil. The plots are 25 m by 4 m (100 sq. m) with 1 m border areas between plots. The site has an average slope of 12 % and it is westlooking.

During 1997 there were recorded a variable number of rainy events that determined runoff only under dry beans, corn and continuous fallow. Data collected at these crops are presented in the tables no. 1 and no. 2. A strong relationship is emphasised by plotting individual soil versus Caesium – 137 losses as shown in figures no. 1 and no. 2.

2.2. Aggrading data on discontinuous gullies

The aggrading of the discontinuous gully floor represents an interesting erosional process. For a short term its trend is apparently a slight one but for a long term it gets a good significance. Anyway, in most cases the bed aggrading by very recent sediment is simultaneous with the proper gulling induced by gullyhead advance.

The study was conducted in several small watersheds from the neighbourhood of Perieni Station in order to determine the aggrading rate and the relation of the profile distribution of Cs-137 to organic matter and soil texture. For this report Roscani and Timbru basins have been selected. The floor of these discontinuous gullies is typical for what is called "***short diffusor***" as illustrated in figures 3 and 4. Soil samples from two gully heads have been contiguously collected, each by 5 cm thickness.

Data obtained on this study are shown graphically. Figure 5 illustrates a remarkably close association of aggrading rate with the major world nuclear events. According to this chart there are obviously three Caesium - 137 peaks:

- the major one (56.9 Bq/kg) placed at 25-30 cm depth, due to Chernobyl accident from April 1986;
- the second (9.2 Bq/kg) between 145-150 cm depth coinciding with the peak in bomb activity during the early 1960„s especially in 1963;
- the third (3.9 Bq/kg) placed at 170-175 cm depth due to increasing of fallout during the 1950"s more precisely in 1959.

If the temporal variation in annual 137 Caesium fallout for Milford Haven, UK (as cited by D. E. Walling and T. A. Quine, 1993) is taken into account it is possible to assess that the minimum value (2.0 Bq/kg) located at 100 – 105 cm depth was recorded in 1969. Under these circumstances, the temporal variation of 137 – Caesium activity in recent alluvium reveals a nonuniform running of mean annual aggrading rates as shown in figure 6. A close distribution was obtained by computing temporal variation of mean annual precipitation for daily rains over 40 mm each (figure 7).

Therefore, on the floor of discontinuous gullies in comparison with the average annual aggradation rate by 4.4 cm/year over the long period 1954-1996 (43 years) it is clear that:

- the first period of time (1954 – 1959) had a smaller rate by 25 %;
- the second period (1960 – 1969) by its higher value with 58 % represents the peak siltation stage;
- the third interval (1970 – 1985) is similar with the annual average;
- the last interval (1986 – 1996) shows the lowest aggradation rate and it is 42 % smaller than mean annual value.

In other terms, it is possible to separate the contribution of these typical periods to the siltation on 190 cm alluvial thickness:

- 10 % for the period 1954 – 1959;
- 37 % for the period 1960 – 1969;
- 37 % for the period 1970 – 1985 and
- 16 % for the period 1986 – 1996.

A mention must be made that the six years interval, 1964 – 1969, gets 24 % from the total aggradation.

Since the alluvial thickness is by 210 cm it means that the discontinuous gully head which determined gully floor siltation was located there 48 years ago (210 cm / 4.4 cm · year^{-1}). If plotting gully length of 43 m versus the above period of time, that means the annual gully head advance was by 0.90 m/year. This value is similar with the conventional evaluation made by I. Ionita (1998).

On Timbru watershed, Falciu Hills, have been observed only two Cs – 137 peaks:

- 139.5 Bq/kg at 25-30 cm depth from alluvial sediment belonging to 1986;
- 4.5 Bq/kg at 145-150 cm depth coinciding with the decline in fallout after the 1963 Nuclear Test Ban Treaty.

Lack of the third peak means that this gully appeared after 1959. Therefore, its average rates of aggradation with recent alluvium of gully floor are similar with Roscani site:

- 4.4 cm/year for the period 1963-1997 (long term average on 34 years);
- 5.0 cm/year for the period 1963-1986
- 2.7 cm/year after 1986.

The alluvial thickness in Timbru gully is of 163 cm and if dividing by 4.4 cm/year it means that the discontinuous gully head which determined gully floor siltation was placed there 37 years ago. So that, the annual gully head advance was by 0.85 m/year (gully length 31.4 m / 37 years) which is very close with previous site.

Table 1 - Water, soil, 137- Cs and humus losses during 1997 at Perieni, Romania

Dry beans plot

No.	Rain		Runoff c.m./ha	Runoff ratio	Sediment concentr. g/l	**Erosion** t/ha	**Caesium - 137**		Organic matter	
	Date	Ammount mm					Bq/kg	KBq/ha	%	Kg/ha
1	June 20	19.6	129.5	0.66	50.1	**6.493**	34.5	**224.0**	3.4	220.8
2	July 27	28.9	13.5	0.05	22.4	**0.302**	37.4	**11.3**	4.0	12.1
3	Aug. 03	48.7	76.0	0.16	11.0	**0.836**	33.4	**27.9**	3.7	30.9
	Total	**97.2**	**219.0**	**0.23**		**7.631**		**263.2**		**263.8**
Corn plot										
1	June 20	19.6	40.4	0.21	96.0	**3.878**	30.5	**118.3**	3.6	139.6
2	June 24	12.9	2.2	0.02	19.9	**0.044**	31.0	**1.4**	3.9	1.7
3	July 27	28.9	77.0	0.27	23.8	**1.832**	26.7	**48.9**	3.5	64.1
4	Aug. 03	48.7	138.5	0.28	26.1	**3.615**	31.5	**113.9**	3.8	137.4
5	Aug. 26	47.4	10.5	0.02	11.9	**0.125**	33.6	**4.2**	3.9	4.9
	Total	**157.5**	**286.6**	**0.17**		**9.494**		**286.7**		**347.7**

Table 2 - Water, soil, 137- Cs and humus losses under continuous fallow runoff plot during 1997 at Perieni, Romania

No.	Rain		Runoff c.m./ha	Runoff ratio	Sediment concentr. g/l	**Erosion** t/ha	**Caesium - 137**		Organic matter	
	Date	Ammount mm					Bq/kg	KBq/ha	%	Kg/ha
1.	June 20	19.6	155.2	0.79	145.7	**22.609**	32.9	**743.8**	2.8	633.1
2.	June 24	12.9	10.0	0.08	48.5	**0.485**	24.4	**11.8**	3.1	15.0
3.	July 26	27.8	14.0	0.05	76.0	**1.064**	33.3	**35.4**	2.8	29.8
4.	July 27	28.9	138.7	0.48	90.3	**12.525**	29.9	**374.5**	3.5	438.4
5.	Aug. 03	48.7	232.0	0.48	103.9	**24.105**	26.8	**646.0**	2.4	578.5
6.	Aug. 26	47.4	12.5	0.03	27.0	**0.337**	20.7	**7.0**	1.8	6.1
7.	Aug. 30	6.4	25.0	0.39	76.9	**1.922**	18.2	**35.0**	3.1	59.6
8.	Aug. 31	5.5	29.0	0.53	75.4	**2.187**	23.6	**51.6**	2.2	48.1
9.	Oct. 13	17.9	29.0	0.16	21.7	**0.629**	24.1	**15.2**	2.5	15.7
10.	Oct. 15	14.4	18.0	0.13	5.9	**0.106**	20.5	**2.2**	2.4	2.5
	Total	**229.5**	**663.4**	**0.29**	**99.4**	**65.969**		**1922.5**		**1826.8**

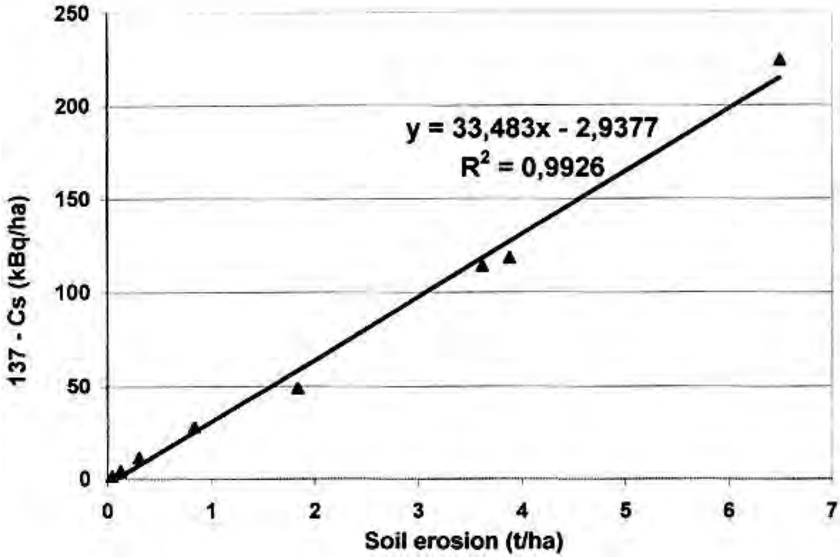

Fig. 1 Relationship of soil and Caesium –137 losses for dry beans and corn during 1997, Perieni-Barlad, Romania

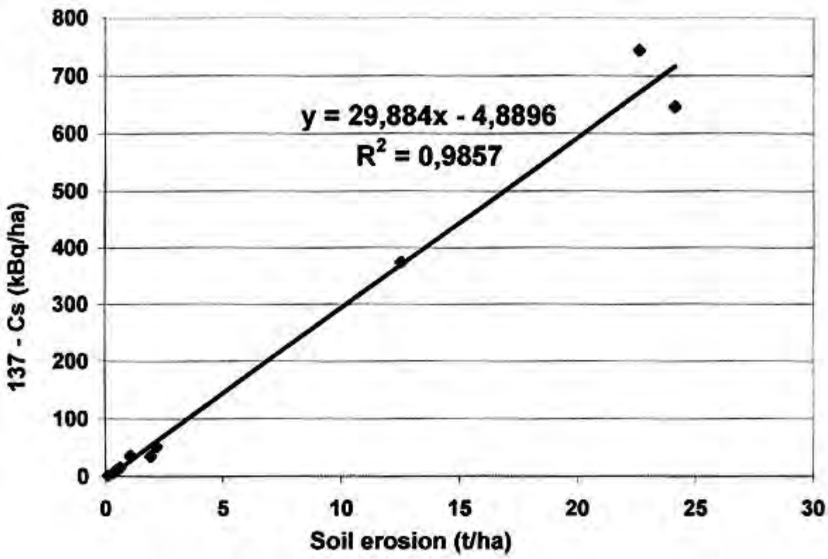

Fig. 2 Relationship of soil and Caesium –137 losses for continuous fallow during 1997, Perieni-Barlad, Romania

Fig. 3 Batteries of discontinuous gullies on Roscani Valley, near Perieni - Barlad, Romania

Fig. 4 Discontinuous gullies on Timbru Valley, Falciu Hills, Romania

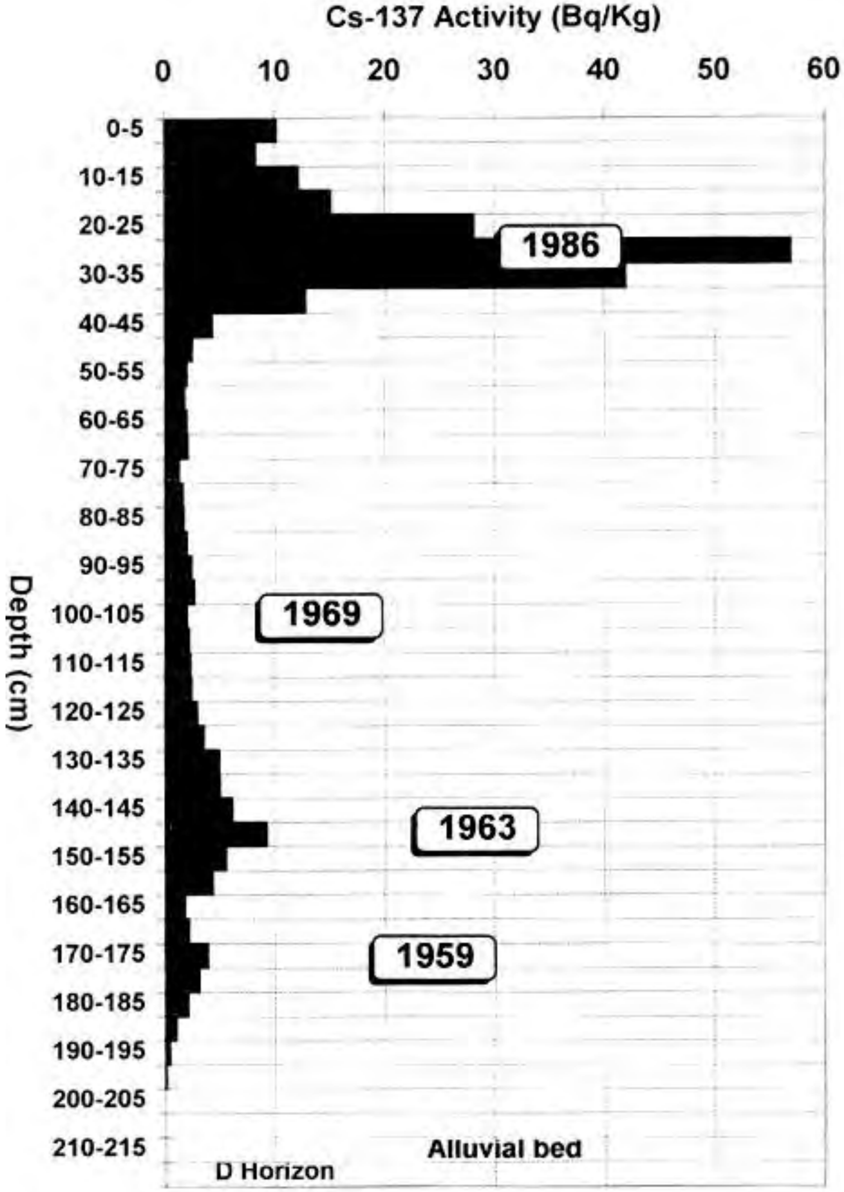

Fig. 5 Caesium - 137 distribution in the alluvial fill from the discontinuous gully head no. 4, Roscani Valley, Romania, 12.XII.1996

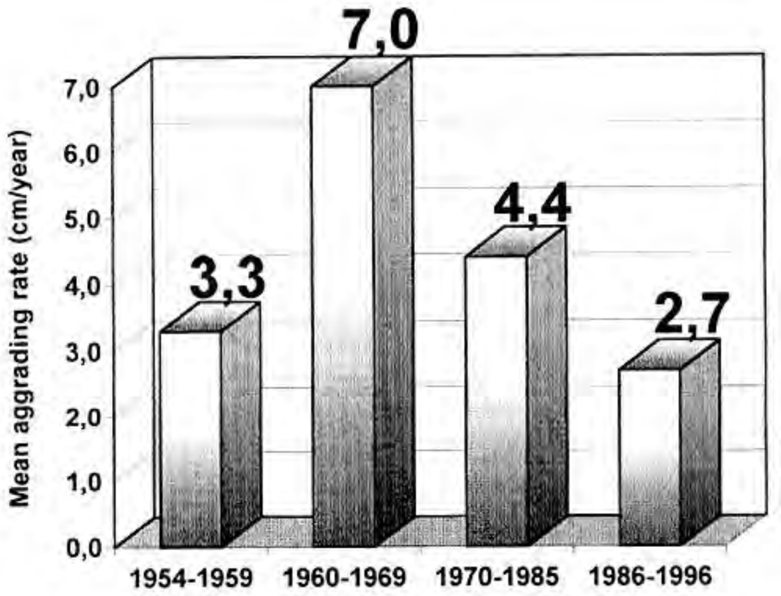

Fig. 6 Mean annual aggrading rate of a discontinuous gully floor on Roscani Valley, Tutova Rolling Hills, Moldavian Tableland – Romania

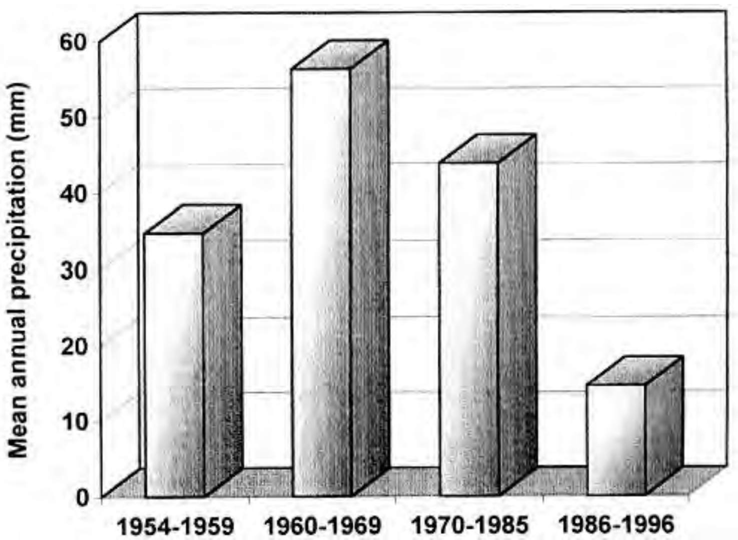

Fig. 7 Variation of mean annual precipitation for daily rainy events over 40 mm on Barlad, Romania (1954-1996)

Figures 8 and 9 do not illustrate a coincidence (similar profile distribution) between Caesium - 137 and organic matter peaks. The highest organic matter content in both sites it is placed in the upper part of the alluvium profile. The dry period of time after 1984 could be an appropriate explanation for a more intense bioaccumulation on the gully floor and for higher organic matter content.

As regards the relation of Caesium - 137 to soil texture there were recorded two cases: - a normal distribution of Caesium - 137 with the silty-clay curve in Roscani Valley (figure 10);

- an opposite distribution in Timbru Valley where the 137 - Cs peaks are coinciding with low values (minimum) for silty-clay content (figure 11). These situation would suggest that the effects of soil texture and the magnitude of the clay fraction must be considered as cited by Walling D. E. and Quine T. A. (1963).

2. 3. Siltation data on small reservoirs

Studies on siltation rates in reservoirs have been conducted in small watersheds covered by wooden soils.

For this report we came back at the Antohesti reservoir on Upper Berheci River to revise the Cs-137 distribution (figure 12). The previous report included a graph made by sampling with an Eijkelkamp auger kit in August 1996. During May 1997 a proper profile was digged in the same place, the tail of the initial lake, now filled with recent sediments (figure 13). In addition, it was possible to dig a partial profile in the upper part of the present lake which was emptied by water for a short period of time (figure 14).

This information is plotted on figures 15 and 16. For both sites the peak activity of Caesium - 137 is located between 55 – 60 cm depth. This means that the average siltation rate after Chernobyl accident was by 5.0 - 5.5 cm/year. Also, it is possible to assess the normal aggradation rate of the previous Berheci flood plain: 1.6 cm/year for the period between 1963 – 1984 (year of dam construction). It will be observed that when we are dealing with a mixed moisture condition (dry and wet in the area filled with sediments) the peak value is high enough (192.0 Bq/kg). But the highest peak value was occurred under lake condition rising up to 335.9 Bq/kg.

Figure 17 shows the Caesium – 137 distribution on Gaiceana reservoir. This is laying out in Hutu watershed which is by the same size (4665 ha) with the upper Berheci watershed. Area under woodland is by 46% in Hutu catchment and only 10 % in upper Berheci. In Gaiceana reservoir the Caesium – 137 peak value is placed at 70 – 75 cm depth (70.4

Bq/kg) and it is almost three times smaller than in Antohesti reservoir (192.0 Bq/kg). So that, the mean annual siltation rate by 6.4 – 6.8 cm/year is higher in Gaiceana reservoir. By the other hand, the Caesium–137 low values above "Chernobyl peak" are indicating that the main sediment source is channel network.

The rain pattern during May 1986 on Moldavian Tableland, Eastern Romania, could explain the differences regarding the magnitude of the Cs – 137 peak values. It is known that 1986 was a very dry year for Romania.

During late April there was no rain but around May 10 and 11 there were recorded small but significant rains: 13.1 mm in the upper Berheci, 7.0 mm in the Falciu Hills and 2.8mm in middle and lower Berheci. That is why the Caesium – 137 peak was by 190 – 336 Bq/kg on Antohesti area, 140 Bq/kg on Falciu Hills and 57 – 70 Bq/kg on the Lower Tutova Rolling Hills.

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IONITA I. (1998) *Geomorphological study of the land degradation on middle Barlad watershed*. Univ. of Jassy, Romania.

WALLING D.E. & QUINE T.A. (1993) *Use of Caesium-137 as a Tracer of Erosion and Sedimentation: Handbook for the Application of the Caesium-137 Technique.* Univ. of Exeter, UK.

NOTE: Article communicated at the Second Research Co-ordinated Meeting of Soil Erosion and Sedimentation CRPS - International Atomic Energy Agency, Vienna, Austria, 1998.

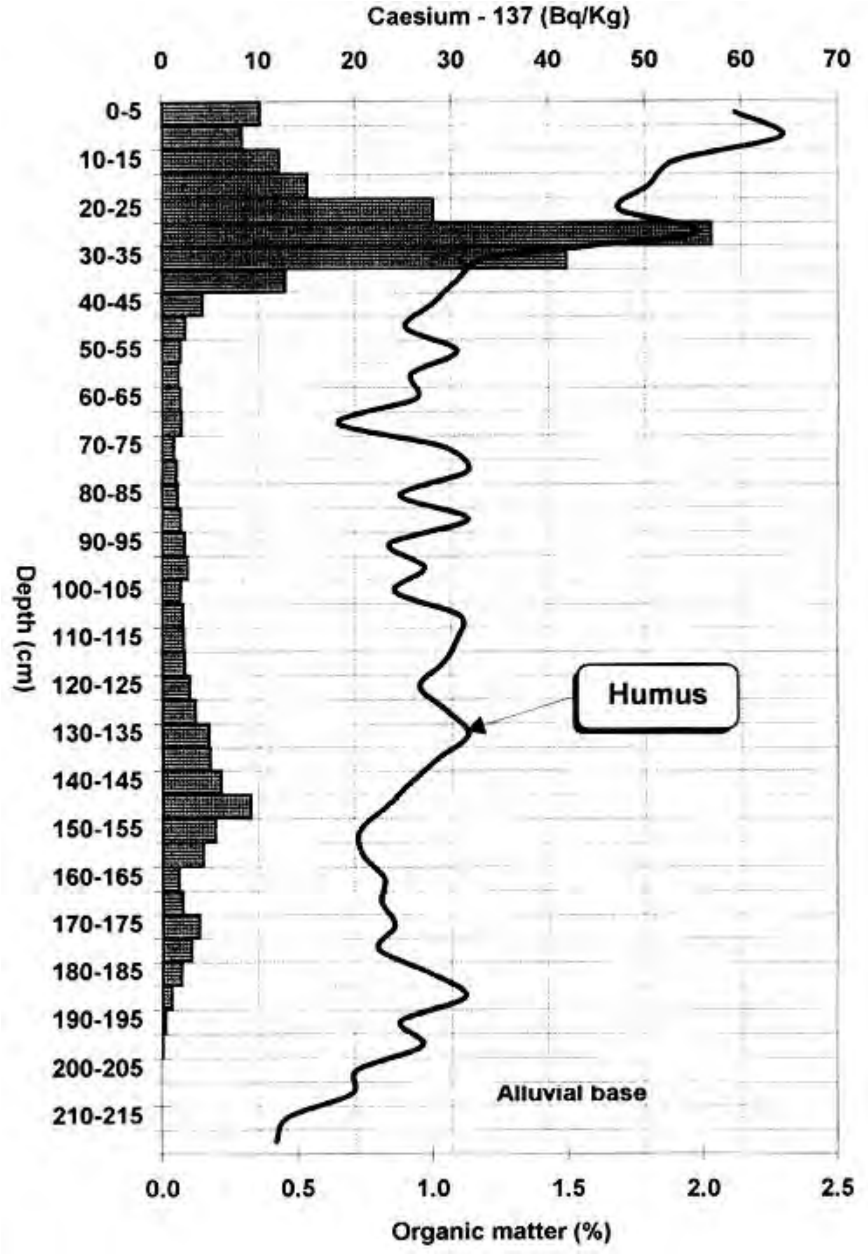

Fig. 8 Distribution of 137- Caesium and organic matter content in the alluvial fill from the gully head no. 4, Roscani Valley - Moldavian Tableland, Romania, 12.XII.1996

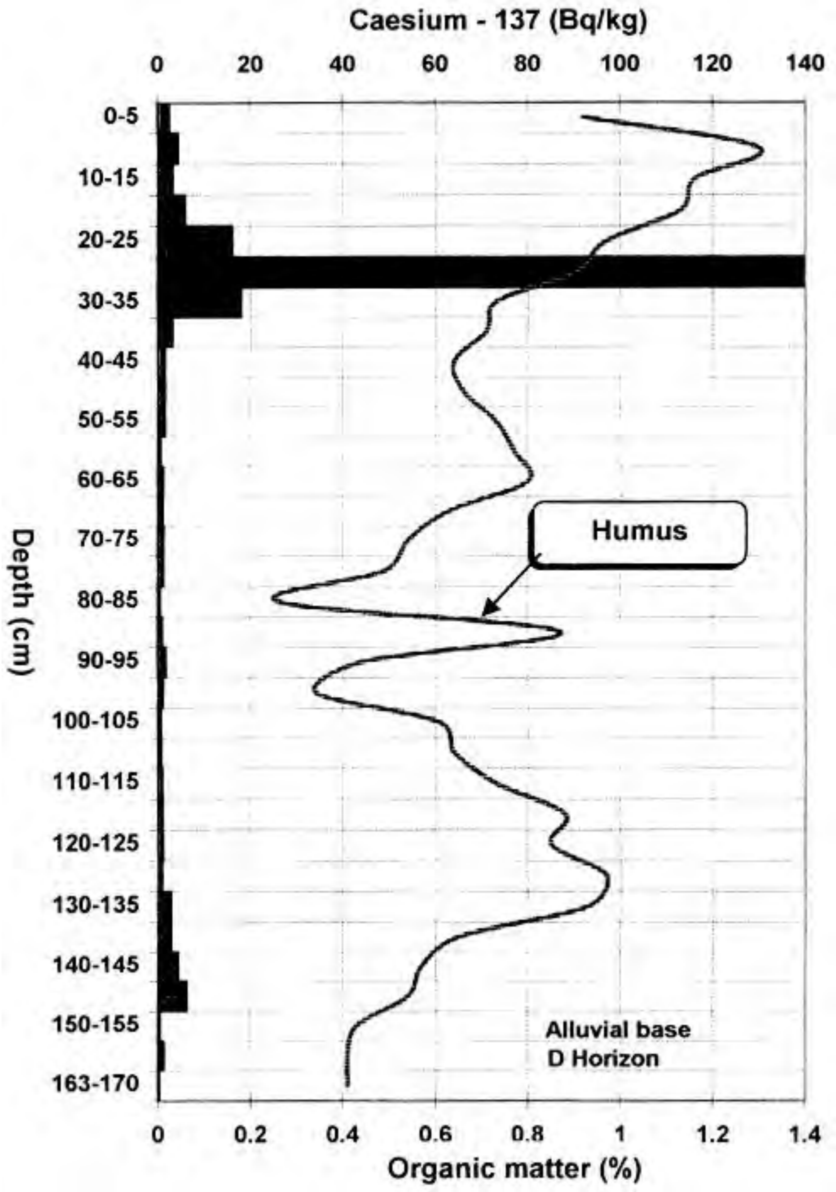

Fig. 9 Distribution of 137- Caesium and organic matter content in the alluvial fill from the gully head no. 8, Timbru Valley - Moldavian Tableland, Romania, 13.XII.1996

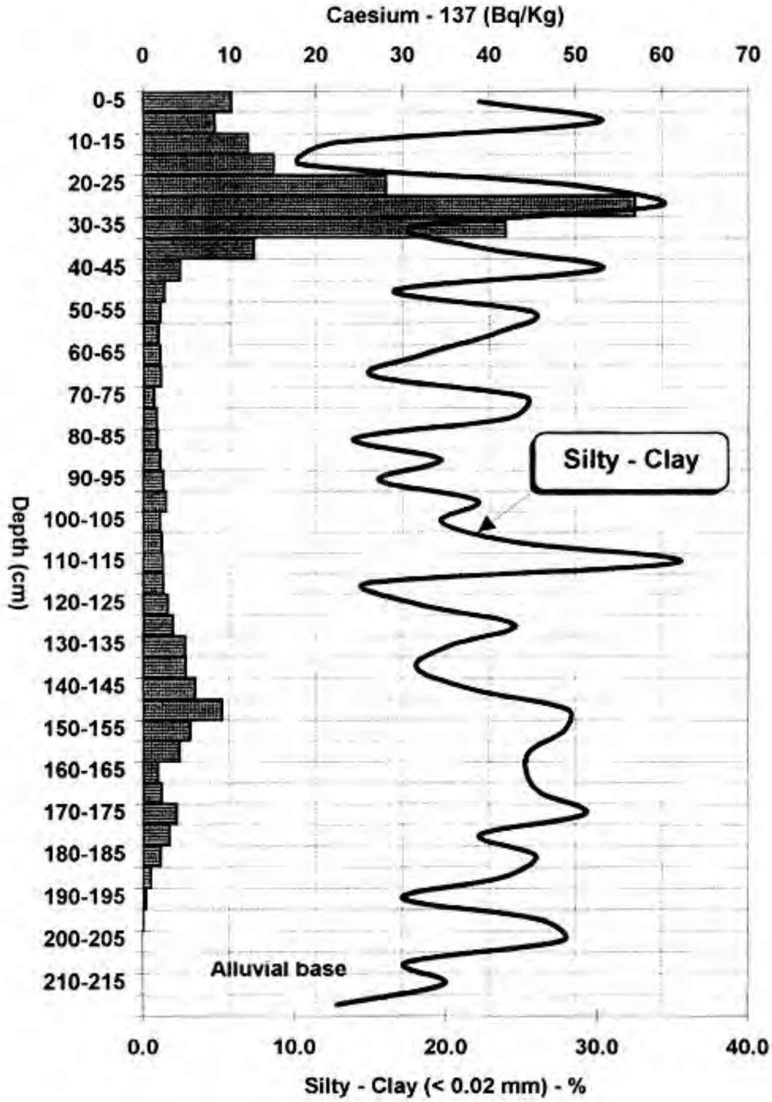

Fig. 10 Distribution of 137- Caesium and silty – clay content in the alluvial fill from the gully head no. 4, Roscani Valley - Moldavian Tableland, Romania, 12.XII.1996

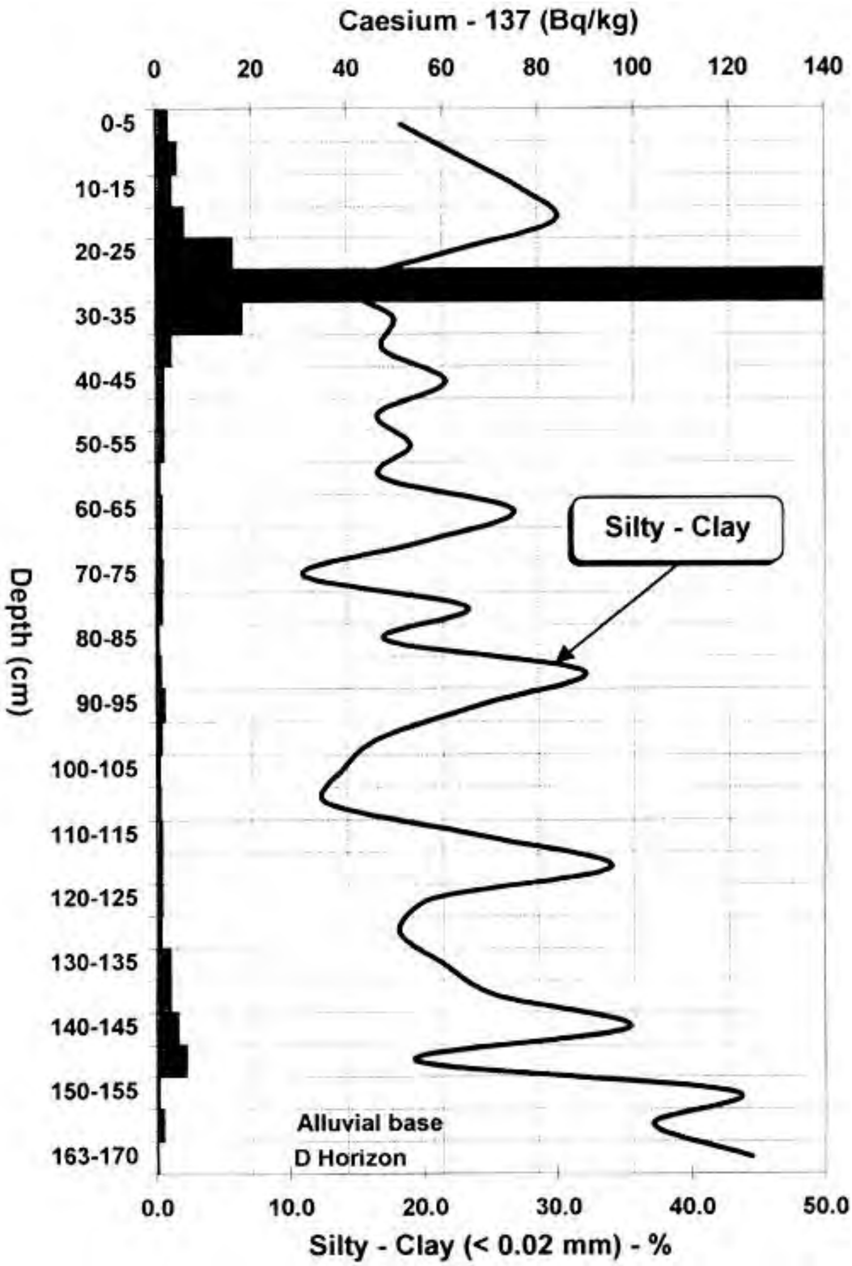

Fig. 11 Distribution of 137- Caesium and silty – clay content in the alluvial fill from the gully head no. 8, Timbru Valley - Moldavian Tableland, Romania, 13.Xll.1996

Fig. 12 The Upper Berheci Basin, Romania

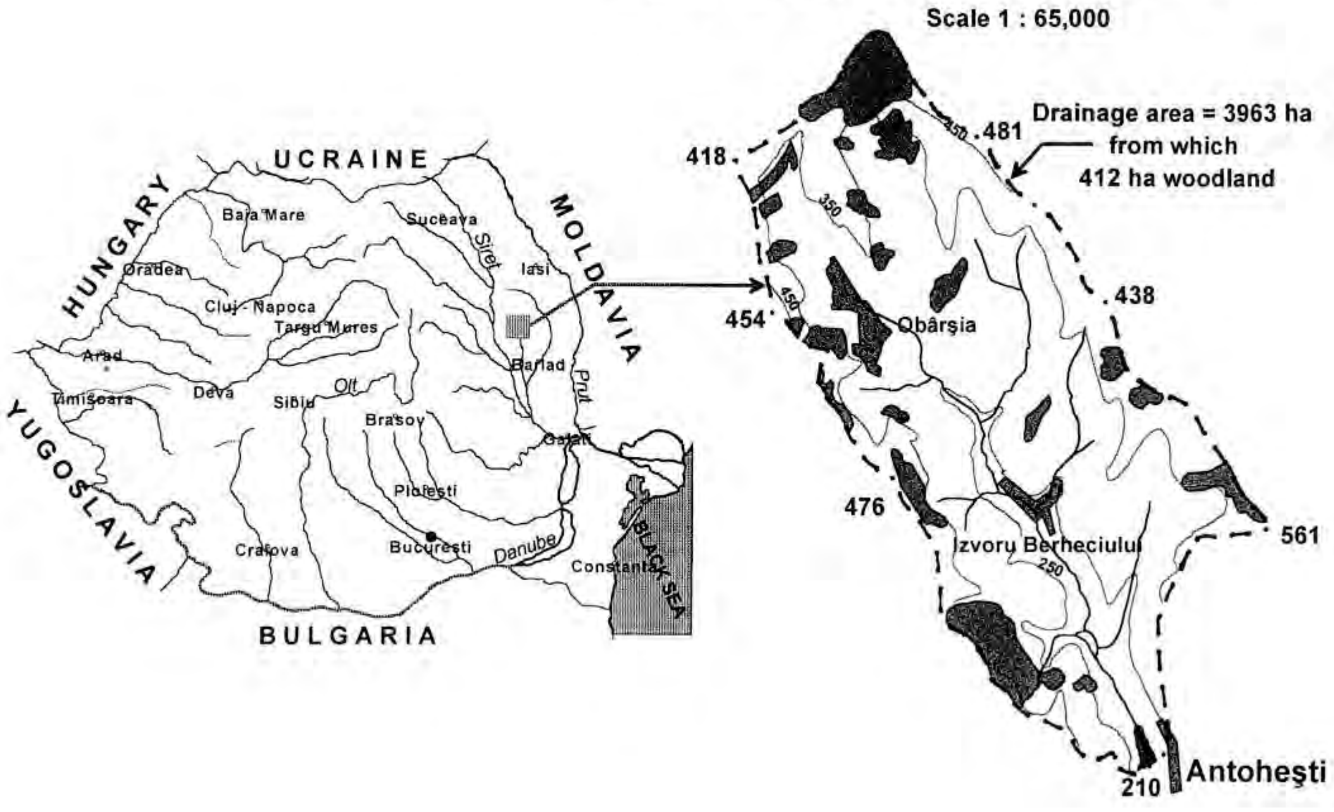

Fig. 13 Profile in recents sediments, Antohesti, Romania

Fig. 14 Antohesti reservoir during May 14, 1997

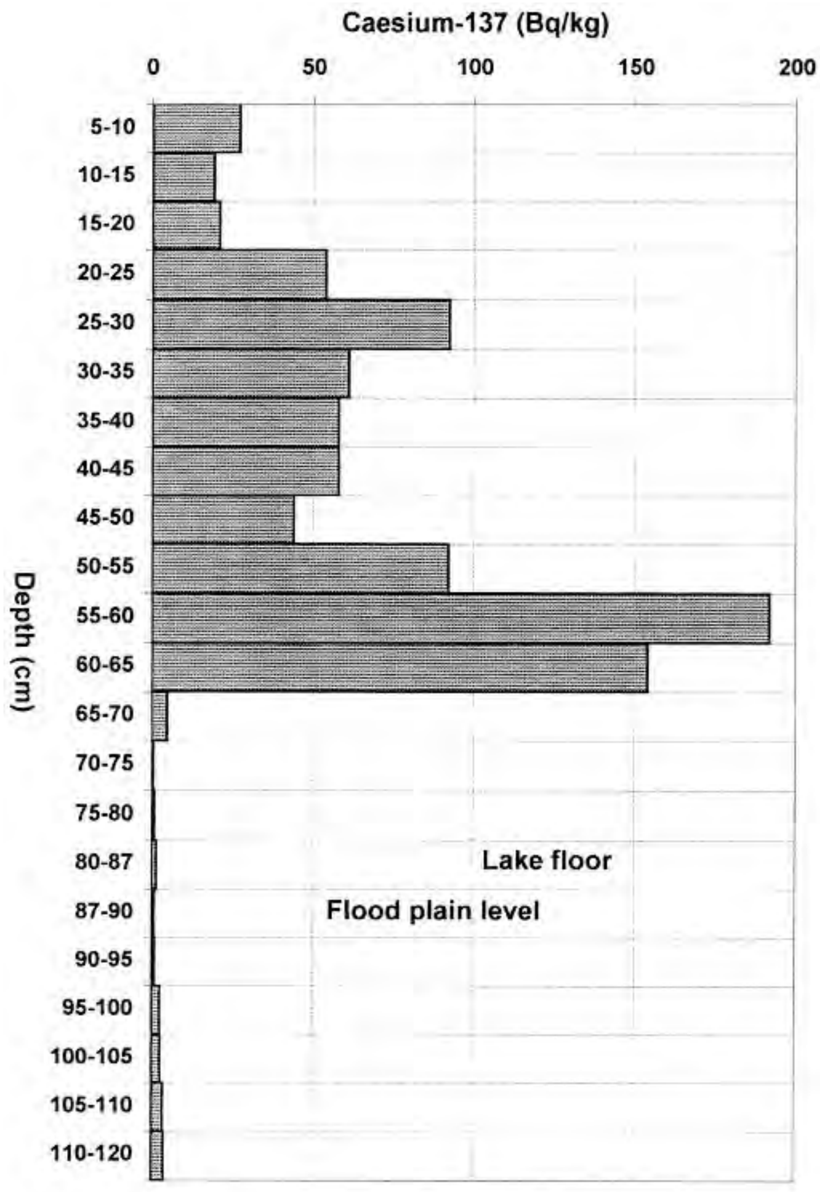

Fig. 15 Distribution of 137-Caesium in the Antohesti reservoir on Upper Berheci River, Romania, under mixed conditions (May 14, 1997)

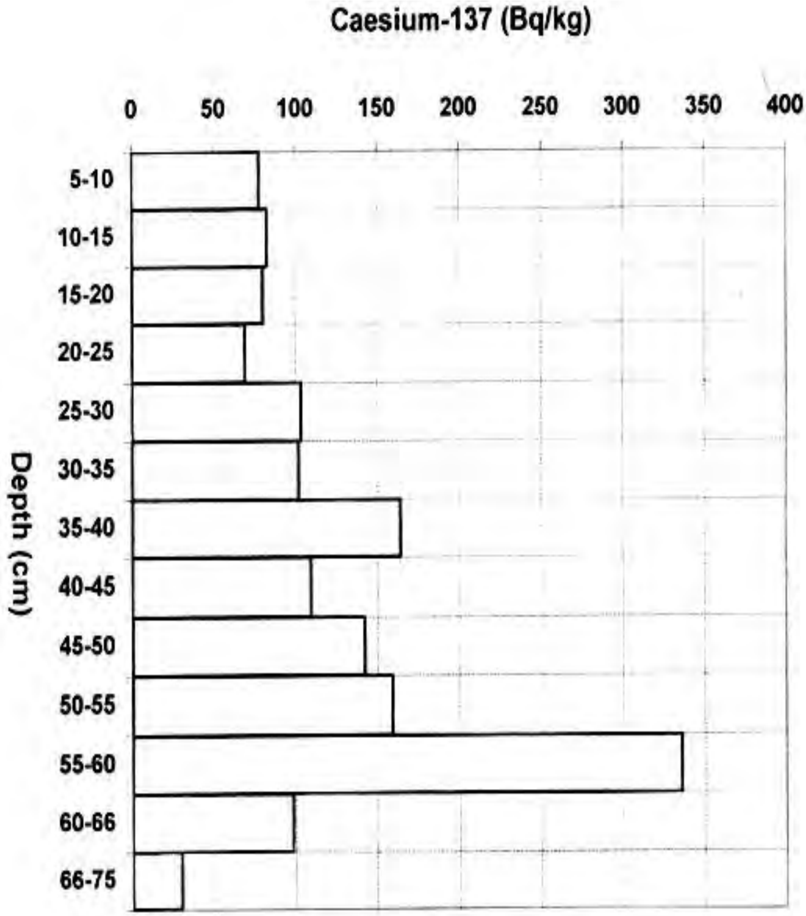

Fig. 16 Distribution of137-Caesium in the Antohesti reservoir on Upper Berheci Basin, Romania, under lake conditions (May 14, 1997)

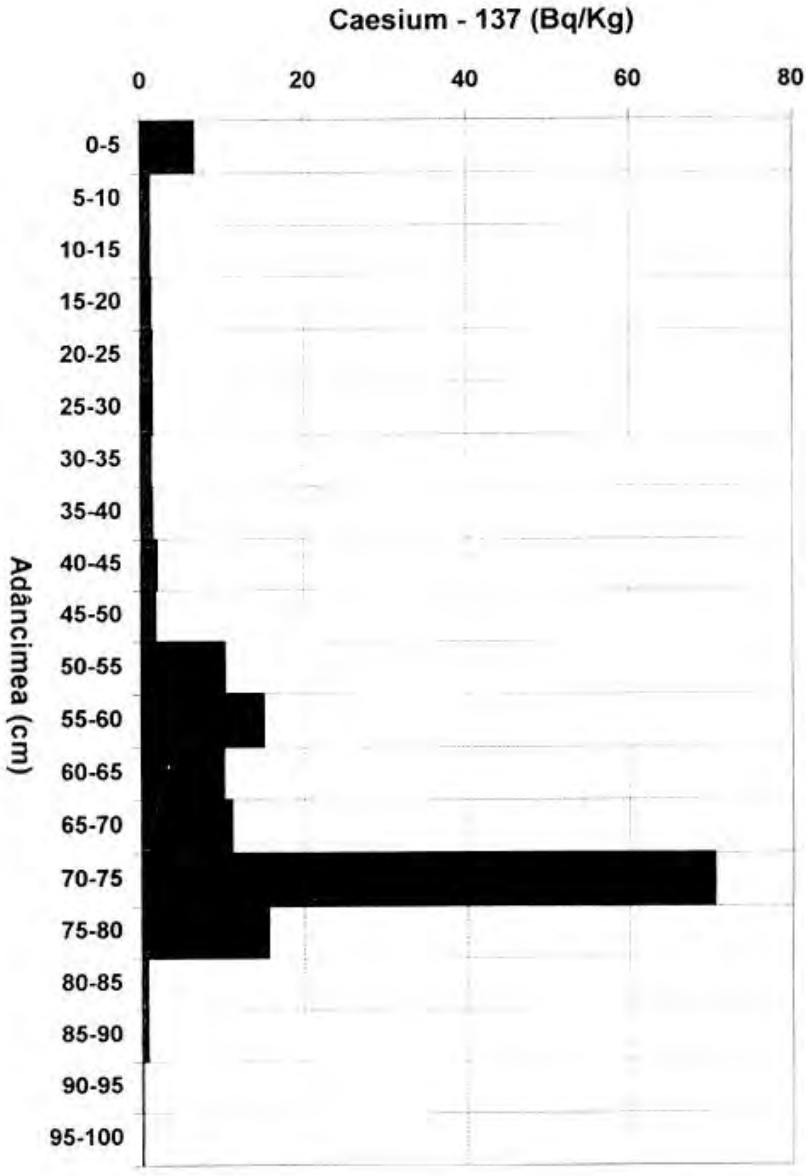

Fig. 17 Distribution of Caesium - 137 in the Gaiceana reservoir, middle Berheci basin, Romania, under mixed conditions (May 14, 1997)

RESULTS ON THE NON - CONVENTIONAL ASSESSMENT OF EROSION AND SEDIMENTATION FROM MOLDAVIAN TABLELAND

ION IONITA, ROMULUS MARGINEANU

Abstract

The potential for using fallout Caesium-137 measurements to estimate rates of erosion and deposition is explored.

Erosion plot studies provided a strong relationship by plotting individual Caesium-137 versus soil losses under row spaces crops during 1997.

A detailed investigation of the pattern of longer-term sedimentation rates within the floor of small discontinuous gullies has indicated a remarkably close association of deposition rates with the major world nuclear events. The average annual aggradation rate was by 4.4 cm/year over the long period of 43 years (1954-1996).

Annual siltation rates on small reservoirs are ranking between 5.0-6.8 cm/year after Chernobyl nuclear accident on 26 April, 1986.

Introduction

Soil erosion and sedimentation frequently create serious problems in Moldavian Tableland. During recent years a more accurate assesment of the land degradation rates by means of a new method is needed.

Caesium-137 technique has been used extensively over the past 25 years in world research and applications to measure soil erosion.

This study would be the first Romanian attempt of using Caesium-137 as a tracer or as an important tool for investigation soil erosion, gullying and lake siltation.

Results obtained

Three case studies can be usefully introduced, to demonstrate the potential for using environmental radionuclides in a range of investigations of erosion and sedimentation. These case studies exemplify the following:

- Establishing relationships between soil and Cs - 137 losses within runoff plots;
- Evaluating aggradation rates of some discontinuous gullies by recent alluvial deposition on their floor;
- Determine siltation rates on small reservoirs using Cs-137 as a tracer.

Erosion plots data

Field measurements on water, soil, 137 - Cs and humus losses have been conducted at Perieni Research Station in a small watershed, Tarina Valley, Tutova Rolling Hills. Several plots are used, all with a cropping history, fully instrumented for measuring runoff and soil loss. They are cultivated with different crops as follows: corn, dry beans, winter wheat, bromegrass. The check plot is used as permanent fallow which is always free of weeds. The plots are laying out on loamy textured mollisoil. The plots are 25 m by 4 m (100 sq. m) with 1 m border areas between plots. The site has an average slope of 12 % and it is westlooking.

During 1997 there were recorded a variable number of rainy events that determined runoff only under dry beans, corn and continuous fallow. A strong relationship was emphasised by plotting individual soil versus Caesium - 137 losses as shown in figures no. 1 and no. 2.

Aggrading data on discontinuous gullies

The aggrading of the discontinuous gully floor represents an interesting erosional process. In most cases the bed aggrading by very recent sediment is simultaneous with the proper gullying induced by gullyhead advance.

The study was conducted in several small watersheds from the neighbourhood of Perieni Station in order to determine the deposition rate with alluvial fill and the relation of the profile distribution of Cs-137 to organic matter and soil texture. For this paper Roscani and Timbru basins have been selected. The floor of these discontinuous gullies is typical for what is called "***short diffusor***" as illustrated in figures 3 and 4. Soil samples from two gullyheads have been contiguously collected, each by 5 cm thickness.

Data obtained on this study are shown graphically. Figure 5 indicates a remarkably close association of aggrading rate with the major world nuclear events. According to this chart there are obviously three Caesium - 137 peaks:

- the major one (56.9.Bq/kg) placed at 25-30 cm depth, due to Chernobyl accident on 26 April, 1986;
- the second (9.2 Bq/kg) between 145-150 cm depth is coinciding with the peak in bomb activity during the early 1960's, especially in 1963;
- the third (3.9 Bq/kg) placed at 170-175 cm depth due to increasing of fallout during the 1950's, more precisely in 1959.

Over the long period 1954-1996 (43 years) the average annual deposition rate was by 4.4 cm/year. Figure 6 shows us the mean annual aggrading rates for specific periods of time.

In other terms, it is possible to separate the contribution of these typical periods to the siltation of 190 cm alluvial thickness:

- 10 % for the period 1954 - 1959;
- 37 % for the period 1960 - 1969;
- 37 % for the period 1970 - 1.985 and
- 16 % for the period 1986 - 1996.

A mention must be made that the six years interval, 1964 - 1969, gets 24 % from the total aggradation.

Since the alluvial thickness is by 210 cm it means that the discontinuous gullyhead which determined gully floor siltation was located there 48 years ago (210 cm / 4.4 cm . year^{-1}). If plotting gully length of 43 m versus the above period of time, that means the annual gullyhead advance was by 0.90 m/year. This value is similar with the conventional evaluation made by I. Ionita (1998).

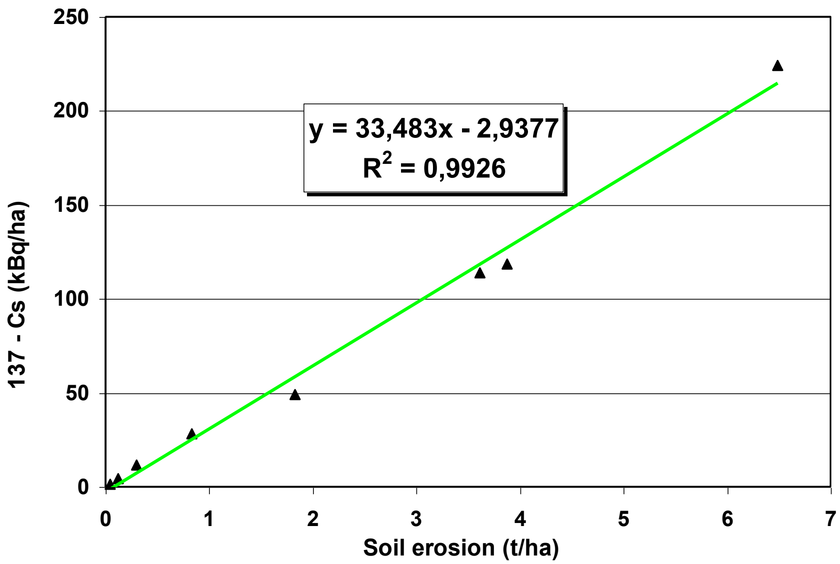

Fig. 1 Relationship of soil and Caesium-137 losses for dry beans and corn during 1997, Perieni - Barlad, Romania

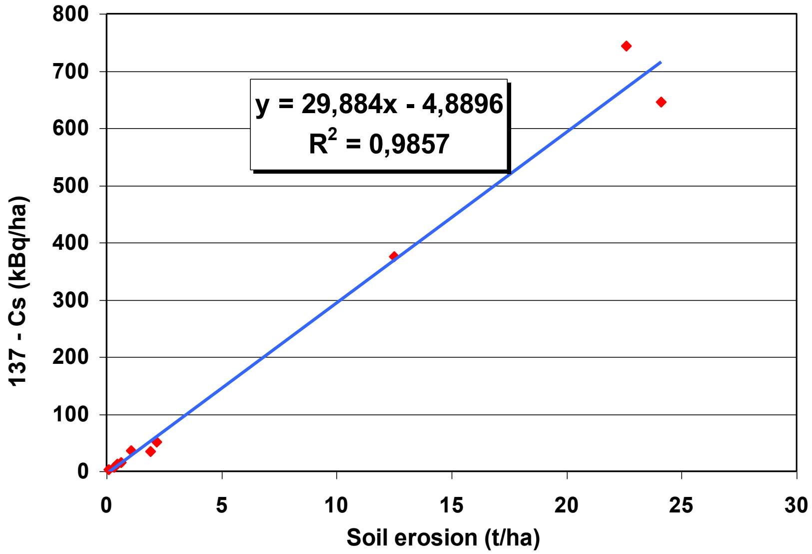

Fig. 2 Relationship of soil and Caesium-137 losses for continuous fallow during 1997, Perieni - Barlad, Romania

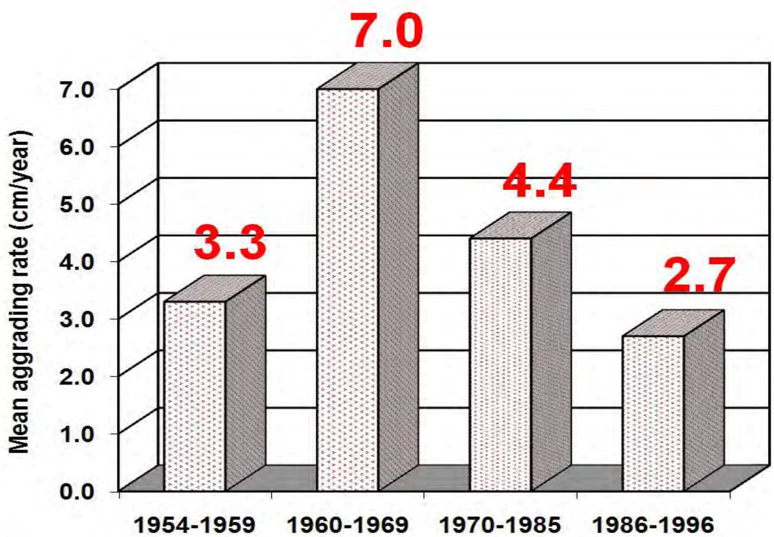

Fig. 6 Mean annual aggrading rate of a discontinuous gully floor on Roşcani Valley, Tutova Rolling Hills, Moldavian Tableland - Romania

On Timbru watershed, Falciu Hills, have been observed only two Cs - 137 peaks:

- 139.5 Bq/kg at 25-30 cm depth from alluvial sediment belonging to 1986;
- 4.5 Bq/kg at 145-150 cm depth coinciding with the decline in fallout after the 1963 Nuclear Test Ban Treaty. Lack of the third peak means that this gully appeared after I 959. Therefore, its average rates of aggradation with recent alluvium of gully floor are similar with Roscani site:
- 4.4 cm/year for the period 1963-1997 (long term average on 34 years);
- 5.0 cm/year for the period 1963-1986
- 2.7 cm/year after 1986.

Siltation rates on small reservoirs

Studies on siltation rates in reservoirs have been conducted in small watersheds covered by wooden soils: Antohesti reservoir on upper Berheci basin and Gaiceana reservoir on middle Berheci basin. Both reservoirs were set up in 1984.

For both sites the peak activity of Caesium - 137 is located between 55 - 60 cm depth. This means that the average siltation rate after Chernobyl accident was by 5.0 - 5.5 cm/year. This value is double in comparison with the siltation rate occured after April 1986 on the discontinuous gully floors. Also, it is possible to assess the normal aggradation rate of the previous Berheci flood plain: 1.6 cm/year for the period between 1963 - 1984 (year of dam construction). It will be observed that when we are dealing with a mixed moisture condition (dry and wet in the area filled with sediments) the peak value is high enough (192.0 Bq/kg). But the highest peak value was occurred under lake condition rising up to 335.9 Bq/kg as shown in figure 7. The fluctuations of Caesium- l37 activity after 1986 underline surface and gully erosion are the main sediment sources.

The rain pattern during May 1986 on Moldavian Tableland, Eastern Romania, could explain the differences regarding the magnitude of the Cs - 137 peak values. It is known that 1986 was a very dry year for Romania. During late April there was no rain but around May 10 and 11 there were recorded small but significant rains: 13.1 mm in the upper Berheci, 7.0 mm in the Falciu Hills and 2.8mm in middle and lower Berheci. That is why the Caesium - 137 peak was by 190 - 336 Bq/kg on Antohesti area, 140 Bq/kg on Falciu Hills and 57 - 70 Bq/kg on the Lower Tutova Rolling Hills.

REFERENCES

IONITA I. (1998) *Geomorphological study of the land degradation on middle Barlad watershed.* Univ. of Jassy, Romania.

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Fig. 7 Distribution of 137- Caesium in the Antohesti reservoir on Upper Berheci Basin, Romania, under lake conditions (May 14, 1997)

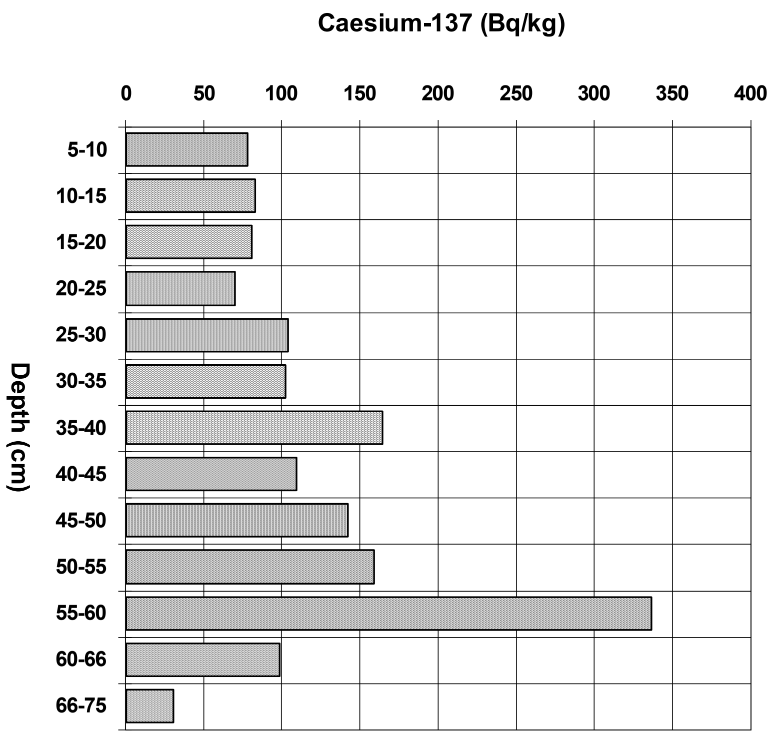
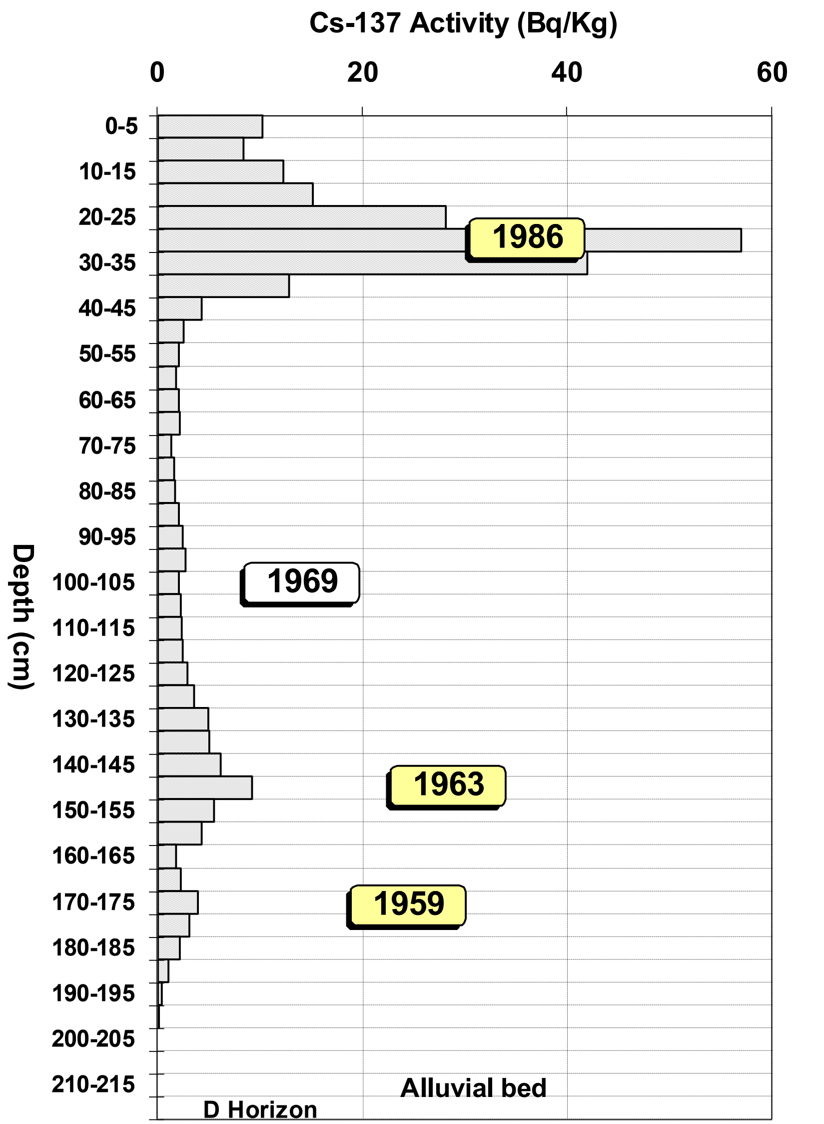


Fig. 5 Caesium - 137 distribution in the alluvial fill from the discontinuous gully head no. 4, Roscani Valley, Romania, 12.XII.1996



EROSION AND CLIMATIC RISC AT THE WHEAT AND MAIZE CROPS IN THE MOLDAVIAN PLATEAU

MIRCEA MOTOC, ION IONITA, DUMITRU NISTOR

Abstract: The paper tries to estimate the erosion risk due to precipitation and surface runoff in the Moldavian Plateau. The plateau variability to the climatic factors is considered for the wheat and maize crops. As climatic factors, precipitation and temperature have the highest influence upon the crop. Mathematical models have been elaborated for the simulation of the biomass and useful product formation.

Consideration was also given to the assessing of the fertilizer efficiency on soils under various erosion conditions, in a wheat-maize rotation, on lands with different slopes and facing.

Introduction

The Moldavian Plateau is the geomorphological unit where drought causes very high damages to agriculture. The relief conditions and the water resources do not allow the use of irrigation to cover the moisture deficit and therefore, in the future too, the system of agriculture without irrigation will still be used, depending on precipitation. Wheat and maize are the main crops in the area. The droughty feature of the area is determined not only by the precipitation deficit but also by the relief which diminishes the precipitation efficiency by the surface runoff and the decrease of the useful water capacity in the soil, as an effect of the surface erosion. The analysis of the drought surface runoff, as well as the erosion one.

The data basis includes the 1970-1994 period, resulted from the research performed at the Central Research Station for Soil Erosion Control, Perieni by I. Ionita, D. Nistor, T. Neamtu, C. Carlan, C. Agache and those made on the pilot production sector (1993).

Hydrological risk

The hydrological regime of the soils located on slopes is influenced by the surface runoff. The runoff volume decreases the effect of the precipitation on the crop field. Out of the risk factors concerning runoff on slopes, the climatic risk is of a special interest. Most of the calculation methods for the volume of the surface runoff have in view, as risk indicator, the precipitation during 24 h and the soil moisture prior to the event. The successive precipitation increases the runoff volume.

The estimation of the runoff on slopes can be done by means of Hi15 indicator proposed by Stanescu P. (1969) and where H is the amount of precipitation and i15 the intensity of the torrential nucleus on a 15-minute duration.

By analyzing the data obtained by means of the 25 m long runoff plots with a 12% slope for a 25-year period, the conclusion was that on the bare lands, treated as continuous fallow, 139 rain events caused surface runoff and erosion. For the entire period, 543 mm were lost by runoff, representing a 22 mm annual mean. For the mentioned slope and soil, the runoff was recorded for the months of May, June, July, August and September. Very seldom, on long slopes, significant runoff occurs as well as during snowmelt accompanied by rainfalls. We shall further on present the runoff caused by rainfalls. As we shall refer to the runoff impact upon the crop we shall have in view only those events causing a surface runoff higher that 5 mm. The number of events included in this category is 35, representing 25% of the total number of events having caused runoff. By analyzing the correlation between the runoff volume and the precipitation having determined it, it has been noticed that this correlation is weak, determined by the previous moisture to the event or by the rainfall intensity.

In order to eliminate a part of the variability sources, we have calculated the sum of the precipitation inducing runoff, on months and then on years, as well as the associated runoff. Figure 1 presents the monthly distribution of the multiannual values of the precipitation having caused runoff, of the Hi15 indicator that, along with the precipitation amount, includes also the intensity of the torrential nucleus lasting 15 minutes and the runoff in mm on continuous fallow.

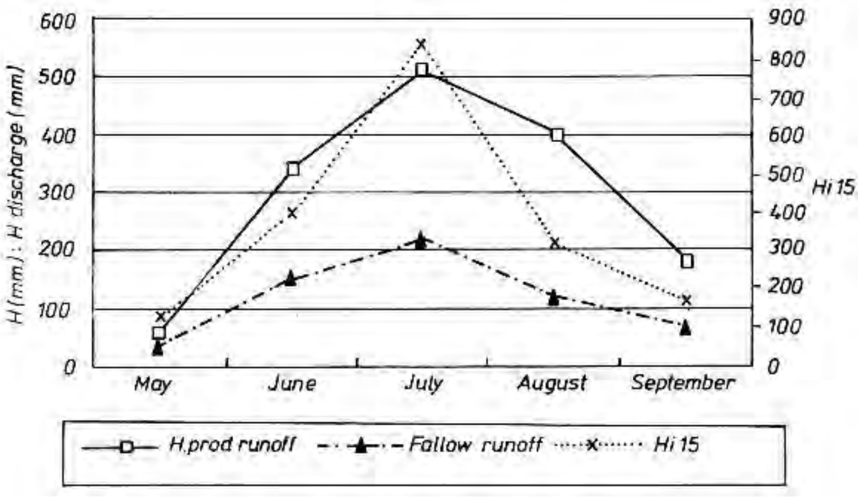


Figure 1. Rainfalls determining the runoff, Hi15 and runoff on continuous fallow

A good agreement can be noticed between the precipitation inducing runoff and Hi15 and the precipitation with runoff, except for August when the low previous soil moisture determined a decrease of the runoff. From the performed analysis, it seems that only the rainfalls exceeding 20 mm and Hi15 exceeding the value of 10 should be considered. The runoff volume in mm represents the product between the precipitation amount and the runoff ratio.

By selecting the rainfalls according to the previously mentioned criterion and by calculating the sum on years, we have calculated the runoff ratios for fallow, maize and wheat. The data are presented in Table 1.

Table 1. The runoff ratios at fallow, maize and wheat

Crop	Months					
	May	June	July	August	September	Annual total
Land	0.67	0.41	0.40	0.28	0.30	0.37
Maize	0.61	0.28	0.18	0.15	0.00	0.19
Wheat	0.14	0.04	0.04	0.05	0.05	0.04

At the continuous fallow, the peak values are achieved in June and July, which then decrease in August and September due to the moisture deficit and increase in May, a month with moisture excess. At maize and wheat, there are differences according to the water consumption of the plants and their interception degree.

Further on Tables 2 and 3 show, by years and months, the rainfalls having caused runoff as well as the measured and computed runoff, depending or the established runoff ratios for the fallow and maize. At wheat, the water losses by runoff are insignificant. The determination coefficient for the computed runoff, by the proposed method, is by 0.41 for the bare lands and by 0.31 for the maize crop.

Table 4 presents the runoff risk at fallow, maize and wheat. At fallow and maize, the highest risk occurs in June and July, and for wheat, the maximum risk conditions occur in August and September, if the land is tillaged after harvesting. If the stubble is maintained, the risk differs very little from that in the previous months.

The value of the hydrological risk is of interest (Table 5). At wheat, in 84 out of 100 years, a surface runoff higher than 5 mm is not expected, at maize - in 32 years and at fallow in 28 years.

High runoff volumes, by 40-45 mm, are likely to occur in 12 out of 100 years at fallow and in 4 years at maize. At wheat, the maximum runoff does not exceed 25 mm and is possible in 8 years. The runoff impact upon the precipitation deficit and implicitly the maize and wheat yield reduction will be presented within the context of the participation of other factors too in the formation of the crop.

Erosion risk

The researches carried out in our country and abroad regarding the assigning of certain climatic indicators for the estimation of the erosion risk are very numerous and refer especially to the surface erosion. Among significant climatic factors, an important part is played by the precipitation aggressiveness. According to Wischmeier (1959), this is noted with R and is defined as the product between the kinetic energy of the rainfall and the intensity of the torrential nucleus lasting 30 minutes, in mm/hour (R = EI30). other authors have in view the precipitation corresponding to a 24-h duration. By means of this the runoff volume is determined as well as the maximum discharge corresponding to the concentration time and then the eroded soil volume.

In our country, the indicator Hi15 proposed by Stanescu P. (1969) is used. The research carried out has established the necessity to consider the rainfalls with Hi15 > 10. A comparative study, with several indicators, carried out by Motoc M. and Ionita I. (1983) showed that indicator Hi15 is superior or at least close to the performance of other indicators. Assigning of the erosion risk must have in view the erosion effect upon the crop. From this standpoint, the following risk categories are of interest: at singular events or successive at a short interval, of 1-3 days, at the annual erosion cycles occurring in case of a long period (groups of years with a minimum erosion followed by a group of years with severe erosion) and the erosion rate as a long-term multiannual mean.

Table 2. Fallow. Precipitation (H) measured and computed runoff >5 mm

Item.	Year	May				June				July				August			
		H. (mm)	C. runoff	H. calc.	H meas.	H. (mm)	C. runoff	H. calc.	H meas.	H. (mm)	C. runoff	H. calc.	H meas.	H. (mm)	C. runoff	H. calc.	H meas.
1	1970	-	-	-	-	-	-	-	-	56	0.40	22	13	73	0.28	20	10
2	1971	-	-	-	-	-	-	-	-	78	0.40	31	24	-	-	-	-
3	1972	-	-	-	-	-	-	-	-	44	0.40	18	10	147	0.28	4	29
4	1973	-	-	-	-	-	-	-	-	81	0.40	32	45	-	-	-	-
5	1974	-	-	-	-	79	0.41	32	30	-	-	-	-	-	-	-	-
6	1975	-	-	-	-	-	-	-	-	86	0.40	34	18	-	-	-	-
7	1976	-	-	-	-	-	-	-	-	-	-	-	-	70	028	20	24
8	1977	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	1978	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	1979	-	-	-	-	56	0.1	23	20	-	-	-	-	-	-	-	-
11	1980	-	-	-	-	4	0.41	20	20	24	0.40	1	14	-	-	-	-
12	1981	-	-	-	-	22	0.41	9	8	-	-	-	-	-	-	-	-
13	1982	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	1983	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	1984	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	1985	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	1986	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	1987	-	-	-	-	45	0.41	18	24	67	0.40	27	34	22	0.28	6	8
19	1988	-	-	-	-	57	0.41	23	16	-	-	-	-	-	-	-	-
20	1989	-	-	-	-	-	-	-	-	-	-	-	-	55	0.28	16	28
21	1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	1991	-	-	-	-	-	-	-	-	76	0.40	3	43	-	-	-	-
23	1992	-	-	-	-	29	0.41	12	21	-	-	-	-	-	-	-	-
24	1993	51	0.67	34	34	-	-	-	-	-	-	-	-	-	-	-	-
25	1994	-	-	-	-	-	-	-	-	-	-	-	-	26	0.28	8	11
	Suma	51	0.67	34	34	336	0.41	13	139	512	0.40	205	206	393	0.28	111	110

Table 3. Maize. Precipitation (H) measured and computed runoff >5 mm

Item.	Year	May				June				July				August			
		H. (mm)	C. runoff	H. calc.	H meas.	H. (mm)	C. runoff	H. calc.	H meas.	H. (mm)	C. runoff	H. calc.	H meas.	H. (mm)	C. runoff	H. calc.	H meas.
1	1970	-	-	-	-	-	-	-	-	5	0.18	10	0	7	0.15	4	5
2	1971	-	-	-	-	-	-	-	-	78	0.1	14	6	-	0.75	-	-
3	1972	-	-	-	-	-	-	-	-	4	0.18	8	0	147	0.15	22	12
4	1973	-	-	-	-	-	-	-	-	81	0.1	15	35	-	-	-	-
5	1974	-	-	-	-	79	0.28	22	18	-	-	-	-	-	-	-	-
6	1975	-	-	-	-	-	-	-	-	86	0.18	16	17	-	-	-	-
7	1976	-	-	-	-	-	-	-	-	-	-	-	-	70	0.15	10	12
8	1977	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	1978	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	1979	-	-	-	-	56	0.28	16	5	-	-	-	-	-	-	-	-
11	1980	-	-	-	-	48	0.28	1	15	24	0.1	4	0	-	-	-	-
12	1981	-	-	-	-	22	0.28	6	5	-	-	-	-	-	-	-	-
13	1982	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	1983	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	1984	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	1985	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	1986	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	1987	-	-	-	-	45	0.2	13	23	67	0.18	12	22	22	0.15	3	10
19	1988	-	-	-	-	57	0.28	16	14	-	-	-	-	-	-	-	-
20	1989	-	-	-	-	-	-	-	-	-	-	-	-	55	15	8	17
21	1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	1991	-	-	-	-	-	-	-	-	76	0.18	14	14	-	-	-	-
23	1992	-	-	-	-	29	0.28	8	15	-	-	-	-	-	-	-	-
24	1993	51	0.61	31	31	-	-	-	-	-	-	-	-	-	-	-	-
25	1994	-	-	-	-	-	-	-	-	-	-	-	-	26	0.15	4	4
	Summ	51		3	31	336	0.2	94	95	512	0.18	93	94	393	0.15	58	60

Table 4. Precipitation and runoff in mm and %, by months

	May	June	July	August	Septem-ber	Total	…out of the annual total
mm							Runoff reported at H producing runoff
H total	2423	1945	1621	1321	972	8282	
H prod. runoff	51	336	512	393	172	1464	100
Runoff land	34	139	206	110	54	543	37
Runoff maize	31	95	94	60	0	280	19
Runoff wheat	7	14	23	20	20	84	5
%							
H total	29	23	20	16	12	100	
H prod. runoff	3.0	23	35	27	12	100	
Runoff land	6	25	38	20	11	100	
Runoff maize	11	34	34	21	0	100	
Runoff wheat	8	17	27	24	24	100	

Table 5. Number of years out of 100 with a various runoff at fallow, maize and wheat

Classes mm	Land		Maize		Wheat	
	25 years	100 years	25 years	100 years	25 years	100 years
0-5	7	28	8	32	21	84
5-10	1	4	4	16	1	4
10-15	1	4	4	16	1	4
15-20	3	12	4	16	0	0
20-25	4	16	2	8	2	8
25-30	2	8	0	0	0	0
30-35	3	12	2	8	0	0
35-40	1	4	0	0	0	0
40-45	3	12	1	4	0	0

Erosion risk at singular or successive events at a short interval, of 1-3 days

These events cause damages to the crops by carrying seeds away and destroying plants. The volume of the damages depends on the level of the precipitation aggressiveness, the soil moisture previous to the event and the plant cover protection offered to the soil. Previously, the monthly distribution of the runoff was shown. Wheat appears to offer a good protection along the entire vegetation period. The most sensitive is the maize crop where the critical period is including the month of May and the first decade of June. From the measurements and observations carried out for the 1970-1994 period, on the runoff and erosion plots and on large areas under farming conditions, significant effects appear to occur at singular or successive events for values of indicator Hi15 > 45, in May or the first decade of June. The damages increase as the events occur closer to the sowing time. In this case the resowing of the crop is required. This threshold is valid for the 12% slope and soils with medium favourability to rift formation. By analyzing the data for the mentioned period, the precipitation aggressiveness appeared to exceed the mentioned threshold in two years: 1987 and 1993. In 1987, two successive rainfalls reached a Hi15 value of 64 and in 1993 a value of 45. The risk appears therefore in 8 out of 100 years, the singular or successive events at a 1-3 days interval causing direct damages to the maize crop. The rill formation depends not only on the rainfall aggressiveness but also on the slope gradient, the slope length, the soil favourability to their formation and conservation tillages and practices. Therefore, the research on the rill erosion is of a special interest. Some - results regarding this matter were published by Motoc M. and Ouatu O. (1985).

The risk in terms of the annual erosion cycles sequence

As for the liquid runoff we shall present the estimation method, through and assessment on the basis of the field data from the runoff plots, over a 25-year period.

The used climatic indicator defining the rainfall aggressiveness is Hi15. Table 6 shows, years and a 5-year group average, the values of the rainfall aggressiveness and of the erosion in t/ha/year for the fallow, maize and wheat crops.

In order to eliminate the variability determined by crops, we have established the regression equation for the annual values and the mean by 5-year groups at fallow. The equation is the following:

Y = 0.403 * Hi15 - 0.056, determination coefficient 0.761

If the data are grouped by every 5 years, the determination coefficient is 0.850. Through grouping the data by months, the determination coefficient is 0.996. The very high determination coefficient by months justifies the use of this assessing method. Table 7 shows the monthly distribution of the precipitation aggressiveness indicator and sail losses in t/ha/year and Table 8 shows the weight of each indicator.

Table 6. Rainfall aggressiveness and soil losses, annual values and by 5-year groups

Item	Year	Hi15	Erosion (t/ha/year)			Groups of 5 years			
			Land	Maize	Wheat	Hi15	Land	Maize	Wheat
1	1970	86	30.5	6.8	0	85.5	34.1	8.8	0.4
2	1971	55	23.0	3.8	0.5				
3	1972	140	35.5	4.3	0.3				
4	1973	87	39.0	8.8	0.6				
5	1974	60	43.0	20.0	0.2				
6	1975	155	85.0	4.8	1.6	65.5	22.7	1.4	0.6
7	1976	20	11.5	0.6	2.7				
8	1977	34	2.3	0	0				
9	1978	66	7.4	0	0				
10	1979	53	6.5	1.6	0				
11	1980	82	47.7	7.1	0.8	39.8	16.5	2.5	0.2
12	1981	0	0	0	0				
13	1982	20	9.0	0	0				
14	1983	75	22.0	4.1	0				
15	1984	22	4.0	1.1	0				
16	1985	50	14.0	5.8	0.2	88.8	40.6	15.5	1.2
17	1986	34	6.5	0	0				
18	1987	175	97.2	48.7	3.0				
19	1988	97	32.3	14.9	0				
20	1989	84	52.6	8.0	2.4				
21	1990	19	1.5	1.3	0	80.0	24.9	7.0	1.9
22	1991	169	65.5	3.0	8.8				
23	1992	66	14.0	2.7	0				
24	1993	130	50.0	27.0	0.8				
25	1994	16	8.3	1.0	0				
Sum		**1795**	**708**	**175.4**	**22.0**				
Mean		**72**	**28**	**7.0**	**0.88**				

Table 7. Monthly distribution of the indicator Hi15 and of the erosion on fallow, maize and wheat

Indicator Hi15 and erosion in t/ha	Values over 25 years						
	May	June	July	August	September	Total	Mean
Hi15	114	384	835	308	153	1800	72
Fallow erosion	52	167	334	97	50	700	28
Maize erosion	40	68	48	19	0	175	7
Wheat erosion	3	1	1	5	12	22	0.88

It is emphasized that, as for the runoff, maximum values in June and July and a marked effect of the wheat and maize protection. The 12 t/ha/year soil loss difference in May between the fallow and the maize is explained by the reduced number of events in May, normal for this month. The erosion at the maize crop should be close to that of the fallow.

Table 8. Monthly weighing of the indicator Hi15 and of the erosion on fallow, maize and wheat

Indicator Hi_{15} and erosion in %	Values over 25 years					
	May	June	July	August	September	Total
Hi_{15}	6.4	23	46	17	8.6	100
Fallow erosion	7.0	24	48	14	7	100
Maize erosion	23.0	39	27	11	0	100
Wheat erosion	10.0	5	5	20	60	100

Table 9 includes the ratio in terms of the precipitation aggressiveness and erosion at the fallow, maize and wheat crops and Table 10 the ratio of the erosion at the maize and wheat crops versus that at the fallow. By using the previously mentioned regression equation for the fallow rainfall aggressiveness directly, by means of the correction coefficients in Table 9 and 10, the monthly erosion at the maize and wheat crops was estimated. Thus, for the maize crop, the determination coefficient is 0.965, very high, by using the protection coefficient by months.

Table 9. Monthly distribution of the erosion at fallow, maize and wheat, versus Hi_{15}

Indicator Hi15 and erosion as against Hi15	Relative values over 25 years					
	May	June	July	August	Septem ber	Total
Hi_{15}	1	1	1	1	1	1
Fallow erosion	0.46	0.43	0.40	0.31	0.32	0.388
Maize erosion	0.35	0.18	0.06	0.06	0	0.097
Wheat erosion	0.03	0.002	0.002	0.016	0.080	0.012

Table 10. Monthly distribution of the erosion at maize and wheat versus fallow

Erosion	Relative values over 25 years					
	May	June	July	August	September	Total
Fallow erosion	1	1	1	1	1	1
Maize erosion	0.77	0.41	0.14	0.19	0	0.25
Wheat erosion	0.06	0.006	0.003	0.05	0.24	0.03

It is clear that the proposed method for the estimation of erosion has a very high degree of accuracy as compared to the one for the surface runoff.

The erosion cycles will be emphasized by means of the moving average over three-year groups (Fig. 2). In this case the correlation coefficient is 0.780, higher in terms of the annual values method of 0.761. Figure 3 represents the variation of the moving average for the 25-year period for the maize crop. Two cycles of high values and one with very low or insignificant values are emphasized. The same figure shows the moving average of the maize yield, the monoculture variant with optimum mineral fertilization. We have chosen the monoculture variant as it shows the highest soil losses by erosion.

No obvious yield decrease is noticed after a very strong erosion cycle. The determinant climatic factor of the yield is the hydrothermal coefficient. This problem will farther on be analyzed in the chapter regarding the climatic indicators and the climatic risk in the determination of the wheat and maize yield. The long-term erosion cycles are of great interest from another point of view too. The duration of the cycles with minimum erosion indicates the recovering potential of the soil fertility by technological measures, and the duration and magnitude of the cycles with intense erosion show the diminishing potential of the soil fertility. Such analysis for several localities would be the basis for the mapping of the erosion potential according to a new criterion.

The multiannual mean erosion rate-indicator of long-term erosion risk

One of the restricting factors is the soil depth that can be used by the plant roots. Another limiting factor is the humus contents. These factors are strongly influenced by the long-term rate of the soil erosion. We have previously presented the method for the estimation of the erosion rate (t/ha/year) and its influence upon the maize yield for the lands with a 12% slope and a 25-m long plot. For the maize crop, the mean erosion rate for a 25-year period was 7 t/ha/year, and for the wheat crop it was 0.88 t/ha/year. Under these circumstances, the yield losses are insignificant. By farming over large areas, the slope and slope length are much higher.

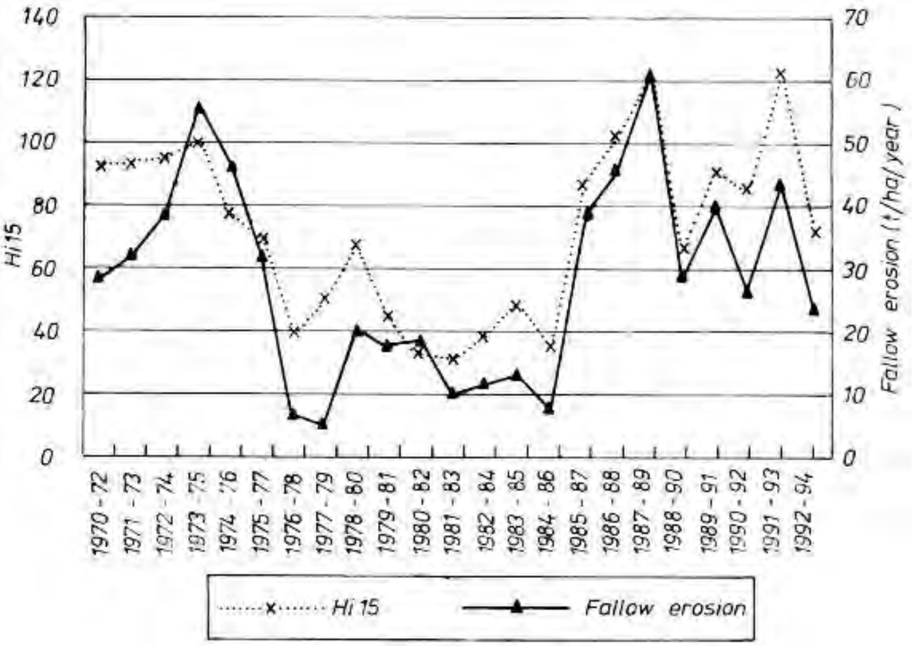


Figure 2. Moving average on 3 years for pluvial aggressiveness Hi15 and erosion at fallow, t/ha/year

The estimation of the erosion rate for various conditions of precipitation aggressiveness, relief, soil, erodability, the soil protection by vegetation and conservation tillages and practices is achieved by means of the relation proposed by Motoc M., (1970).

$$E = K * Ln * im * S * C * Cs$$

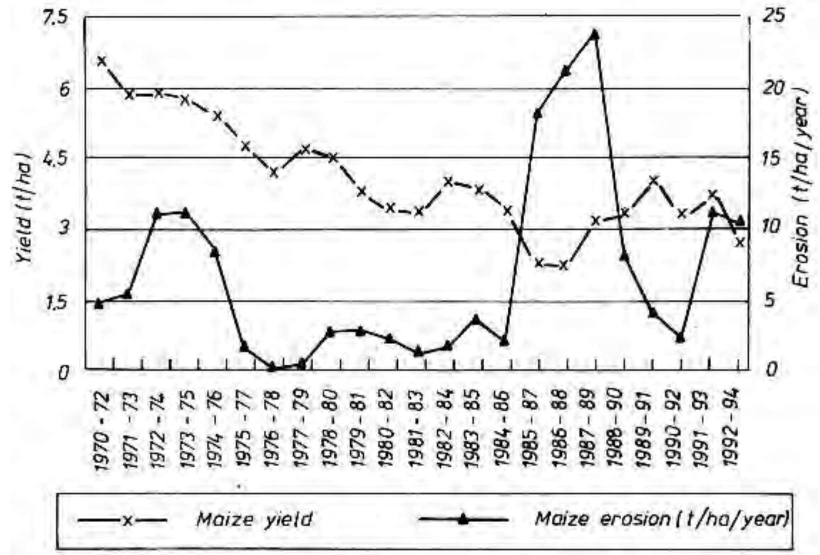


Figure 3. Moving average over 3 years for maize crop and erosion

where: E - erosion rate in t/ha/year; K - erosivity representing soil losses at the precipitation aggressiveness unit, L, I, S, C and Cs with value I; L - slope length, m; i - slope, %; C - coefficient for the soil protection by vegetation; Cs - coefficient for the soil protection by soil erosion control measures and practices.

Under experimental conditions, for the analysed case:

K = 0.130

L = 25

n = 0.3

i = 12 %

m = 1.4

S = 0.8

C = 0.8, cultivated maize in crop rotation;

Cs = 1.0, no Soil Erosion Control

For the wheat crop C = 0.12

The erosion estimated rate by this model is:

- maize = 7.0 t/ha/year
- wheat = 1.0 t/ha/year

According to the model presented previously:

- fallow erosion rate = 28 t/ha/year
- wheat erosion rate = 0.88 t/ha/year.

Correction coefficients (Table no.10):

- at the fallow = 1
- at the maize = 0.25
- at the wheat = 0.03

The very good agreement between the values estimated by this generalizing calculation relation and those established on the basis of the data from the runoff plots for a period of 25 years, is explained by the very close values of the precipitation aggressiveness. For the mentioned relation, we have used the value 71 for the precipitation aggressiveness from the zonation proposed by Dragan Livia and Stanescu P. (1970). The precipitation aggressiveness in the analyzed case, for a 25-year period, is 72. It is therefore confirmed that the mapping of the precipitation aggressiveness and the validity of the generalization relation presently used with the recommended parameters for the Moldavian Plateau.

In order to estimate the erosion risk, we will use the mentioned relation for the following hypotheses:

- Slope gradient: 20%
- Slope length: -200 m; -400 m
- Coefficient S = 1
- Coefficient C:
- monoculture maize =1
- monoculture wheat = 0.12
- Maize 70% of the surface
- Wheat 30% of the surface

The period considered is 70 years, alter the agricultural reform, when the lands were divided into up and down plots with highest slope.

Table 11. The erosion rate and the depth of the eroded soil on a hillside by 20% slope

Variants	Monoculture maize		Monoculture wheat		70% maize; 30% wheat		Weight (volume) (g/cm^3)
	Erosion rate (t / ha /year)	Eroded soil depth (cm)	Erosion rate (t / ha / year)	Eroded soil depth (cm)	Erosion rate (t / ha / year)	Eroded soil depth (cm)	
L = 200 m	43	25.08	6.0	3.0	31.8	18.40	1.2
L = 400 m	52	30.33	6.2	3.6	37.3	22.92	1.2

The present erosion state is in terms of the soil depth already eroded before the agricultural reform and of the technologies applied until now. The pessimistic variants chosen for conservation tillages and practices have in view the present situation in various localities situated in this area where the entering into possession has been done on the former locations as well as the increasing trend of the surfaces covered by maize and the reduction trend of the wheat surfaces.

Risk of Long-Term Erosion

The climatic indicator of erosional risk being Hi15, we have established its frequency by classes (Table 12).

Table 12. Frequency of the rainfall aggressiveness as annual values

Item	Class Hi15	Number of years out of 25	Number of years out of 100
1	0 - 10	1	4
2	10 – 50	8	32
3	50 – 90	10	40
4	90 – 130	2	8
5	130 – 170	3	12
6	170 - 210	1	4

The class interval has been chosen for the first class 0-10, representing values at which no surface runoff or erosion occurs. The interval value for the other classes is 40. The multiannual mean rainfall aggressiveness with the value 72 corresponds to the 3rd class (50-90).

The multiannual mean value is therefore achieved in 40 years out of 100. The estimation and therefore of the erosion risk frequency is made by means of the generalization equation previously presented for the desired condition.

Indicators and Climatic Risk in the Formation of the Wheat and Maize Yield

Indicators and their validation

Among the climatic factors, precipitation and temperature have the highest influence upon the yield. Various mathematical models have been elaborated for the simulation of the biomass and useful product formation. Most of them refer to wheat and maize. There are such preoccupations in our country too: Simota Catalin (1953); Saulescu N. (1993) and Craciun M., (1993). Most of the models regarding the yield formation have in view the fact the surface of the crop canopy, in terms of the unit surface (LAI index), has a determinant role in the yield formation and this is in terms of the temperature regime, the water supply of the plants and the nutrient elements. Figure 4 shows, after Tollenaar - 1979, Cao and Moss - 1992, quoted by Bonhomme (1992), the influence of the temperature upon the development of the leaves apparatus for maize and wheat. The result is that for wheat, temperatures above 15°C up to 32°C have a constant influence upon the development of leaves while for maize, starting with the active temperature threshold of10°C, the part of the temperature increases up to 32°C. Therefore, for wheat, the favorable crop areas, as the area we refer to, can have only precipitation as a determinant climatic factor. For maize, we have to consider temperature too. We consider that an indicator such as the hydrothermal index representing the ratio between the precipitation and the active temperature is of interest.

Motoc M. (1968) established for the vine a close correlation between this indicator and the grape production. Another problem is to establish the period for which these indicators are calculated. In order to solve this problem, we shall use the results of the researches carried out by Botzan Marcu (1972) at Chiscani - Braila research station and by Grumeza N. (1989 and 1994) at the experimental field of Cosmesti - Tecuci. These data refer to the water consumption under irrigated regime for the wheat and maize crops (Table 13).

For wheat, the critical period is March-June with maximum consummations in June.

For maize the data regarding the water consumption on crop stages are also interesting.

Table 13. Water consumption in % for the vegetation period

Locality	Plant	Month							Total
		March	April	May	June	July	August	Sep-tember	
Chiscani-Braila	Wheat	11	16	35	38	-	-	-	100
	Maize	-	9	9	16	26	28	12	100
Cosmesti -Tecuci	Wheat	-	20	35	45	-	-	-	100
	Maize	-	-	12	23	26	23	16	100

Table 14 gives data after Botzan Marcu (1972) for the Chiscani-Braila research station.

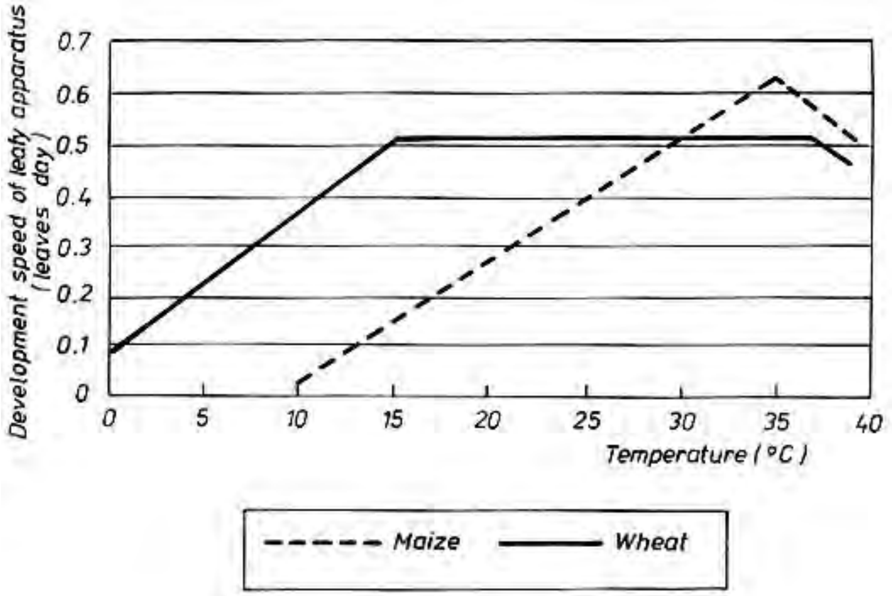


Figure 4. Leaf occurrence speed in terms of temperature

Table 14. Water consumption of maize by crop stages

Phase	Interval	Consumption (%)
Sprouting – 8 leaves	15.V – 15.VI	10
8 leaves – earring	16.VI – 10.VII	17
Earring - …..	11.VII – 9.VIII	34
…… - yellow ripening	10.VIII – 27.VIII	22
Yellow ripening - harvesting	28.VIII – 25.IX.	17

As the calculation of the proposed indicator will be made by months, two variants will be analysed for the critical period: the first one will include the June- August interval and the second - the months of July and August. The analysis carried out resulted in a higher determination coefficient for the second variant.

The researches carried out in our country and abroad have established a very good correlation between yield and the ETR/ETP ratio. The potential evapotranspiration (ETP) is calculated according to the monthly mean temperature. The real evapotranspiration (ETR) is established in terms of the interaction between the cultivated plant and the climatic factors, by means of the water and energy balance. The simplest methods, based on the water balance, have in view, for the inputs, the precipitation and initial resources and for the outputs, the losses by runoff and infiltration. Our paper is meant to establish the climatic risk for a long period. Most of the meteorological stations do not have data records on the initial and final water resources for various crops and thus we shall also use the previously proposed indicators.

From the experiment variants carried out at C.R.S.S.E.C. Perieni we have selected those presented in Table 15.

Table 15. Variants used to test and validate indicators

Item	Variant	Cultivated plant	Slope exposure	Soil and erosion state	Experim. period	Authors
0	1	2	3	4	5	6
1	Monocrop, unfertilized	Wheat	12% eastern	Chernozem slightly eroded	1970-1994	Neamtu Titus
2	Best fertilized monocrop with mineral fertilizers	Wheat	12% eastern	Chernozem slightly eroded	1970-1994	Neamtu Titus
3	... , and best fertilized	Wheat	8-20% east and west	Moderately eroded chernozem variants	1970-1994	Nistor Dumitru, Carlan C.
4	Wheat-maize rotation previously used as arable	Wheat	20-28% south-west	??????	1976-1990	Ionita Ion, Agache C.
5	Best fertilized wheat-maize rotation	Wheat	20-28% south-west	??????	1976-1990	Ionita Ion, Agache C.
6	Unfertilized, former pasture land, wheat-maize rotation	Wheat	20-28% south-west	Chernozem on slope	1976-1990	Ionita Ion, Agache C.
7	Best fertilized, former pasture land, wheat-maize rotation	Wheat	20-28% south-west	Chernozem on slope	1976-1990	Ionita Ion, Agache C.
8	Treatment as in variant 1	Maize	See variant 1			

9	Treatment as in variant 2	Maize	See variant 2
10	Treatment as in variant 4	Maize	See variant 4
11	Treatment as in variant 5	Maize	See variant 5
12	Treatment as in variant 6	Maize	See variant 6
13	Treatment as in variant 7	Maize	See variant 7

The variants allow to reveal the influence of the cultivated plant, of the fertilizing level, of the slope, of the soil erosion state and of the previous use as arable or pasture land.

As a first step, we have performed a graphical analysis of the correlation between the mentioned indicators, calculated by years and crop, for the choice of the equation type in order to adjust the data and to analyse the variation sources, separately.

The type of equation proposed is the semilogarithmic one, also used by Botzan (1972) and Grumeza (1994) for the estimation of the yields in terms of the water consumption for the irrigated crops. Table 16 presents the established equations and the determination coefficients for each of them. Crop yield Y is in t/ha.

Table 16.

Variant	Regression equation	Cultivated plant	Determination coefficient for annual values	Determination coefficient for multiannual mean values
1	Y = 0.624 * lnx-2.011	Wheat	0.218	0.896
2	Y = 1.734 * lnx-6.655	Wheat	0.440	0.926
3	Y = 2.690 * lnx-10.297	Wheat	0.473	0.935
4	Y = 0.828 * lnx-3.095	Wheat	0.552	0.951
5	Y = 2.154 * lnx-9.039	Wheat	0.813	0.944
6	Y = 1.769 * lnx-6.907	Wheat	0.849	0.931
7	Y = 3.063 * lnx-12.888	Wheat	0.889	0.929
8	Y = 0.714 * lnx+3.260	Maize	0.483	0.976
9	Y = 1.765 * lnx+6.675	Maize	0.783	0.990
10	Y = 1.45 * lnx+4.068	Maize	0.591	0.945
11	Y = 2.392 * lnx+6.315	Maize	0.579	0.969
12	Y = 2.197 * lnx+6.380	Maize	0.424	0.984
13	Y = 3.445 * lnx+9,276	Maize	0.501	0.982

The identification of the variability sources, besides the proposed indicators, contribute to the increase of the low annual determination coefficients, especially for wheat. The most favorable years for the wheat crop where 1980, 1984 and 1993 (Table 17).

Table 17. Precipitation in mm during March-June period and wheat yield in kg/ha

Year	Precipitation (mm)	Yield (kg/ha)
1980	279	5200
1984	287	5600
1993	260	6758
Total	**826**	**17558**
Mean	**276**	**5852**

The optimum indicator regarding precipitation has the value 276. Having in view the precipitation sum is over 4 months, their distribution by months has a significant part in the yield formation. Table 18 shows the distribution by months, in mm and percentages, of the precipitation, in the very favorable years for wheat and in the years with precipitation very close to the optimum values over 4 months but with much lower yields. The chosen variant represents the technological optimum (3rd variant).

Table 18. Monthly distribution of precipitation

Variant	Total mm	March		April		May		June		Yield
		mm	%	mm	%	mm	%	mm	%	kg/ha
Optimum, mean 1980, 1984 and 1993	276	52	19	74	26	71	26	79	29	5852
Close to optimum for precipitation, deficit as yield 1970	250	26	10	46	18	147	56	41	16	2750
Close to optimum for precipitation, deficit as yield 1971	246	49	20	14	6	93	38	90	37	2850

The precipitation concentration in May, 56% of the total for the analysed period (1970) or in May or June, determined a decrease of the yield. The correction of the indicator as against the deviations from the optimum distribution must be the object of separate researches.

From the graphical analysis and that of the value series by years, in 1978, 1988 and 1991 the value of the precipitation indicator resulted to exceed by far the optimum value, causing a decrease of the yield when it had values higher than 300. In this case, the efficient precipitation has been calculated in terms of the achieved yield and the indicators initially established have been corrected. This operation regards only variants 1, 2 and 3; the rest (5-7) being located on slopes higher than 20%. The slope gradient and facing increased the water losses and therefore, no yield decrease is noticed as a result of the 300 mm threshold exceedance. Hence, in 3 out of 25 years or in 10 out of 100 years, on slopes under 12%, there is the risk of a wheat yield decrease by precipitation excess.

Another variability source is the surface runoff. The previously presented results have shown that for wheat, on low or moderate slopes, the water losses by the surface runoff are insignificant. In case of slopes higher than 20%, they become significant even for wheat. According to the researchers carried out by means of the runoff plots during 1997, the runoff exceeded 20 mm on 12% slopes. In the case of 20% slopes, they can be estimated at 30 mm, determining yields below 1 t/ha, even with the optimum fertilizing variants.

In the long-term research we must also have in view the effect of introducing new varieties with a higher productivity and of the improvement of the farming technologies. These factors can be revealed by means of the precipitation efficiency coefficient. Table 19 presents, for the 3rd variant, significant data in this sense.

The low values of the efficiency coefficient during the first 5 years are explained, as we have previously mentioned, also by the unfavorable distribution of precipitation by months. The quantification of the precipitation distribution effect and of the implementing of new, more productive varieties still remains to be solved.

Table 19. Mean over 5-year groups of the precipitation, yields and efficiency ratios at wheat

Period	Precipitation (mm)	Yield (kg/ha)	Efficiency coefficients. Rec./Prec.	Remarks
1970-1974	221	2916	13.2	
1975 -1979	230	4514	19.6	
1980-1984	217	4150	19.1	
1985 –1989	165	2760	16.7	
1990-1994	216	5221	24.0	

For maize the situation is clearer, the performances of the chosen indicator being better. Some corrections can be made in terms of the same previously analysed factors. As regarding the monthly distribution of the hydrothermal coefficient, the situation is simpler, as there are only 2 months. From the analysis carried out, the fact has resulted that only in one single year, 1976, a high amount of precipitation fell after the 15th of August and therefore, it has been partially valorized. This justified the correction of the hydrothermic coefficient from 0.600 to 0.400.

The hydrothermal coefficients exceeding by four the value obtained were achieved in 1978, which justified the correction of the value from 0.721 to 0.621. Another important factor is the surface runoff, which has higher values. Thus, in 12 years out of 25, for maize, during the vegetation period, runoffs exceeding 10 nun are recorded. The highest volume is in June when the volume of precipitation is the highest.

A critical situation occurred, like for wheat, in 1987, with the surface runoffs in July and August, which exceeded 20 mm. They have determined the correction of the hydrothermal coefficient from 0.406 to 0.294. In case of the slopes higher than 20%, the impact is stronger, which explains the very low maize yields during that year.

The effect of introducing hybrids with a high productivity is more obvious than for wheat, as can be noticed from Table 20.

Table 20. Mean over 5-year groups of the hydrothermal coefficient, of the corn yield and the yield/hydrothermal ratio *100

Period	Hydrothermal coefficient	Yield (kg/ha)	Yield hydr. coef.*100
1970 -1974	0.545	5820	106
1975 -1979	0.501	5096	102
1980 -1984	0.353	4744	135
1985 -1989	0.266	4256	158
1990 -1994	0.267	3822	141

The more reduced effect during the last 5 years can be explained by the fact that in 4 out of 5 years the hydrothermal coefficient had very low values, below 0.200, and the stress effect was very strong even for the varieties with a high productivity.

Besides the variability sources presented, those that were not the object of our study are: the hydric or hydrothermic conditions previous to the proposed period, the correct achievement of important technological elements as weeds, diseases or pests, control the land preparation, the period and conditions of the sowing etc.

The object of our paper was not the achievement of a mathematical model for the yield simulation but the determination of the participation degree of precipitation and temperatures for the establishment of the climatic risk. The proposed indicators have a bioclimatic character as they report the climatic events to the plant requirements.

The Plant Nutrition Institute of Italy (1989) recommended for yield estimation, in terms of the hydric regime, the logistical equation. By using an equation:

$$\mathbf{Y=a / [1 +b \exp(-mx)]}$$

where for wheat: x - precipitation in mm; y - yield in t/ha;
we have obtained for wheat in rotation and optimum fertilization (variant 3), a determination coefficient equal to 0.501, therefore higher than 0.473 obtained from the semilogarythmical equation. If the years previously mentioned an unfavorable precipitation distribution by months are eliminated, as well as the last 4 years with a strong reaction on yield increasing by the introduction of new varieties with a higher productivity and the improvement of the farming technology, the correlation coefficient sensibly increases to 0.777.

Efficiency of Fertilizers for Wheat and Maize and Crop Rotation at Wheat as Against the Climatic Indicators, on Slopes Higher than 12% and Soils with a Weak Erosion

The graph representations in Figures 5 and 6 emphasize the small influence of the proposed climatic indicators, for a monocrop with no fertilizers. The fertilizers effect increases with the value of the climatic indicators up to the optimum threshold which is 280 mm for wheat and 0.650 hydrothermal coefficient for maize. The strong differentiation of the crop rotation variant does not represent only its influence but also the influence of other factors with a positive effect. The results come from the production domain including lands with a mean 10 - 12% slope; therefore soils with a higher mean production potential.

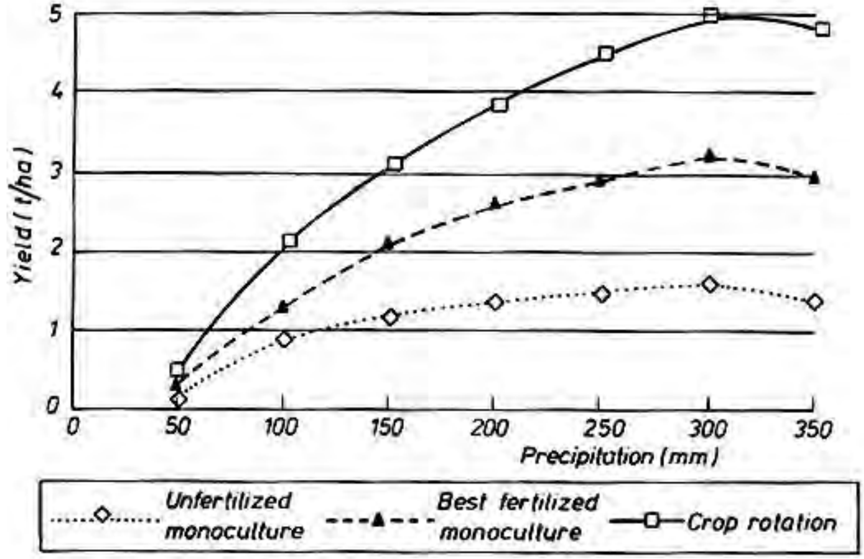


Figure 5. Efficiency of fertilizers with optimum rates and crop rotation, for wheat on 12% slopes

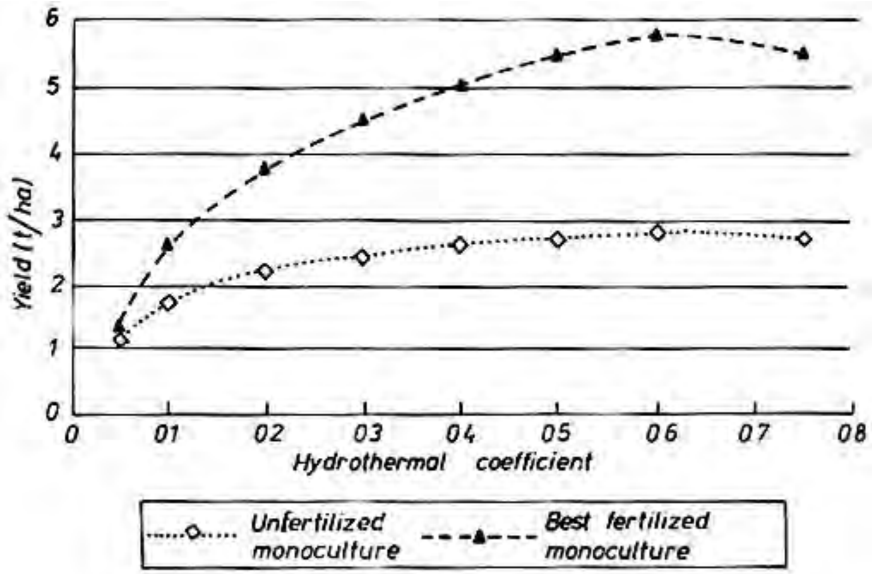


Figure 6. Efficiency of fertilizers for maize, as against climatic indices on 12% slopes

EFFICIENCY OF FERTILIZERS ON SOILS UNDER VARIOUS EROSION STATES, IN A WHEAT-MAIZE ROTATION, A 20-24% GRADIENT AND SOUTH-WESTERN FACING SLOPE

By examining Figures 7 and 8 a strong difference can be noticed of the yield on the uneroded soils in case of a land previously used as pasture as compared to an arable land with a strongly eroded soil. On eroded soils the efficiency of the fertilizers is higher.

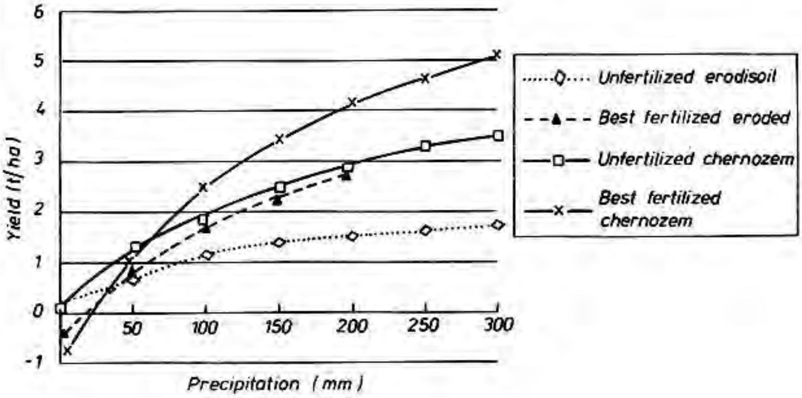


Figure 7. Yield and efficiency of fertilizers for wheat, on a 20-24% slope

Thus, by using mineral fertilizers in optimum rates, form the eroded soils yields are obtained that are close to those obtained on a previous pasture unfertilized land. The land to which the results were referred, had benefited from an efficient erosion control, being arranged in bench terraces and mixed with contour strip cropping.

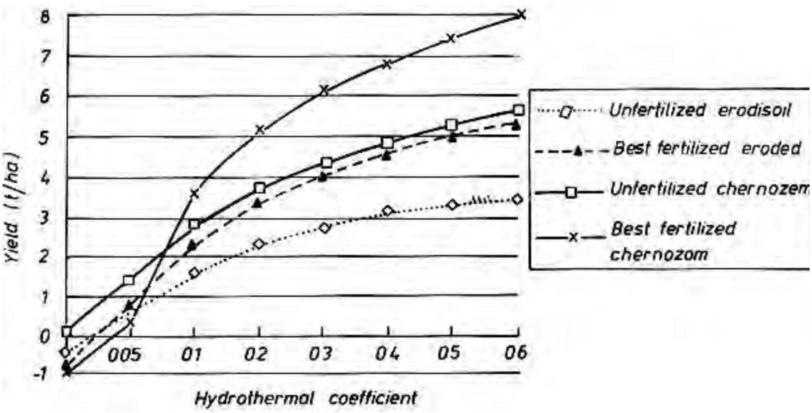


Figure 8. Yield and efficiency of fertilizers for maize, on a 20-24% slope

LONG-TERM EVOLUTION OF THE CLIMATIC INDICATORS AND OF THE MAIZE AND WHEAT YIELD

The criterion chosen to determine the long-term trend was the moving average over three years in order to reveal the influence of the unfavorable or favorable successive years. Figures 9 and 10 show the results during the 1970-1994 period for the variant of wheat in crop rotation and maize monocrop, best fertilized. It can be noticed that, first of all, there is a good agreement between the yield and the proposed climatic indicators, which confirms the previously formulated conclusions.

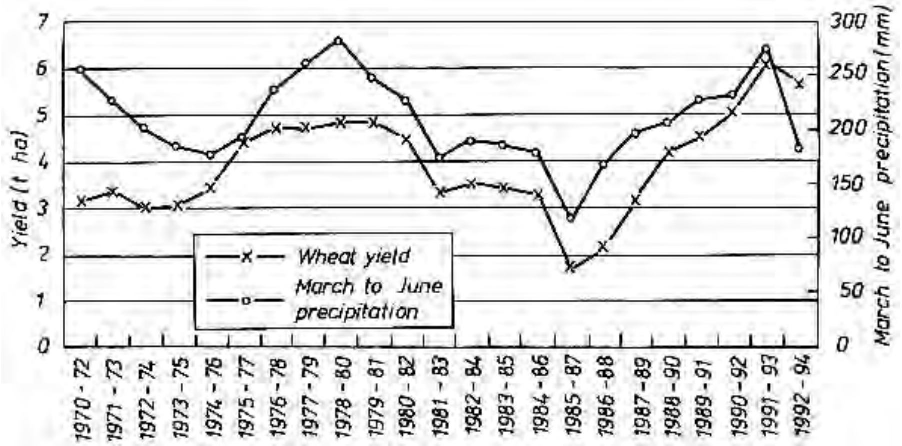


Figure 9. Moving average on three years for precipitation and wheat yield in crop rotation

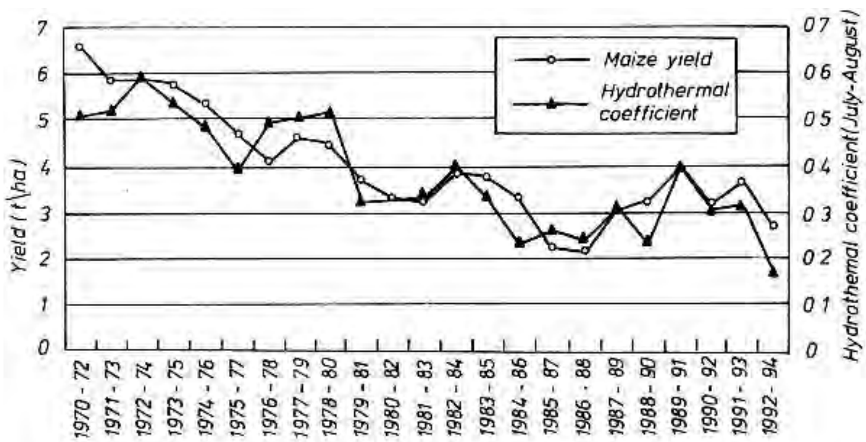


Figure 10. Moving average three years maize yield and hydrothermal coefficient

The precipitation valorization coefficient for wheat is weak during the first period and very good during the last one. For maize, an obvious increasing trend can be noticed for the hydrothermal deficit, the best conditions being at the beginning of the period. The valorization coefficient of the hydrothermal conditions increases, as it was previously noticed, being influenced by the higher production capacity of the new cultivated hybrids.

Having in view the conclusions over a 25-year period we have extended the analysis for a longer period of 54 years, representing the period 1940-1994. Figure 11 represents the evolution of the moving average of the two climatic indicators for wheat and maize.

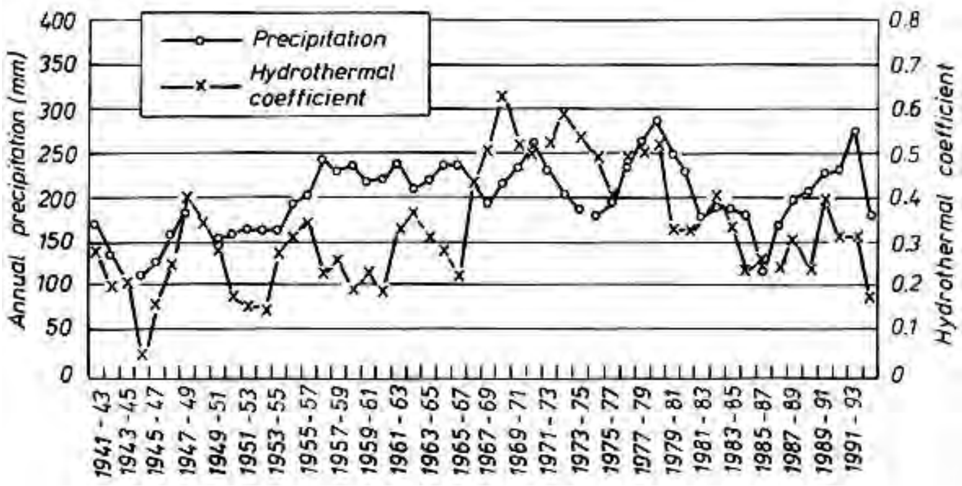


Figure 11. Moving average over three years for precipitation (March-June) and hydrothermal coefficient (July-August)

A larger variability of the indicator is noticed for maize as compared to the one for wheat, which records the lowest values during the most unfavorable periods. A 42-year cycle can be noticed when the most unfavorable conditions occur for wheat as well as maize. During the analysed period an obvious decreasing tendency cannot be noticed for the indicators values over the critical periods, for wheat during 1943-1946 and 1986-1987 and for maize during 1943-1946 and for 1988 and 1992. It is interesting to continue watching the evolution of the indicator for maize in order to see if there is a clear recovery trend as it is for wheat.

The moving mean helps to formulate methodological conclusions. The 25-year period (1970-1994) is representative, including the decreasing part of the climatic conditions, from the very favorable years to those with very low values. For wheat, the influence of the variants with a high productivity and of the technological improvement during the last period is confirmed as well as the possibility to correct the value of the precipitation indicator during the first period. Thus, a significant increase of the determination coefficient is achieved.

YIELD VARIABILITY AS AGAINST RELIEF, SOIL, EROSION, CULTIVATED PLANT, FARMING TECHNOLOGIES AND THE VALUE OF THE CLIMATIC INDICATOR

The chosen and previously presented variants allow the quantification of the influence of these factors. The analysis interval was, as for the moving mean, 54 years (1941-1994). The measured values were for a 25-year period (1970-1994) for the 12% mean slope and for the 12% mean slope and for the 20-24% slopes they were for a 14- year period (1976-1989). For the years without direct measurements the yield was estimated by means of the established equations (Table 16).

From the decisive factors for the yield, the climatic factor has a main part. During the analysed period, the wheat yield varied from 0.3 t/ha in the years with minimum values of the climatic indicator to 6.75 t/ha in the most favorable years in case of optimum technologies and for maize, from 0 to 8 t/ha/year with an optimum fertilizing. Maize ensures a double production as compared to wheat and the optimum fertilizing with mineral fertilizers gives 23-90% production increases. Table 21 shows the mean and relative values of the yields for a 54-year period. For the eroded soils, the fertilizers have a higher efficiency and maize ensures a better mean yield as compared to wheat, as it is cultivated after perennial grasses.

Table 21. Mean and relative values of the wheat and maize yields

Cultivated plant	Rotation	Treatment	Mean yield over 54 years (t/ha)	Relative values (%)		
Eastern mean slope 12%, slightly eroded chernozem						
Wheat	Monocrop	Non-fertilized	1.280	100		
	Monocrop	Best fertilized	2.415	189		
	Rotation	Best fertilized	3.775	295		
Maize	Monocrop	Non-	2.250	100		

		fertilized				
	Monocrop	Best fertilized	4.320	192		
South-western 20-24% slope, non eroded slope chernozem soil, farmer pasture						
Wheat	Wheat/maize	Non-fertilized	2.324	100	189	100
	Wheat/maize	Best fertilized	3.128	135	255	100
Maize	Wheat/maize	Non-fertilized	3.550	100	287	100
	Wheat/maize	Best fertilized	4.732	133	385	100
Cultivated plant	Rotation	Treatment	Mean yield over 54 years (t/ha)	Relative values (%)		
South-western 20-24% slope, eroded soil farmer arable						
Wheat	Wheat/maize	Non-fertilized	1.230	100	100	53
	Wheat/maize	Best fertilized	2.263	184	179	72
Maize	Wheat/maize	Non-fertilized	2.576	100	209	73
	Wheat/maize	Best fertilized	3.160	123	257	67

CLIMATIC RISK REGARDING THE WHEAT AND MAIZE CROP

When estimating the climatic risk, we had in view the climatic accidents such as: hail, frost, thermal shocks or agrotechnical conditions for sowing. The crops were set up during the optimum period.

The yields achieved or estimated have been grouped in classes. The chosen class interval was 0.5 t/ha. The estimated and measured yields do not differ by more than 0.5 t/ha except for very few cases.

Figures 12 - 17 present the number of years out of 100 when yields are achieved according to each class. We consider the years when the yield levels are below 0.5 t/ha as years of total calamity, when the soil quality or the fertilizers do not contribute to obtaining higher yields. Especially for maize, on the high slope lands with south-western facing, they have a negative effect. Thus, for the maize cultivated on eroded soils - in 6-7 years out of 100, the crop compromised, and for wheat - in 4-6 years.

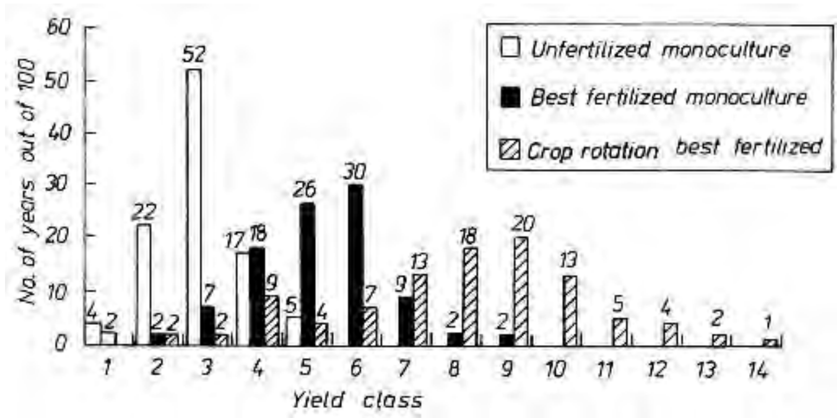


Figure 12. Frequency of years with various wheat yield levels, on 12% slope

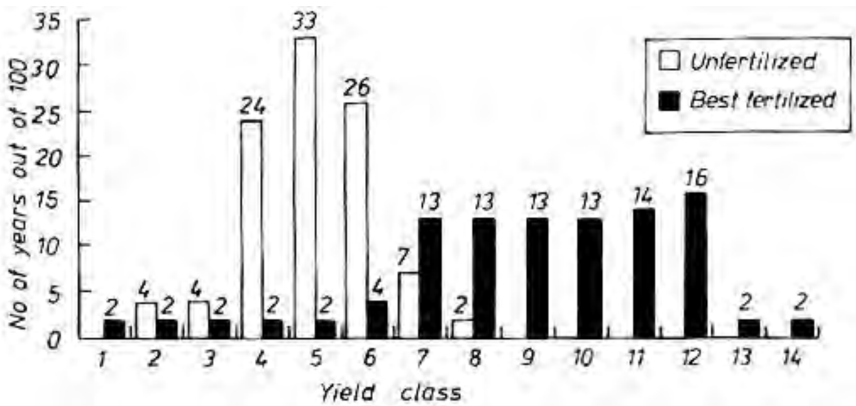


Figure 13. Frequency of years with various maize yield levels, on 12% slope

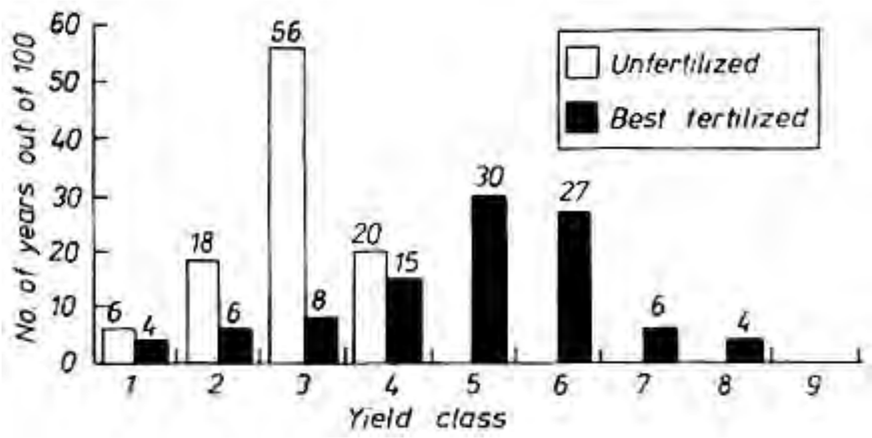


Figure 14. Frequency of years with various yield levels, erodisoil, on 20-24% slope, wheat crop, under wheat-maize rotation

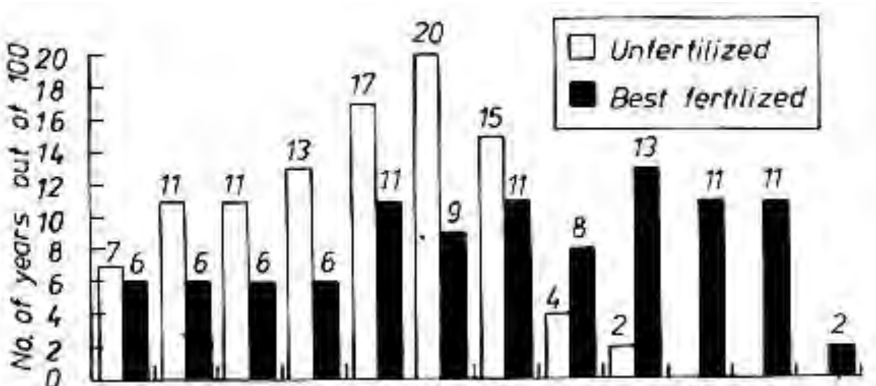


Figure 15. Frequency of years with various yield levels, erodisoil, on 20-24% slope, maize crop, under wheat-maize rotation

Even for the maize cultivated after perennial grasses in 4-6 years out of100, the crop is compromised. Therefore, estimation of the unfavorable years frequency has some advantages as regarding the mean production. By following the distribution of the years on crop classes, there is a more correct assessment of (he risk of each crop under various conditions and a more accurate estimation can be done for the economical efficiency of each crop in terms of the production prices and the crop valorizing prices.

The yields retroactive estimated to the experimentation period suppose the hypotheses of varieties and technologies similar to those practiced during the considered period.

If we refer concretely to the drought during the period 1944-1946, the estimated productions are higher as compared to the achieved ones.

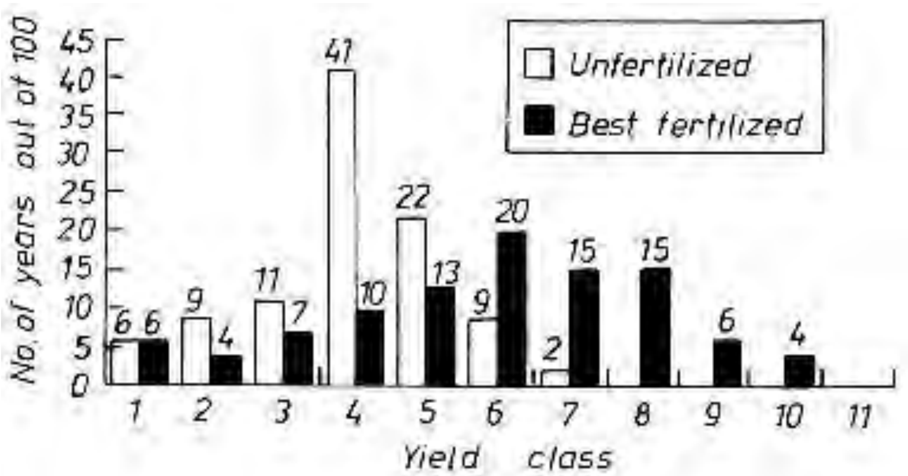


Figure 16. Frequency of years with various yield levels, slope chernozem, farmer pasture, 20-24% slope, wheat crop, under wheat-maize rotation

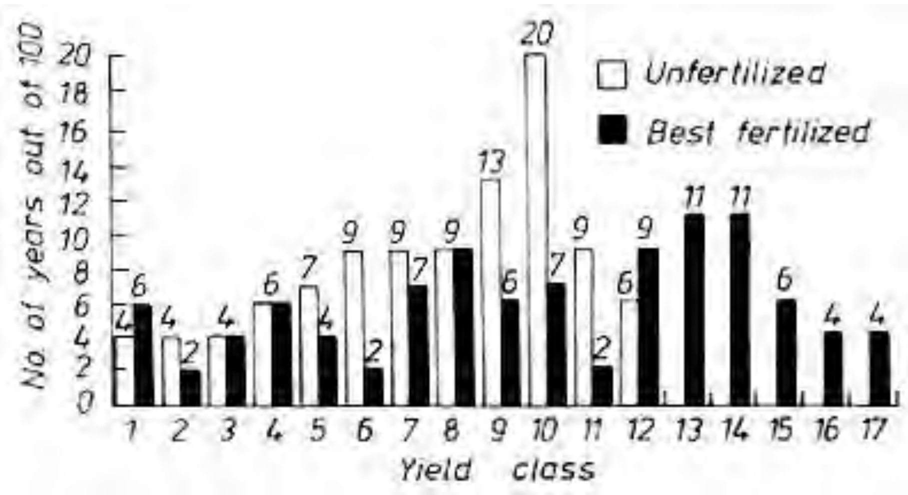


Figure 17. Frequency of years with various production levels, slope chernozem, farmer pasture, 20-24% slope, maize crop, under maize rotation

For the next period, the favorable influence of new varieties and the improvement of the cultivating techniques must be taken into consideration. It must be also mentioned that the technological progress has a very weak influence in the total calamity years. This means, for wheat, a precipitation sum during the period March- June below 50-80 mm, and for maize a hydrothermal coefficient for June and August below 0.050. The 0.5 - 1.0 t/ha production class, corresponding to 50 - 100 mm precipitation and 0.100 hydrothermic coefficient, can be considered as a partial calamity.

In this case, the influence of the farming technology, variety and soil quality is felt, as it can be noticed from the frequency graphs. High effects occur at the third production class (I -1.5 t/ha). This suggests a new classification according to the possibilities to control the drought.

CORRECTION OF THE PRECIPITATION DEFICIT BY CROP IRRIGATION

The climatic risk due to the precipitation deficit can be eliminated by the irrigation of crops. Moldavian Plateau, in the future, there will be no agriculture under irrigation conditions; we will comment upon some results obtained by Grumeza N. (1994) at the experimental field of Cosmesti - Tecuci, located in the same climatic area as the Perieni Station. The experimentation period was 1976 - 1994. By analyzing the mean value of the climatic indicators for the mentioned period, similar conditions resulted for wheat. For maize, more favorable conditions were recorded at Cosmesti - Tecuci, which were reflected in higher productions in the unirrigated variant. By irrigation, for wheat, in the optimum variant, a 203% higher average yield over 15 years was obtained as compared to the unirrigated variant and for maize the yield increase was by 210%.

From the analysis of the climatic indicators' distribution on months, a particular case resulted in 1982 regarding the hydrothermal coefficient. For the months of July and August this has the value of 0.757 exceeding the optimum value. However, by irrigation a significant production increase was obtained determined by a large precipitation deficit in May covered by watering. Therefore, it is justified to correct the hydrothermal coefficient also in the case when it has lower values than 0.100 during the previous months to the critical season.

From the climatic risk point of view the distribution of the years with various production levels at the irrigated and nonirrigated crops, is also of interest. Figures 18 and 19 show the results for the wheat and maize crops. The chosen class interval is larger: 0.1 t/ha for wheat and for maize 1.0 t/ha for smaller yields than 8 t/ha and 2 t/ha for higher yields.

In the nonirrigated variant the distribution is close to that at Perieni, especially for wheat, with some differences determined especially by the used analysis period, 54 years at Perieni and 19 years at Cosmesti, by the different technological level and soil fertility. However, it is important to underline that for wheat in 20 years out of 100, in the unirrigated crop, equal yields are obtained as for the irrigated one, and for maize only in 15 years. The maximum frequency of 43 years out of 100, for irrigated wheat, represents the production class 3 - 4 t/ha and for irrigated maize, at the maximum frequency of 47 years out of 100 corresponds to the 8 - 10 t/ha production class. This proves the high yield potential of maize under irrigation conditions as it valorizes the thermal potential of the area and the lower favourability degree for the unirrigated crop.

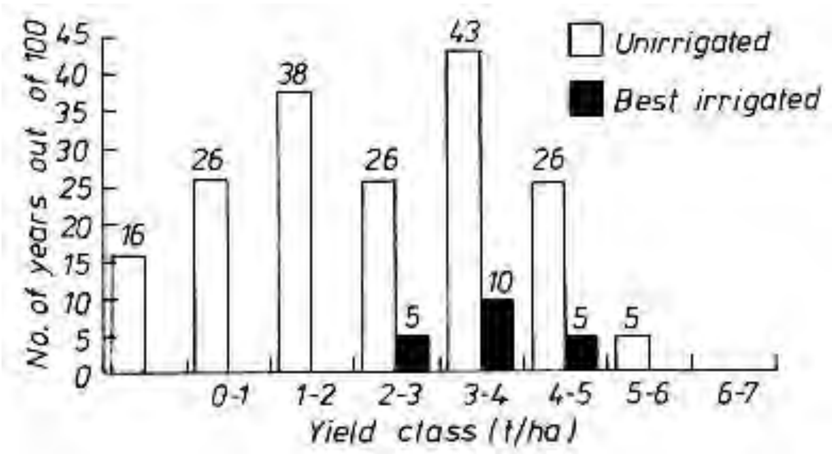


Figure 18. Distribution of wheat yields

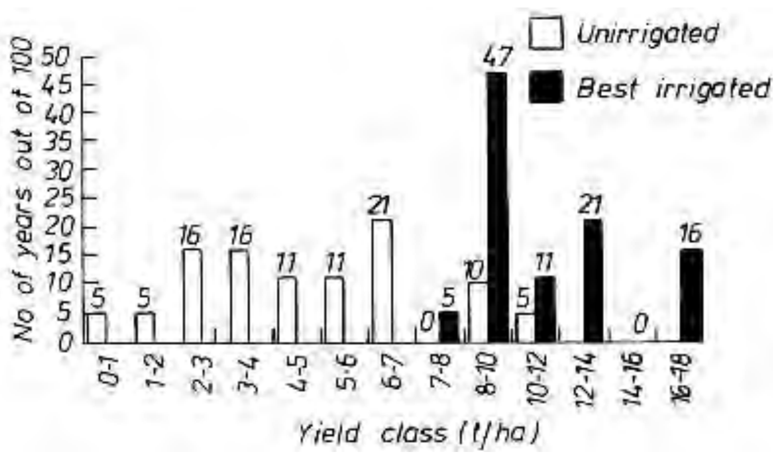


Figure 19. Distribution of maize yields

However, the double production capacity of the maize as compared to wheat determines the cultivators to give priority to maize but the production costs for the product unit are higher as compared to those in the favorable areas.

Conclusions

The purpose of the paper it to carry out a method for the interpretation of the results of long-term experiments and the assigning of some indicators for the erosional and climatic risk at the maize and wheat crops.

From the methodological standpoint, and improvement has been achieved for the estimation method of the runoff and erosion for the slopes with agricultural crops, by introducing correction coefficients on months. We have also established three erosional risk categories, which is a new element in the domain.

As regarding the climatic risk, for the wheat and maize crops, the proposed indicators including the critical period of the crop formation, allow a satisfactory assessing of the crop, without equaling the performances of the deterministic models, but enough to perform long-term analyses.

From the practical point of view, a quantification has been obtained of the climatic favourability in the Moldavian Table and for the wheat and maize crops, on the basis of the frequency of years with various crop yields as well as the effect of technological links such as fertilizers and the crop-rotation under various climatic conditions.

The data presented as tables and graphs serve it1the long-term substantiation of the subsidy policy and of the economical efficiency calculation of the wheat and maize crop as well as of the fertilizer and rotation use. The higher risk in the droughty years for the eroded soils on lands with a slope higher than 20% has been emphasized and quantified as well as the possibility to correct the precipitation deficit by crop irrigation.

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SEDIMENT DELIVERY SCENARIOS FROM SMALL WATERSHEDS

ION IONITA

Abstract: Long -term field measurements of runoff and gully erosion rates from small watersheds under short-term streamflows have been accomplished. Applying field experiences and reviewing what is known about the sediment movement from watersheds allowed to identify two types of sediment delivery scenarios. Briefly they are synchronous and asynchronous. Two case studies were separated within first scenario type when debris production and debris cleanout are almost simultaneously. The case for cold season is related to freeze-thaw cycles and is usually displaying during late winter. The case for warm season is resulting from extremely heavy rainfalls and significant successive rains. The major feature of this less frequent scenario is the huge value of the suspended sediment concentration recorded at the watershed outlet, mainly. The asynchronous scenario has a common occurrence. This type is consisting on a preparing stage during late-winter and early spring and a channel debris cleanout stage by runoff. The shape of turbidity curve is fluctuating with high values during first spring rainstorms and greatly reduced values for each subsequent runoff event throughout the year.

Introduction

Presently, watersheds sediment models and designing of conservation practices are depending upon an adequate quantity of both runoff and sediment-yield data. This is a difficult goal in areas under short-term or "flash" streamflows and high erosion rates, particularly. For nearly 20 years a sediment data collection project was initiated to aid in the understanding of the real hydrological response from small agricultural watersheds subjected to severe erosion. In this sense, the shapes of the sediment concentration curves and runoff hydrographs reflect the impact of the physical conditions on the hydrologic output. The question for which an answer is being sought is weather relating sediment concentration to water discharge may aid in solving some if the sediment-yield problems in Eastern Romania. Among these is a great concern as to the relative contribution of valley-bottom gullies compared to the upland sources of sediment.

The purpose of this paper is to review what is known about the sediment movement from watersheds with temporary runoff and to define the main patterns of sediment delivery by applying field experiences from monitored watersheds near Barlad. The possibility of interpreting discharge-sediment concentration curves for this purpose is explored.

The study area

Topography of the area is characterized by rolling hills of the Moldavian Plateau, Romania. Maximum relief is approximately 321 m and the lowest elevation decreases below 100 m along the flood plain of the Barlad River.

Relatively hot summers and cold winters are resulting in a temperate climate by continental regime with average annual temperature around 9^{o}C. Rainfall distribution throughout the year is bimodal with peak monthly amounts during June and November. Most precipitation falls as rain and its normal mean annual value is about 500 mm (20 inches). Given the high variability of snowcap in space and time, there is a low probability of snowmelt streamflow occurrence in each year.

Several watersheds were established ranging in size from a few to 3,000 hectares for the entire study area. They are underlain by loamy-clayey wooden soils, developed on deep sandy-clayey Pliocene layers. Cropland as the primarily land-use is subsequently followed by pastureland and remote forests.

Most of the data were collected in the Chioara-Ghermanesti watershed (46^{o}20'N 27^{o}50'E) that lies north-northeast of the Barlad City within Falciu Hills. It encompasses 2,963 hectares from which only 12.4% are under forest.

Methods

The main interest was focused on concurrent field measurements of streamflow and sediment as requires the sediment-rating curve-flow duration method. However, considerable efforts have been made to get reliable flow sampling. There were trials to perform both automatic and manual sampling. In many cases, because the suspended sediment concentration (turbidity) is high the ISCO automatic pump sampler did not work out. Therefore, during significant snowmelt runoff a hand operating was accomplished by the dual sampling of streamflow at different sites above the gully headcut and at the watershed outlet, specially. Nearly all samples were collected at a 5 to 15 minutes intervals during the runoff events. During heavy rainfalls the manual sampling was only made in the lower part of the watershed.

Streamflow samples collected above the gully headcut should reflect the quantities of sediment contributed by sheet-rill erosion whereas samples collected downstream represent sediment eroded from both the field and the gully.

Additional streamflow measurements utilized in this study include cross-sectional area of the flow, wetted perimeter, hydraulic radius, velocity of the flow, roughness coefficient, etc.

Gully erosion rates were measured by several procedures. Sufficient details of linear advance rate and areal change would be given by topographic survey. In some locations very accurate data were collected by means of a particular "stake-grid" method. A distinguishing feature of this grid is that the wooden stakes are closely distributed along the main alignments around gully headcut. Volumetric gully erosion rates have been determined by cross-sectioning methods. Such stationary, successive measurements on gully growth have been made several times throughout the year.

Results and discussion

Based on long-term data collected in the southern part of the Moldavian Tableland two major types of sediment delivery scenarios were identified, respectively, **synchronous and asynchronous**.

First scenario type indicates that the two subprocesses of debris production and debris cleanout are almost simultaneously within one stage. The synchronous scenario may occur very seldom. It requires crossing of the factors controlling sediment delivery in an optimum state both at the end of cold season (thermic variations, well-marked field moisture, adequate precipitation and runoff) and during warm season (uncommon heavy or successive rainfalls, high soil moisture content, low effectiveness of plant cover, lack or scarcity of recent debris on gully bottom, significant streamflows). This scenario is to be considered in two cases. Briefly these are **cold season and warm season**.

The case for cold season is related to the freeze -thaw weathering. Relatively marked runoff could result from snowmelt or mixed precipitation during late or gentle prolonged winter, usually. The main feature of such a case is consisting of that gullying represents the major sediment source.

Data collected within Chioara basin during two series of representative snowmelt events should describe this case. The first series is associated to runoff events induced by a **quick thaw** between March 19-23, 1993. In terms of active precipitation that brought changes in the gully configuration estimates run 54.0 mm over the period February 15-March 9, 1993.

Several important conclusions can be gleaned from this five days series subjected to a **high thermic level**:

- Peak water discharges (5.01 c.m/s and 4.02 c.m/s) were recorded during the second and the third days of thawing under daily maximum temperature by 11.4°C and 11.9°C respectively, as shown in Figure 2 and Figure 3.
- Maximum values of measured turbidity are huge ($312\, g \cdot l^{-1}$ or thousands PPM and $279\, g \cdot l^{-1}$). Over these two snowmelt flow events the suspended sediment concentration was ranging between 100 -300 $g \cdot l^{-1}$.
- Peak turbidity is preceding the peak runoff by 60-90 minutes.
- Sediment concentration curve has a pulsatory shape but there was not any debris-free period as suggested by Piest R. F. et al. (1975).
- Sediment delivery by gullying is concurrently with the cleanout of the gully channel during these two days when the snowcap was exhausted. Even the turbidity remains as high as $195\, g \cdot l^{-1}$ during the last two days the peak runoff is drastically diminishing and it did not exceed 1.15 c.m/sec.
- Measured maximum velocity of flow was 2.70 and 2.53 m/sec.
- During this five days series of quick thaw the headcut of Valcioaia and Tumba continuous gullies advanced by 10.1 m and 2.7 m respectively.

For smaller basins as Scranghita-Roscani (90 ha) which is displaying active discontinuous gullies, the snowmelt runoff of March 21, 1980 is of interest, too.

As shown in Figure 4 the sediment concentration and water discharge reached a maximum soon after runoff began. There still is a lapse time between the peak turbidity ($119\, g \cdot l^{-1}$) and peak runoff (0.4 c.m/sec). Then, sediment concentration rapidly decreased to $27\, g \cdot l^{-1}$and got slightly pulsatory to the end with values varying from 30 to $50\, g \cdot l^{-1}$ (30,000-50,000 PPM).

The second series of runoff events at Chioara-Ghermanesti watershed resulted from a **slow and prolonged thaw** dated on March 19-30, 1996 when eight flows occurred. The maximum air temperatures were ranging from 2.8 to 8.1°C as is partly illustrated graphically in Figure 5.

Figure 6 shows the water discharge and turbidity at Chioara basin for three of the eight runoff events of March 1996 when the sediment concentration curves were defined by 81 samples. The basic features of these runoff events occurred under a **lower thermic** level would be summarized as follows:

- Peak water discharge (5.31 c.m/sec) and suspended sediment concentration ($237\, g \cdot l^{-1}$) were recorded during the fifth snowmelt event of March 27, 1996;

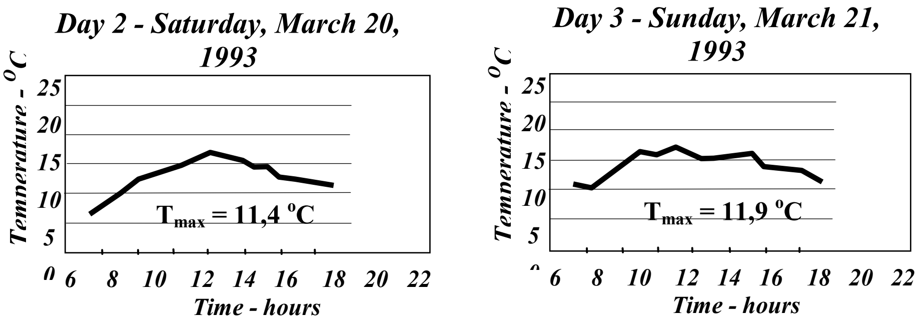

Figure 2.- High air thermic level for March 20-21, 1993 at Barlad

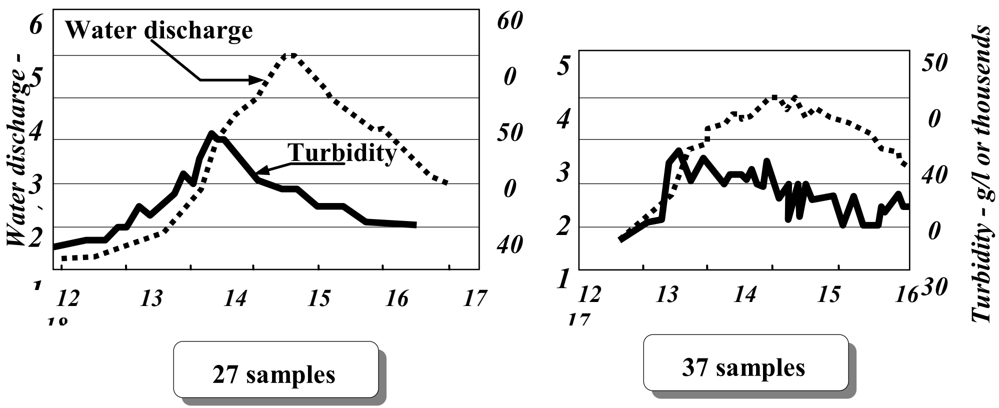

Figure 3.- Hydrograph and suspended sediment concentration during snowmelt events of March 20-21, 1993 at Chioara - Ghermanesti basin (2963 ha), near Barlad

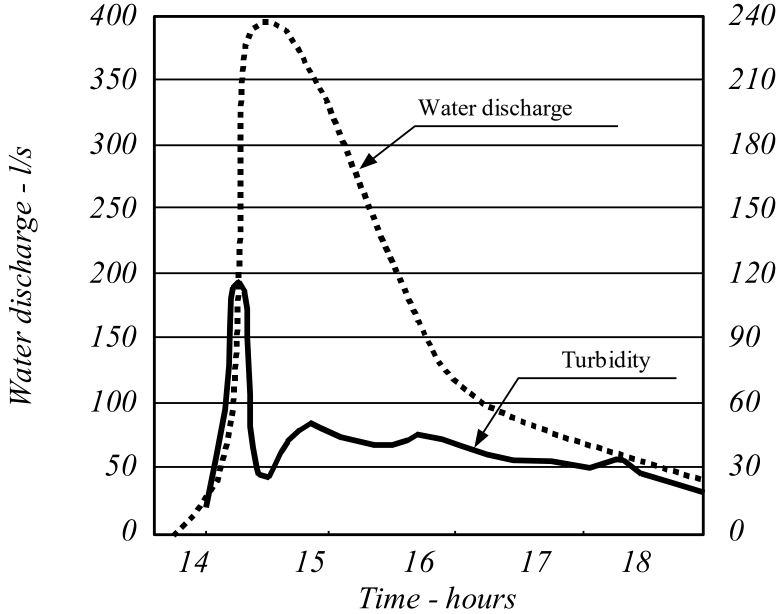

Figure 4.- Hydrograph and sediment concentration on the upper Roscani Valley, during March 2, 1980

- Recording moments of the peak runoff and turbidity are now coinciding;
- Measured stream velocity run to 2.77 m/sec.

Field measurements on runoff above the gully headcut indicate that the sediment concentration values range from 3 to 16 $g \cdot l^{-1}$ on the valley-bottom and around 40 $g \cdot l^{-1}$ within rills on hillslopes. The latter values emphasize those data obtained by simulating rill erosion at Perieni as cited Motoc M. and Ouatu O. (1977, 1985). By the other hand, most of the sediment delivered by hillside rills is deposited on the valley-bottom and it did not reach the main streamflows.

If the flow induced by mixed precipitation on April 15, 1996 is taken into account a linear advance by 13.0 m and an areal growth of 238 sq. meters of Valcioaia gullyhead have been measured.

These data reveal that during significant runoff events occurring over cold season sediment concentration is low in the upper watershed, above the gully headcut and extremely high in the lower watershed. Therefore, under the lack of splash erosion, which is common for the cold season, gullying remains the major sediment source.

The effectiveness of gullying processes is usually greater at late winter as noticed by Ionita I. (1997). This conclusion could be underlined

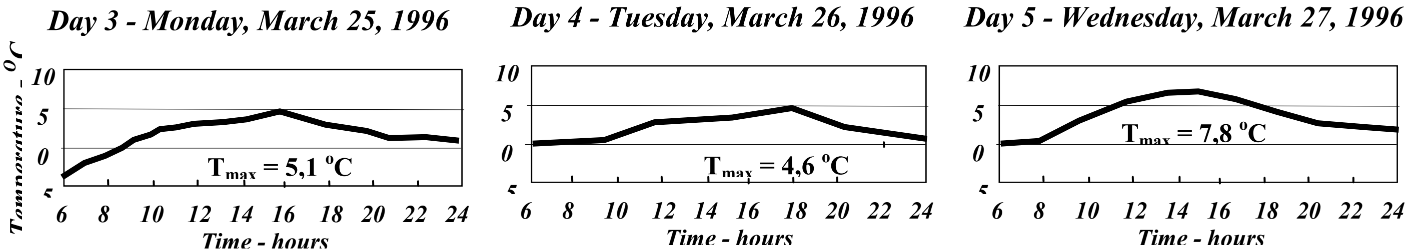

Figure 5.- Low air thermic level for March 25-27, 1996 at Barlad

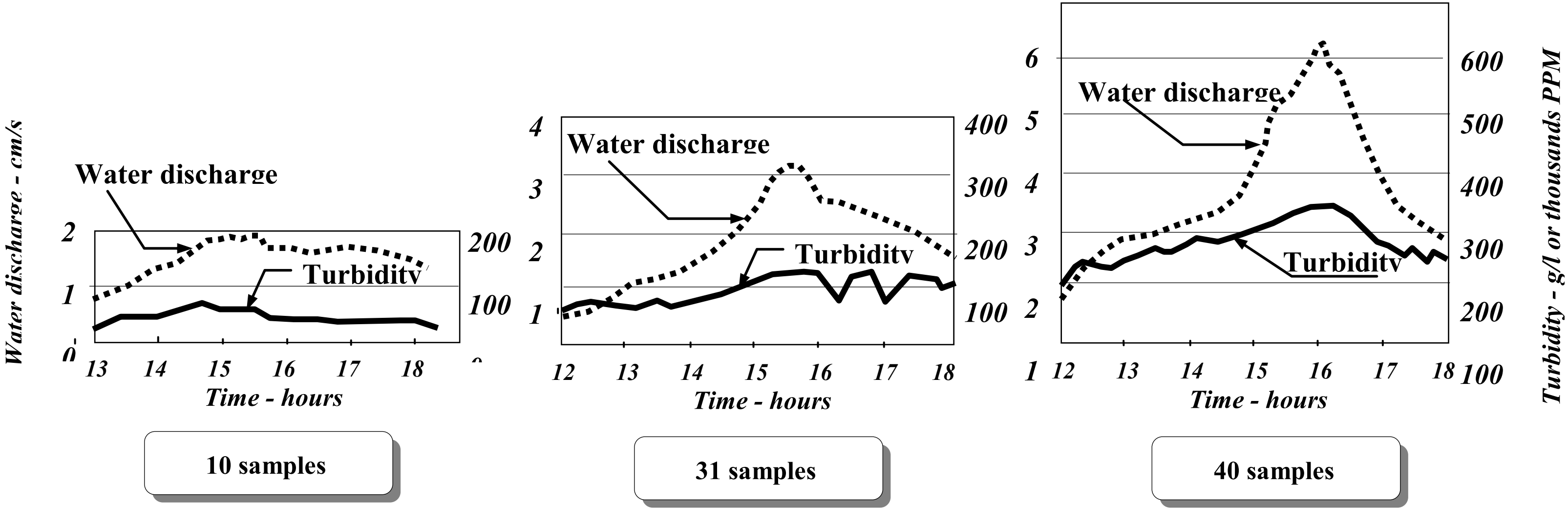

Figure 6.- Hydrograph and suspended sediment concentration during snowmelt events of March 25-27, 1996 at Chioara - Ghe[illegible]manesti basin, Falciu Hills, near Barlad

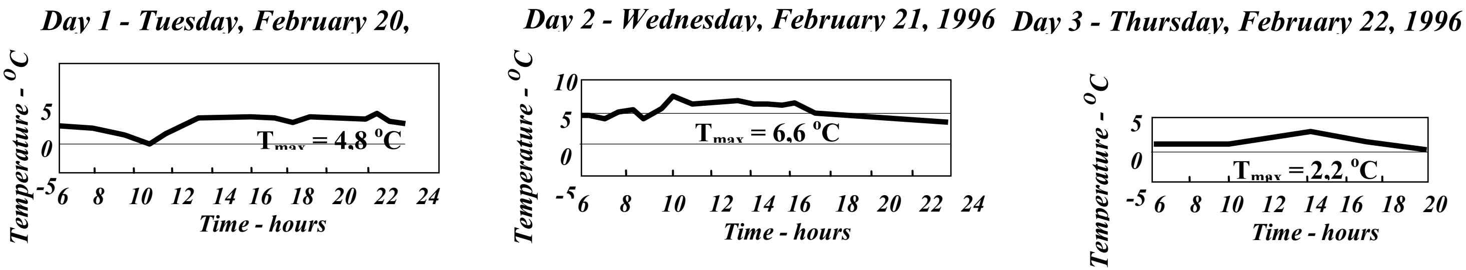

Figure 7- Air temperature for a short thawing "window" during February 20-22, 1996 at Barlad

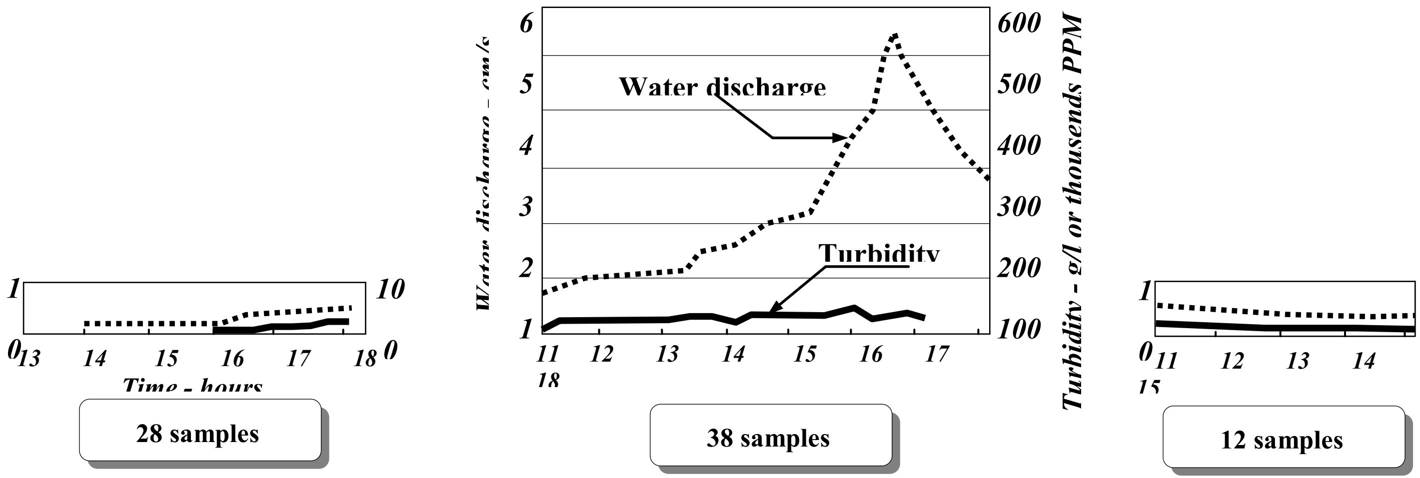

Figure 8- Snowmelt streamflows and turbidity on Chioara - Ghermanesti basin (2963 ha),
Falciu Hills, near Barlad, February 20-22, 1996

by runoff events occurred during an earlier and short thawing "window" on February 20-22, 1996. As shown in Figure 7 the maximum air temperature run to 6.6^{o}C. Figure 8 illustrates that the main streamflows was recorded in the second thawing day. The peak runoff sharply increased at 5.5 c.m/sec and by contrast the shape of turbidity curve was a flat one ranging in the size from 11.0 to 44.0 $g \cdot l^{-1}$. This low erosional response can be explained by the scarcity of gully soil debris. Even the maximum stream velocity was by 2.45 m/sec, the shallow thawing depthhas limited debris supply. The main sediment delivery events will take place one month later.

The **case for warm season** is less frequent than the previous. These few events by synchronism of debris detaching and debris cleanout are related to extremely heavy rainfalls and/or significant successive rains. At least two general conditions are necessary to induce such events. Gully headcut area must be free of soil debris and land must be sufficient wet.

The identified features of this case are:

- Greater chances to occur from late May to middle of July;
- Marked streamflows are associated with high peak water discharges ranging up to several tens of c.m/sec.
- Measured stream velocity is greater than 3 m/sec;
- Sediment concentration is very high within the whole watershed, usually from 100 to 200 $g \cdot l^{-1}$ (100,000-200,000 thousands PPM);
- Measured downstream maximum turbidity was 232-259 $g \cdot l^{-1}$;
- Surface and gully erosion is the main sediment sources.

The **asynchronous scenario** represents the most frequent type over the Moldavian Tableland where detaching of wasted soil debris is not simultaneously with the debris cleanout. Its typical form is corresponding to that two-part cycle described by Piest R. F. et al. (1975) at Treynor watersheds of western Iowa. As stated by the senior author above cited *"the Treynor studies tend to verify that a large part of the gully soil debris accumulates during winter and early spring and is flushed from the channel with the first spring rainstorms"*.

Two stages (subprocesses) have been separated. The **preparing stage** (*debris production subprocess*) is resulting from freeze-thaw cycle. Based on visual evidence and stationary measurements on gully activity from Barlad watershed, usually, a great amount of gully soil debris has been noticed to accumulate soon after the main snowmelt runoff. That means the maximum mass wasting is subsequent to exhausting of almost the entire snowcap and it throws out at a critical thermic level when thaw gets deeper through gullyhead.

Therefore, this stage is strongly depending on the magnitude, frequency and duration of freeze-thaw cycles, specially during late winter.

During the **second stage** of this scenario we are attending with the *cleanout* of the previous prepared debris. In many instances, a partial cleaning of the previous materials mixed with a relatively slight new gullying occurred. However, a fluctuant sediment concentration is prevailing as part of this scenario. Three major runoff events may be recognized in the asynchronous scenario resulting from first spring rainstorms, spring and summer rainstorms and long-term rains.

The first runoff events occurred during late May and June. Marked streamflows are defined by high water discharges resulting from heavy rainfalls. Sediment concentration is very high within the whole basin ranging from 80-120 $g \cdot l^{-1}$ on cultivated hillsides under row spaced crops to 200-300 $g \cdot l^{-1}$ on streams. During such extremely rainstorms, high rates of surface and gully erosion have been recorded.

Later on, relative debris quantities moved are greatly reduced for each subsequent runoff event. The canopy protection of crops is progressively increasing through summer and cause decreasing erosion rates as cited by Motoc M. and Ionita I. (1983), Ionita I. and Ouatu O. (1985 and 1990). Anyhow, fluctuant sediment concentration is related to cover factor, pre-existing gully debris or sediment renewing by surface and gully erosion. Ionita I. (1997) stated that after middle of July there was no significant gullying in the Moldavian Tableland.

Finally, long-term rains on small watersheds are inducing streamflows with low turbidity values varying between 40 to 60 $g \cdot l^{-1}$, usually. That means the shape of sediment concentration curves is pretty flat.

A suggestive understanding of the asynchronous scenario is graphically presented in Figure 9 for a large area (49,100 ha) of Berheci basin from Tutova Rolling Hills at Feldioara. The shape of its suspended sediment discharge curve is obviously depicted by two peaks. The minor maximum must be related to gully debris delivered by snowmelt events during March. The major peak of suspended sediment discharge must result from cleanout of the previous gully soil debris and both surface and renewing gully erosion.

Conclusions

Repeated field measurements in the Moldavian Tableland of Eastern Romania allowed to identify two types of sediment delivery scenarios,

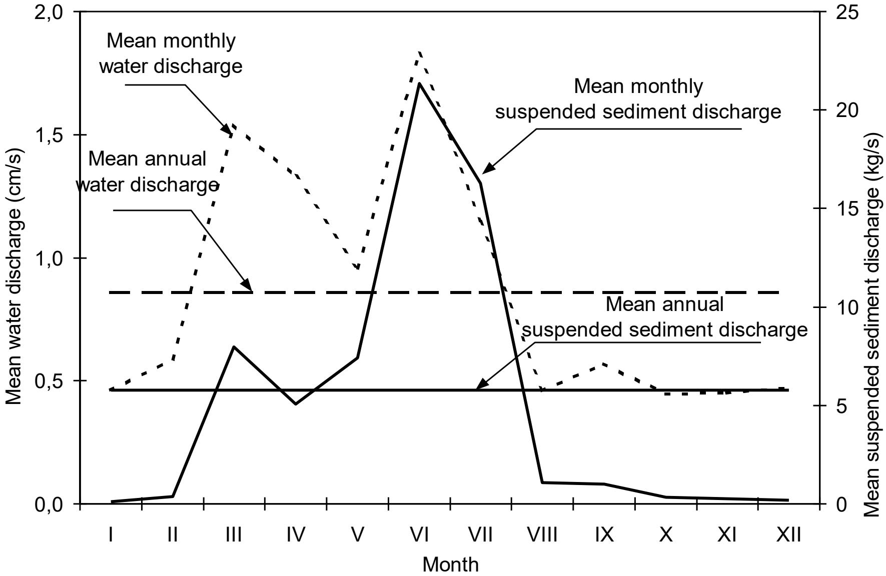

Figure 9.- Mean monthly water and suspended sediment discharges from Lower Berheci basin of Tutova Rolling Hills at Feldioara (1984-1993)

respectively, synchronous and asynchronous. Shape of the suspended sediment concentration curves was used as a main criterion for establishing these scenarios.

Specific findings of the **synchronous scenario** are:

- It may occur very seldom and it is related to cold season, mostly.
- Debris production and debris cleanout are almost simultaneously within one stage.
- Huge values of the suspended sediment concentration (100-300 g/l or thousands PPM) in the lower part of the basin and low values (up to 40 g/l) in the upper basin are indicating that during late or gentle prolonged winter gully erosion is the major sediment source.
- During warm season, especially late May to middle of July, turbidity value is high (100-200 g/l usually) in the whole basin and, therefore, the main sediment sources are surface and gully erosion.

The **asynchronous scenario** represents the most frequent type and it is consisting in two non-simultaneously stages or subprocesses.

The preparing stage, debris production, is resulting from freeze-thaw cycle and the second stage, cleanout of the previous debris, is subsequent occurring. Fluctuant suspended sedimen concentration is prevailing this time.

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HYDRAULIC EFFICIENCY OF THE DISCONTINUOUS GULLIES

ION IONITA

Abstract: Most of the discontinuous gullies overlying the almost tabular sedimentary strata of the Moldavian Plateau-Eastern Romania exhibit both proper gullying, mainly if not exclusively by gully head advance, and aggradation of the gully basin floor. According to Heede (1974) the shape factor of the gullies, relating maximum to minimum depth, expresses both channel shape and hydraulic efficiency of the channels.

Based on a geomorphic approach too, this paper tries to underline that a better understanding of gully hydraulic efficiency may be assessed by another shape factor, obtained by relating present to filled gully cross section. Value 1.0 of this shape factor, S_p/S_f, represents the threshold of hydraulic efficiency. Strong relationships were established by plotting the shape factor to the gully length. In addition, to save time and money, an appropriate substitute expressed as the ratio of gully bottom width (W_b) to gully top width (W_t) was found. The W_b/W_t indicator is easily applicable as it can be very fast determined in the field.

Keywords: discontinuous gullies, aggradation, shape factor

Introduction

During a study of channel characteristics of some western streams, Schumm (1960) discovered that the shape of the channel of stable rivers expressed as a width-depth ratio (F) is related to the percentage of sediment finer than 0.074 mm in the perimeter of the channel (M) as follows:

$$F = 255 \cdot M^{-1.08}$$

This shape factor (F), which is defined as the bankfull top width divided by the bankfull maximum depth, was later often used in the quantitative study of gullies.

Soil Conservation Service of the US Department of Agriculture in the "Technical Release No. 32 (Geology)" of 1966, recommended comparison of the top widths (TW) and depth (D) of a large number of gullies as one method of determining the gully channel widening that will occur. There were established the following relationships for two main conditions:

$D = 0.34TW$ through cohesive materials and

$D = 0.57TW$ in non-cohesive soils.

Therefore the gully width is about three times the depth through cohesive materials and it is about 1.75 the depth in non-cohesive materials.

To establish gully morphology and possible stages of gully development, Heede (1974, 1976) analyzed the hydraulic geometry of 17 gullies located on Alkali Creek watershed, on the western flank of the Colorado Rocky Mountains.

Three hydraulic parameters have been considered as follows:

- Stream order analysis;
- Investigation of the longitudinal gully profile and
- The shape factor, relating maximum to mean depth. Mean depth is the cross-sectional area divided by the bankfull channel width.

The new shape factor is more elaborated than the width-depth ratio (F) established by Schumm. However, Heede suggests that this parameter must be interpreted cautiously because it can relate to a variety of unusual gully cross sections.

According to Heede (1974) the value 2.0 of the shape factor represents the threshold of hydraulic efficiency.

The relatively high values of the shape factor of Alkali Creek gullies indicate hydraulic inefficiency of the channels. Rivers in dynamic equilibrium have an average shape factor smaller than 2.0 and thus a greater hydraulic efficiency.

Based on this concept Maria Radoane et al. (1990) investigated 8 discontinuous gullies located on the northern part of the Moldavian Plateau from Eastern Romania. The Heede's shape factor was determined in 133 gully cross sections for gullies of 173-428 m length. By plotting of shape factor (F) values versus gully length (L) they derived the following relationship:

$$F = 1.287 + 0.00199 \cdot L$$

The correlation coefficient for this relationship is a weak one being 0.392. The intersection point between the regression line and the threshold line of hydraulic efficiency is located at an average distance of 350 m downward the gully head. This would indicate the reach where the gullies express mature stage of development and even the phase of stabilization.

Methods

Long-term study undertaken by Ionita (1998) in the southern part of the Moldavian Plateau, in the neighborhood of Barlad City, allowed to establish a tentative classification of discontinuous gullies, that may become an useful guide to further research.

By means of an Eijkelkamp auger kit the recent alluvia deposited along the gully floor were drilled. Therefore, it was possible to identify the initial gully floor in different cross sections as well as the thickness of sediment progressively deposited within the gullies. Such an opportunity can afford to examine the total gully cross section as follows:

- The present section or the available section at one time in a specific place that is visible for the naked eye and it is determined by classical measurements;
- The filled or siltated section, which is revealed by drilling in the recent alluvia or it is outcropping in some active gully heads.

Results and discussion

On the basis of data limited to gully morphology and the rate of aggradation, there have been distinguished three groups of discontinuous gullies.

1. Group of singly (isolated, classical) gullies where aggradation begins immediately below the headcut area and, as moving downstream, the gully floor gets progressively flaring. The average weight of the siltated area is around 59% of the total. It has the shape of a converse, prolonged funnel (divergent system or long diffusor) as shown in Figure 1.

2. Group of successive (chain, cascade) gullies divided by the rate of aggradation in:

2.1 Alluvial family, where the depositional gully floor is averaging 17-45 % of the total gully area. By their pane configuration there were identified two types:

- Convergent gullies, which through their lobate shape (confusor) look like normal funnel and,
- Divergent gullies wherein the flaring and short gully floor is resembling of a converse funnel (short diffusor) as illustrated in Fig. 2.

These are the most commonly gullies in the study area.

2.2 Erosional family, where the erosion processes are prevailing and aggradation is subsequent.

3. Batteries of discontinuous gullies, which are joining features from the previous two main groups, singly and successive gullies.

Analysis of the total section of discontinuous gullies in the neighborhood of Barlad City allowed to establish a new indicator of hydraulic efficiency by relating present section (S_p) to filled section (S_f). Value 1.0 of this shape factor (S_p/S_f) represents the threshold of hydraulic efficiency within discontinuous gullies. The higher values than this threshold are characterizing the efficient gully reach, capable to evacuate runoff. The subunit values define the inefficient gully reach, that on long-term is stifled by alluvia. Therefore, the significance of these values is different in comparison with that of Heede.

Plotting of present to filled section (S_p/S_f) from 11 total cross sections versus gully length is illustrated in Figure 3. Measurements were made on three isolated gullies of similar 112-120 m length, from Caldarea and Harcioaia Valleys. Graph of the regression equation suggests an inverse but strong relationship (R^2=0.9306) between the variables. On the other hand, it is obviously that the singly discontinuous gullies are exceeding the critical threshold 1.0 only along 43 % of their length. Thus they are associated with low hydraulic efficiency.

Conversely, the successive flaring gullies (short diffusors) are efficient on a double length because only a limited reach, averaging 15 % of the gully length, decreases under the limit value 1.0 of the ratio S_p/S_f. This conclusion is graphically drawn in Figure 4 that defines the same inverse but strong relationship between variables.

Therefore, these two relationships ($y = 4.377 \cdot e^{-0.0339x}$ and $y = 767.67 \cdot x^{-1.491}$) may be differentiately used to point out the position of the total cross sections versus the critical threshold of hydraulic efficiency.

Comparative analysis of data obtained through both indicators (D_{max}/D_{mean} and S_p/S_f) is of interest in the case for successive discontinuous gullies. In Figures 5 and 6 there are plotted the values of these indicators that were determined on 25 cross sections from two gullies:

- The first, located in the upper Jeravat basin, has 542 m length and is associated to a drainage area of 139.8 hectares
- The second lies in Ibana-Simila basin and it is 212 m in length and 216.5 ha in size.

According to Ionita's indicator (S_p/S_f) these gullies are hydrological competent in average along 79 % of their length and only a short reach at the gully outlet decreases under the efficiency limit. With respect to the values of Heede's indicator (D_{max}/D_{mean}) those gullies might present hydraulic efficiency only on 24 % of their total length, the first quarter downstream the gully head, respectively.

Surprisingly, the Heede's indicator presents fluctuating values around threshold 2.0 even at the gully inlet, in the most active gully reach where the gully floor is not associated with aggradation. Of course, under these circumstances the ratio S_p/S_f can not be estimated. In addition, Heede's indicator suggests that the middle reach of gullies is inefficient, too. However, here the present gully cross section is very well defined and during heavy rainfalls the peak streamflows never exceed it.

Therefore, the use of Heede's indicator in analyzing most of discontinuous gullies, that are associated with aggradation is unconvincing one. This approach appears to be particularly valuable when investigating continuous gullies.

Unfortunately, to determine one siltated or filled cross sectional area a lot of work is required. Consequently, it was of value the finding of another parameter that would allow an easier way to assess the indicator of hydraulic efficiency, S_p/S_f. Taking into account that the present section of discontinuous gullies, associated with sedimentation along the gully floor is a trapezoidal one it was concluded that the ratio of bottom width (W_b) to top width (W_t) might be an appropriate substitute.

Relationship between this new morphometric indicator (W_b/W_t), that is very comfortable to be determined in the field, and the indicator of hydraulic efficiency, S_p/S_f, was derived by means of some regression equations. In this way a strong but inverse relation ($R^2 = 0.9533$ or 0.9653) between these indicators has been emphasized under the group of singly discontinuous gullies. The crossing point of the regression line with the threshold line of hydraulic efficiency is around value 0.47-0.48 of the ratio W_b/W_t as shown in Figure 7. The higher values are actually reflecting the hydraulic inefficiency of the gully and they are prevailing as distribution.

In the case for successive, flaring discontinuous gullies (short diffusor) the crossing point rises to 0.59-0.60 value of the ratio W_b/W_t. This finding is illustrated in Figure 8 by plotting of the values from 12 cross sections in Timbru Valley.

A direct and strong relationship ($R^2 = 0.9664$) between those indicators was derived on successive, convergent (confusor) gullies from Vasilache and Timbru Valleys. The critical value of the ratio W_b/W_t is 0.48 but on this type of discontinuous gully the inefficient reach is low weighing. Most of the gully is characterized by overunit values of ratio S_p/S_f (Figure 9). On the other hand, it is of interest to emphasize the influence of soil moisture on hydraulic efficiency of gullies. Figure 10 clearly suggests doubling and even triplication of the hydraulic efficiency under wet gullies if compared with dry gullies from the Upper Harcioaia basin.

Conclusions

- Gully morphology and the rate of aggradation allowed to distinguish three groups of discontinuous gullies. The weighing of the depositional gully floor decreases from 59% under singly isolated gullies to 17-45% of the total gully area within the alluvial family of successive gullies.
- The hydraulic efficiency of discontinuous gullies is assessed by a new shape factor, obtained by relating present (S_p) to a filled (S_f) gully cross

section. Value 1.0 of this shape factor, S_p/S_f, represents the threshold of hydraulic efficiency.

- The isolated discontinuous gullies are exceeding this threshold only along 43% of their length, while divergent successive gullies (short diffusors) have a double hydraulic efficiency.
- Based on a geomorphic approach too, an appropriate substitute expressed as the ratio of gully bottom to gully top width (W_b/W_t) was found.

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Fig. 1 Single discontinuous gully no. 1, Caldarea Valley

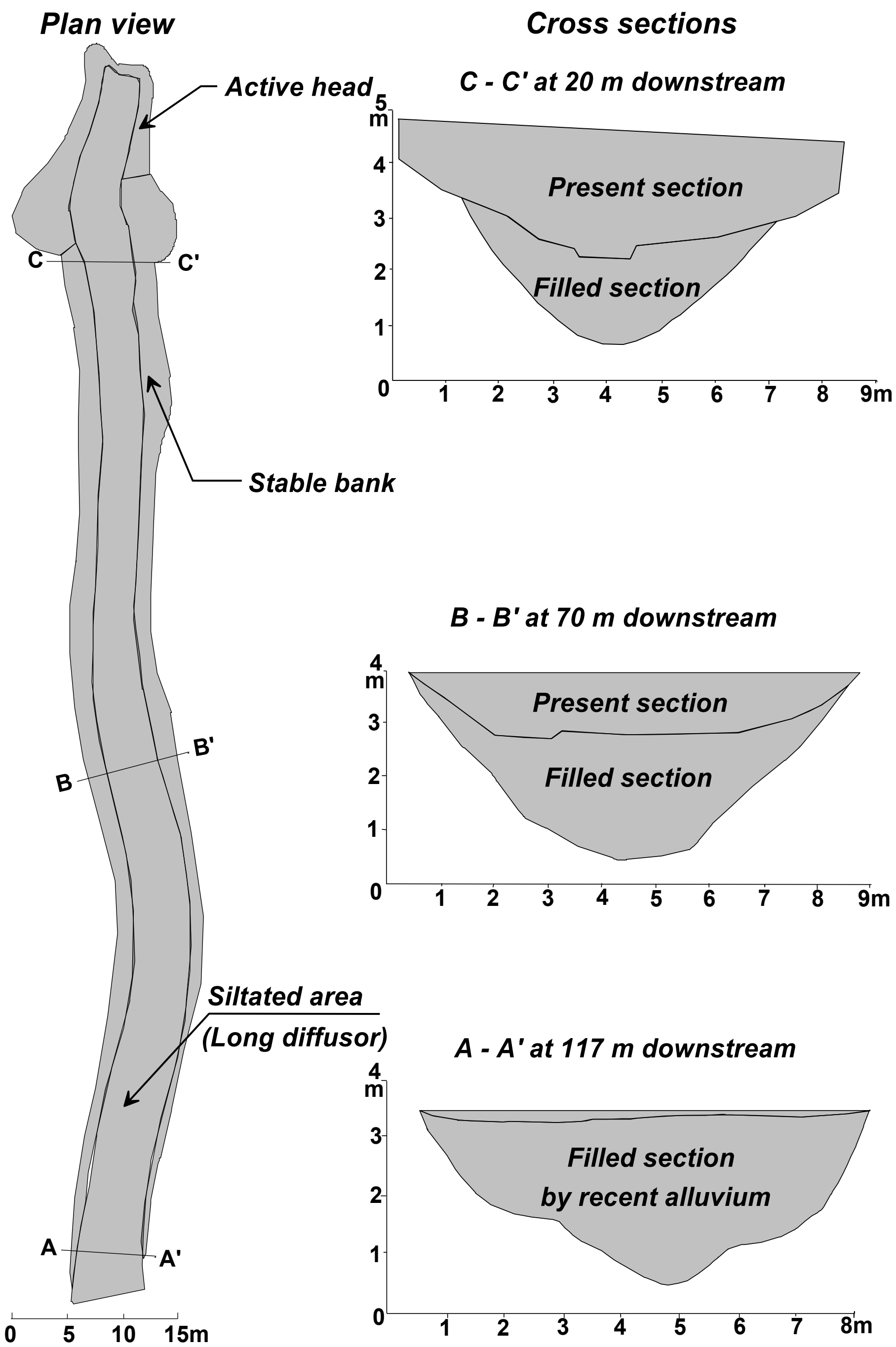
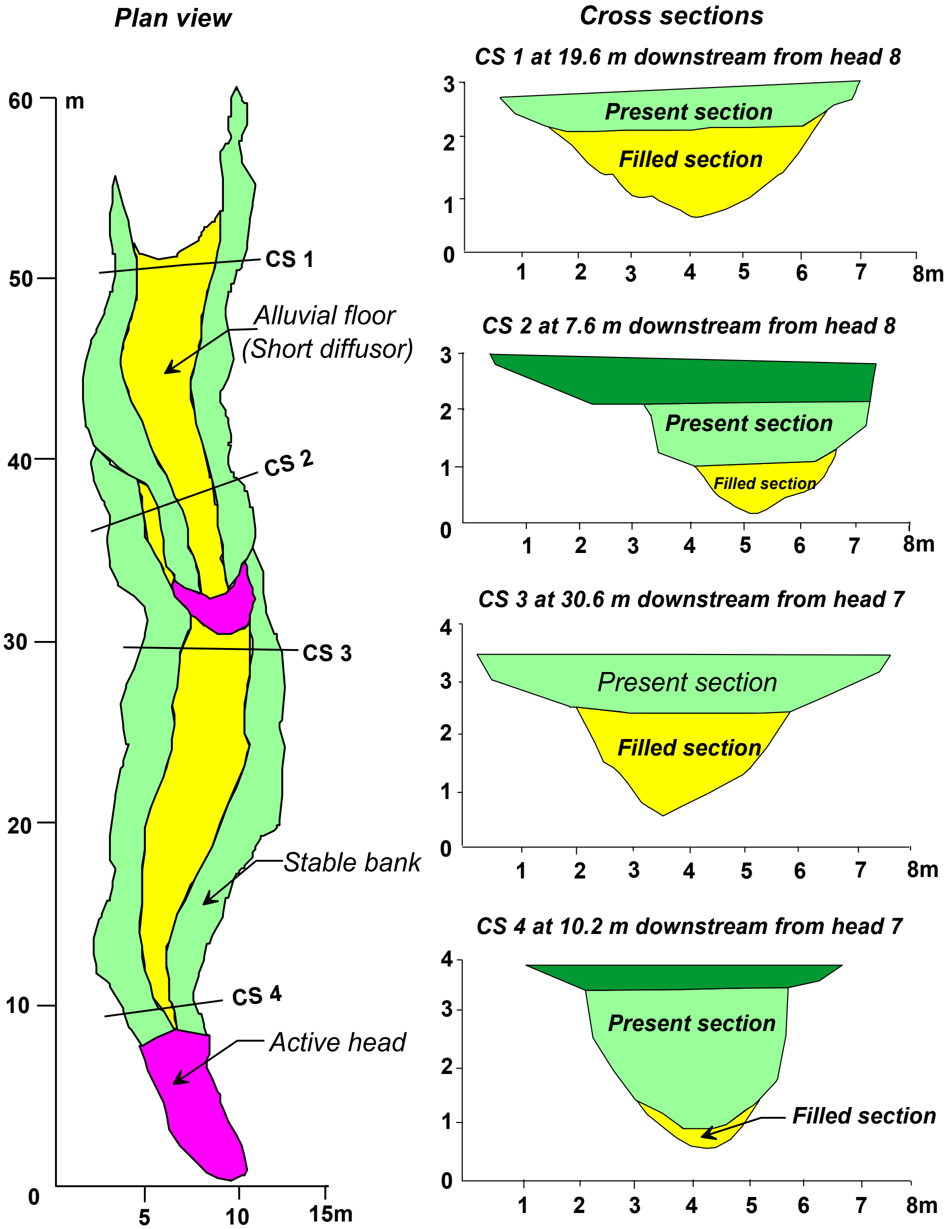


Fig. 2 Successive discontinuous gullies with alluvial, divergent floor ("short diffusors") on Timbru Valley, Falciu Hills - Romania, May 1995



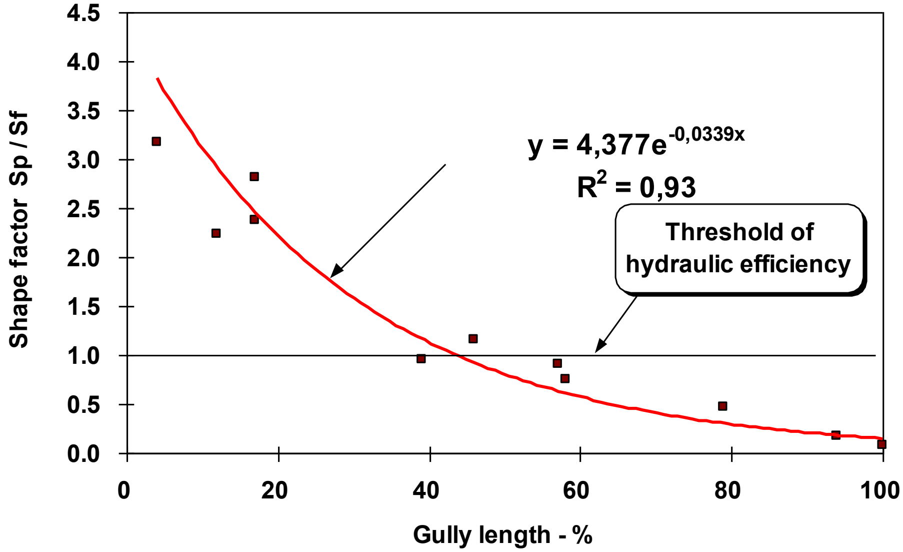


Fig. 3. Relation between shape factor Sp / Sf and length of the single discontinuous gullies ("long diffusors")

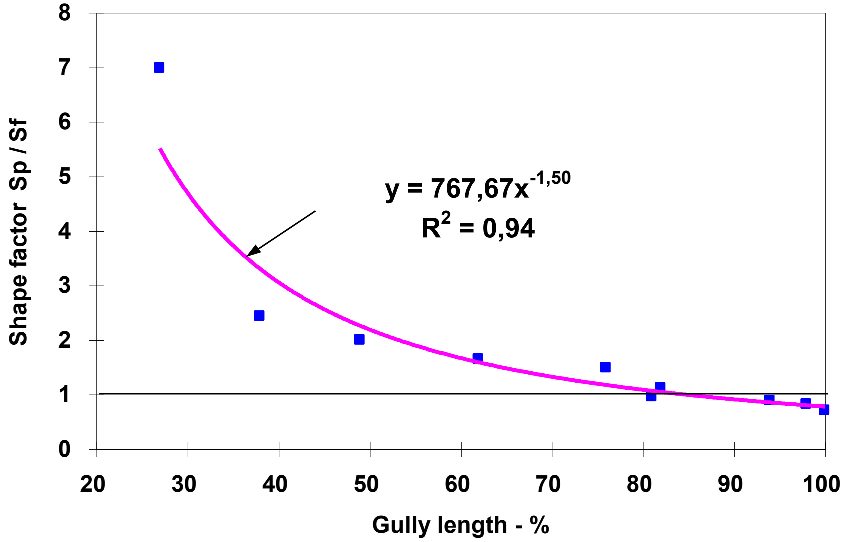


Fig. 4. Relation between shape factor Sp / Sf and length of the successive discontinuous gullies ("short diffusors") in Timbru Valley, Moldavian Plateau - Romania

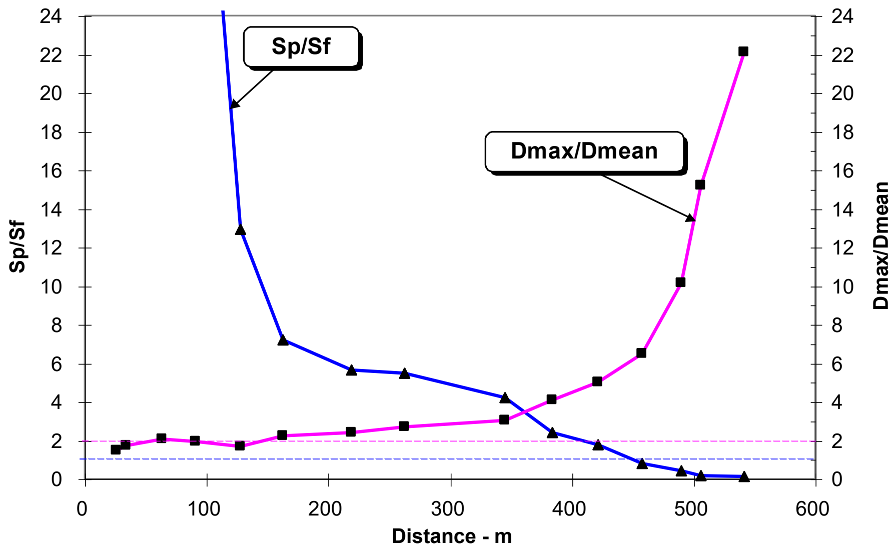


Fig. 5. Comparative distribution of the indicators Sp/Sf and Dmax/Dmean in Pustii Valley, upper Jeravat basin

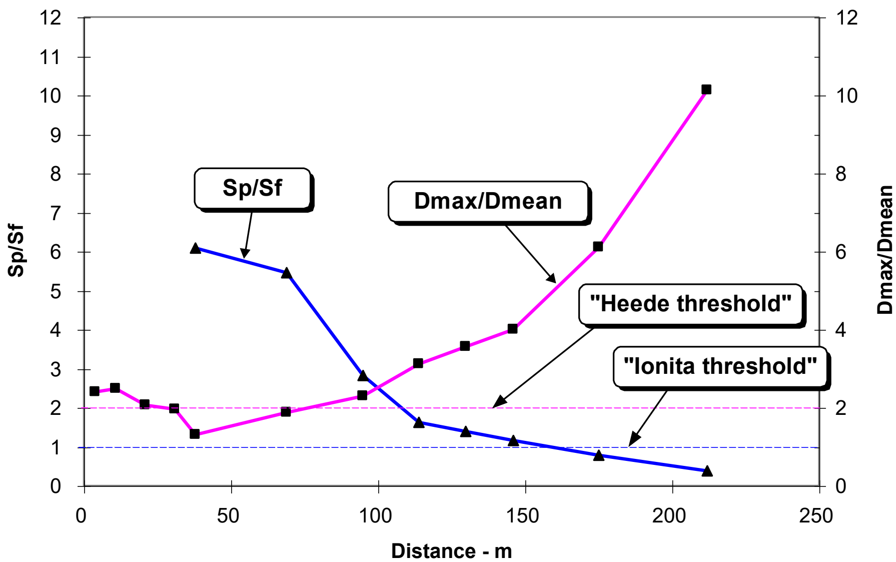


Fig. 6. Comparative distribution of the indicators Sp/Sf and Dmax/Dmean in Gornei - Ibana Valley, Romania

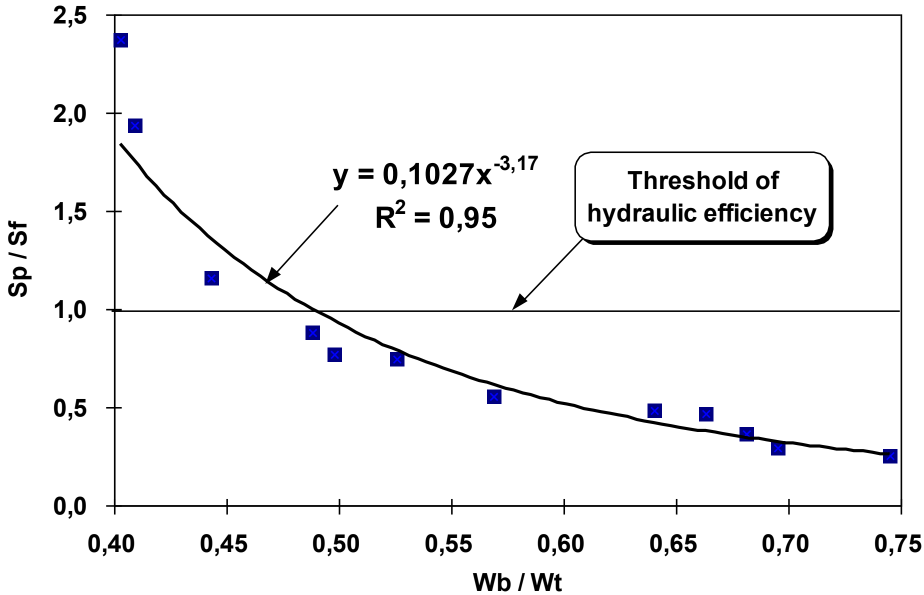


Fig. 7. Relation between the morphometric indicators Sp / Sf and Wb / Wt within single, discontinuous gullies ("long diffusors") in Caldarea Valley - Romania

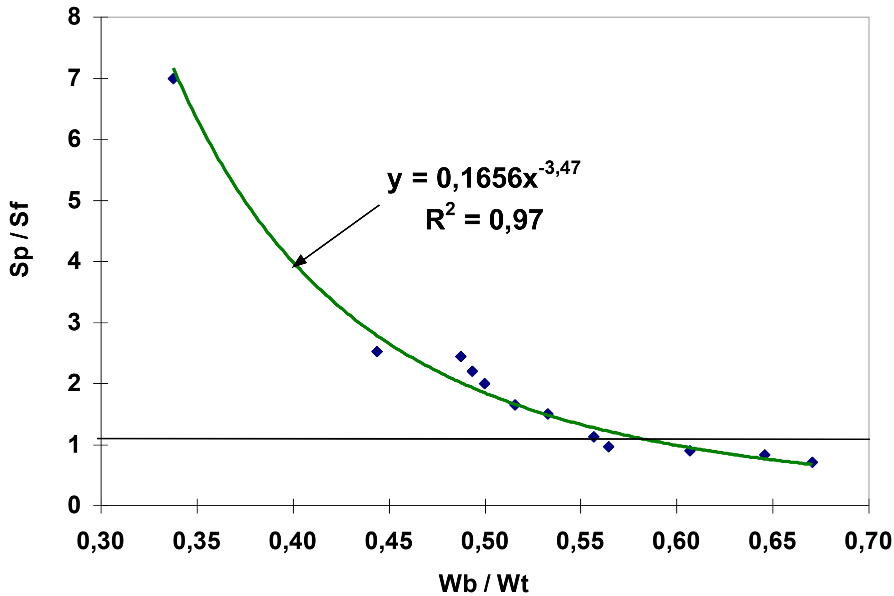


Fig. 8. Relation between the morphometric indicators Sp / Sf and Wb / Wt within successive gullies ("short diffusors") in Timbru Valley

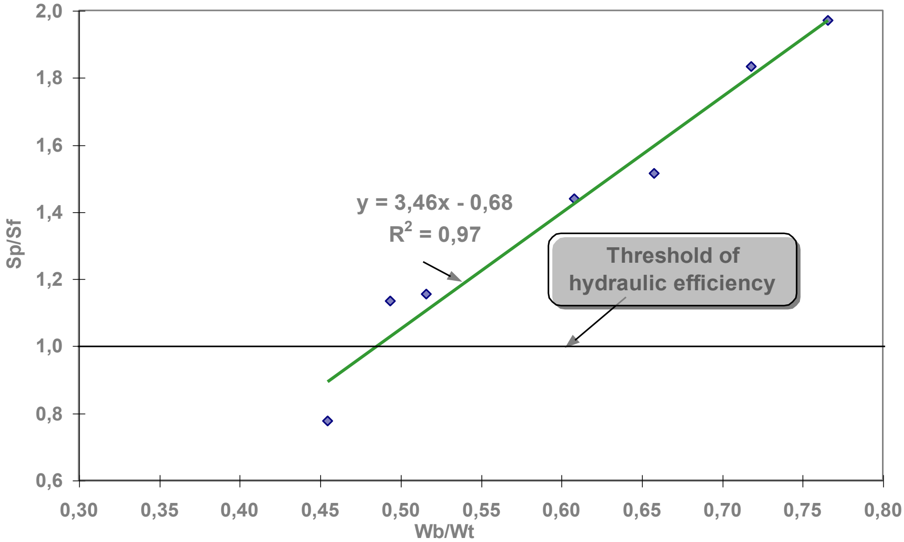


Fig. 9. Relationship between Sp/Sf and Wb/Wt indicators on successive, convergent ("confusor") gullies

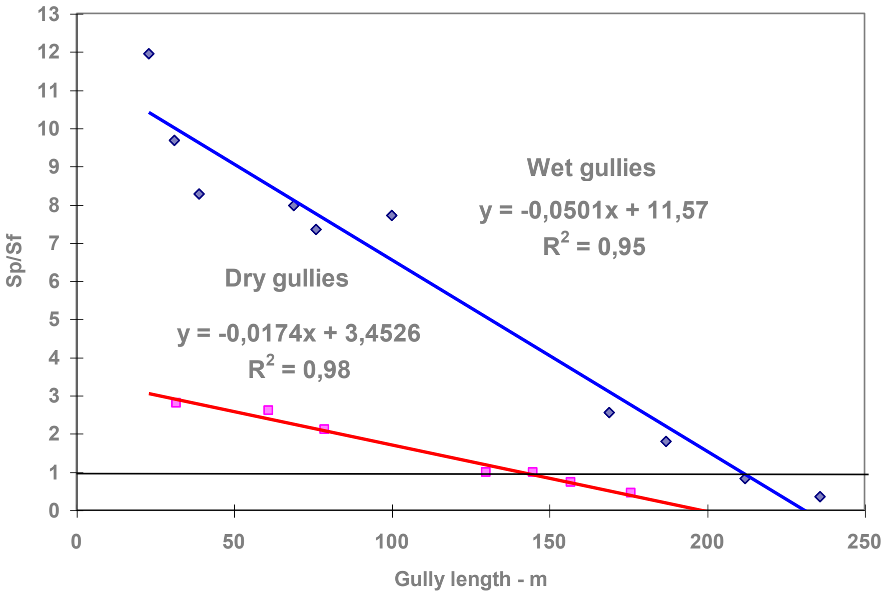


Fig. 10. The influence of soil moisture on hydraulic efficiency of the discontinuous gullies

APPLICATION OF ^{137}CS FOR MEASURING SOIL EROSION / DEPOSITION RATES IN ROMANIA

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

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

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

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

Introduction

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

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

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

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

Study site and methods

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

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

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

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

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

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

Results and discussion

Soil redistribution data

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

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

- A significant ^{137}Cs gain occurs on the lower half of the agroterrace platform, on 4-5 m width (Figure 3 a-b);

- The mean rate of rise of the agroterrace edge is 5.0-5.4 cm/yr. This rate is also equal to the height of the steep backslope divided by the age of agroterrace: 120 cm/22 years = 5.45cm/yr. Results obtained of both methods and validate the prior finding.

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

Gully erosion data

Leopold and Miller (1956) classified gullies as discontinuous or continuous. A discontinuous gully system is characterized by a vertical headcut, a channel immediately below the headcut which often is slightly

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

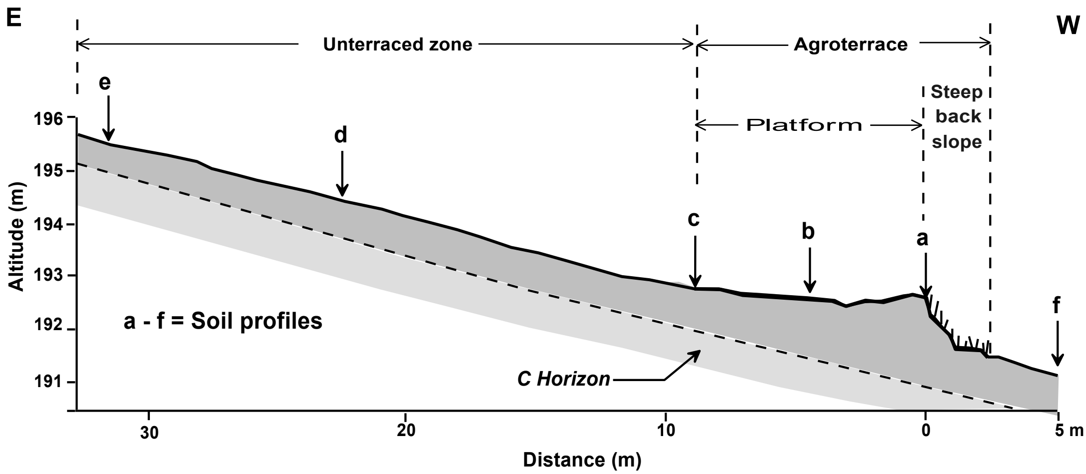

Figure 2 Cross section through an agroterrace on the left valleyside of Tarina Valley, Moldavian Plateau - Romania, 1999

deeper than it is wide, and a decreasing depth of the channel downstream. Where the plane of the gully floor intersects the more steeply sloping plane of the original valley floor, the gully walls have decreased to zero in height and a fan occurs. Heede (1967) stated that discontinuous gullies may occur singly or in a system of chains in which one gully follows the next downslope.

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

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

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

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

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

- The major one (56.9 Bq/kg) at 30-35 cm depth due to Chernobyl accident on April '86;

- The second peak (9.2 Bq/kg) between 145-150 cm depth coincides with the climax in bomb activity during the early 1960s, especially in 1963;

- The third peak (3.9 Bq/kg) at 170-175 cm depth is related to the commencement of ^{137}Cs fallout in 1959.

Thus, over a period of 43 years (1954-1996) the mean aggradation rate on the floor (short diffusor) of gully no. 6 was 4.4 cm/yr. Further, a ratio of 1.7 is obtained when dividing the mean aggrading rate of 5.0 cm/yr over the period 1963-1985 by the rate value of 2.9cm/yr, associated with the period 1986-1996. Then, the age of that gully is equal to the total thickness of alluvial sediments divided by the mean siltation rate = (210 cm/4.4 cm/yr

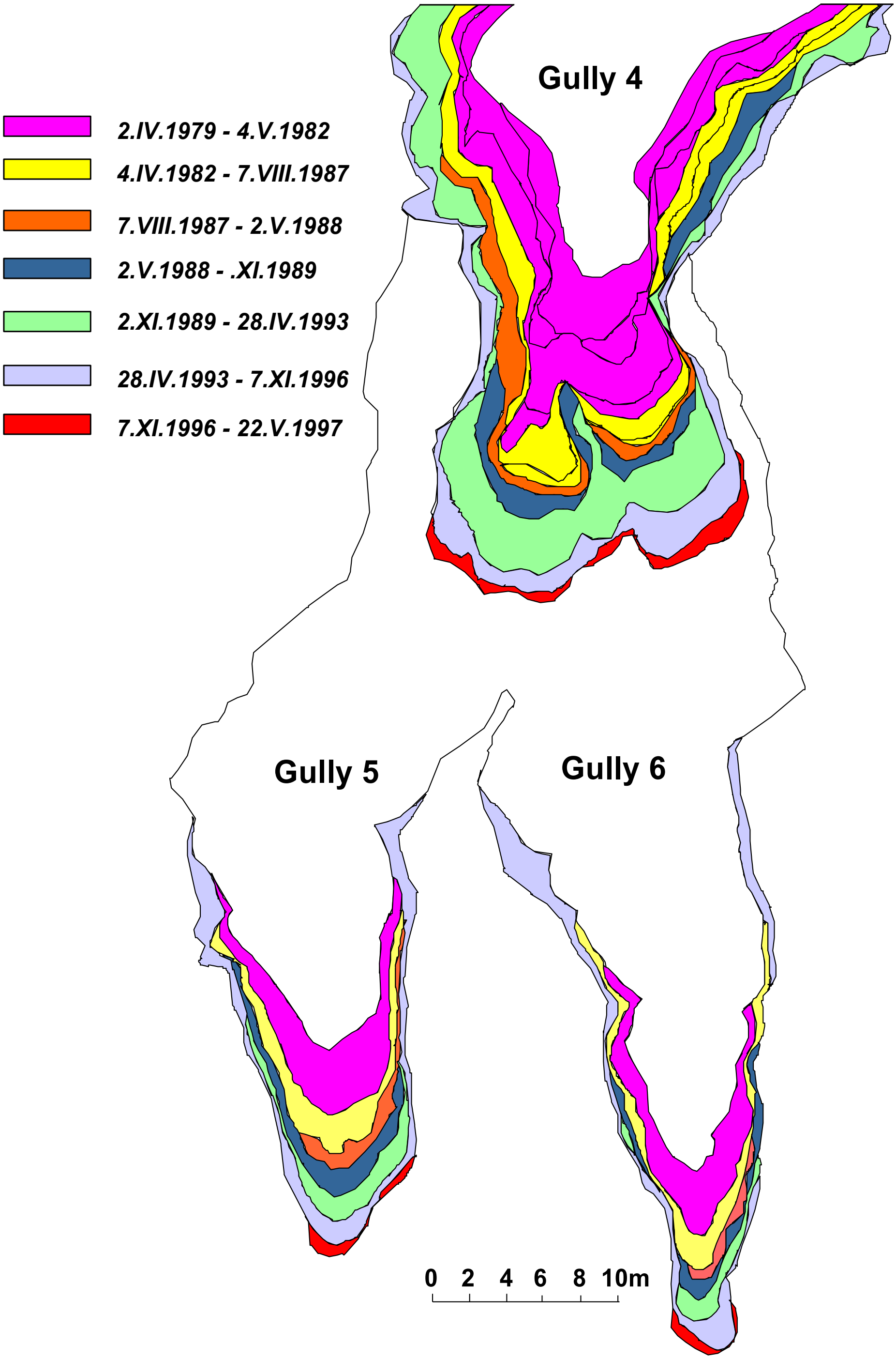

Figure 4 Measured advance of discontinuous gully heads, Roscani Valley, Moldavian Plateau, Romania (1979-1997)

cm/yr) = 48 years. By plotting gully length versus gully age, the average gully head advance can be calculated: 43 m/48 years = 0.90 m/yr. This finding agrees with the conventional value obtained for the period 1960-1996 (Ionita, 1997).

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

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

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

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

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

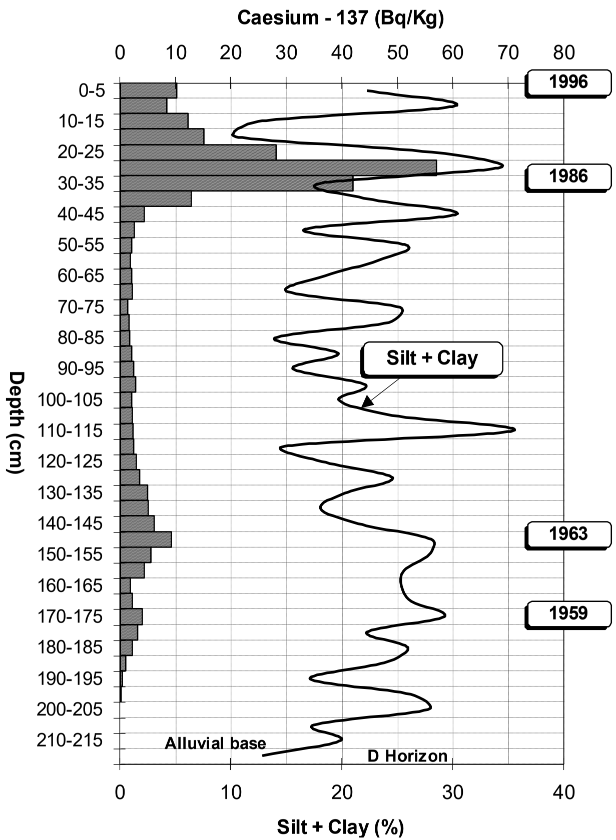

Figure 5 Distribution of Caesium -137 and silt+clay content in the alluvial fill from the gully head no.4, Roscani Valley, Romania - December 12, 1996

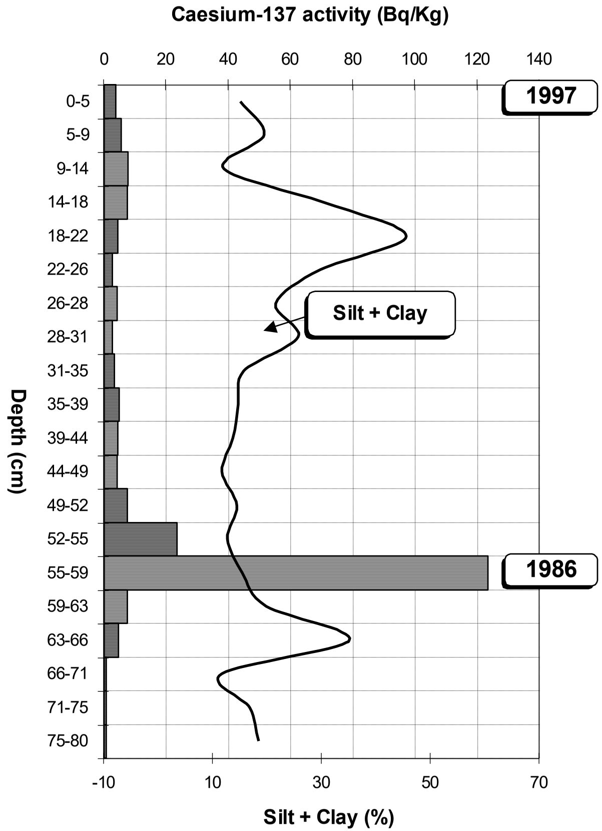

Figure 6 Depth distribution of Caesium -137 and silt+clay content within the alluvial fill of the gully floor no.4, Roscani Valley, Romania - October 10, 1997

grain size composition for both sites is predominantly sandy because the average clay content is around 5% and silt+clay fraction is about 22%.

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

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

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

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

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

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

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

Land management data

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

This finding is supported by the depth distribution of ^{137}Cs, which illustrates that under these circumstances the shape of the ^{137}Cs profile is in the form of a two layers or double cantilever (Figure 10). The first layer clearly occurs below a depth of 70 cm (37.0 Bq/kg) and is connected to the Chernobyl accident of April 1986, while the second is related to the revival in 1993 of the up-and-down hill farming. The mean siltation rates rose from 5.0 cm/yr for the period 1986-1992 to 10.0 cm/yr over the period 1993-1996.

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

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

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

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

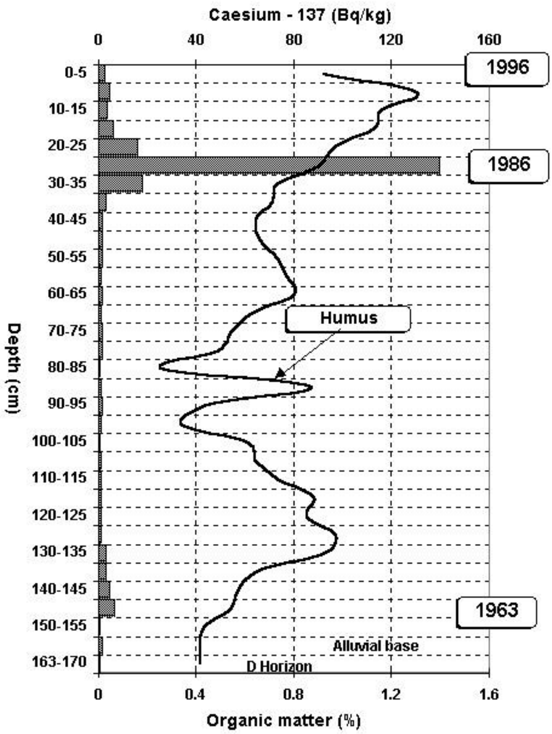

Figure 8 Distribution of Caesium – 137 and organic matter contyent in the alluvial fill from the gully head no. 8, Timbru Valley, December 13, 1996