ORIGINAL ARTICLE

# RESULTS OF TWO DECADES OF RESEARCH WORK ON STABILISATION AND AGRICULTURAL REVALUATION OF AN APPROPRIATED LANDSLIDE

# REZULTATE OBTINUTE IN EXPERIENTE DE LUNGA DURATA ( 20 DE ANI) PRIVIND STABILIZAREA SI REINTRODUCEREA IN CIRCUITUL AGRICOL A TERENURILOR ALUNECATE AMENAJATE

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## REZUMAT

În scopul studierii posibilităților de stabilizare şi valorificare agricolă a terenurilor alunecate s-a luat în studiu, începând din anul 1976, o suprafață de teren neproductiv, degradată prin alunecări, situată în subbazinul hidrografic al Văii Chintenilor, înființându-se un câmp experimental în care se desfăşoară, şi în prezent, cercetări complexe.

Din multitudinea aspectelor cercetate, în această lucrare se prezintă o parte din rezultatele experimentale referitoare la stabilizarea, în timp, a terenului alunecat, în urma executării lucrărilor hidroameliorative şi agroameliorative.

Rezultatele cercetărilor evidențiază faptul că în urma amenajării terenului alunecat, prin drenare şi nivelare, precum şi prin aplicarea unor tehnologii de cultură specifice terenurilor în pantă, deplasările în plan orizontal şi vertical ale masei de pământ alunecate se reduc simțitor, manifestându-se tendința de stabilizare în timp a terenului, respectiv de înscriere a acestuia în condiția de echilibru a versantului din care face parte.



## ABSTRACT

Starting with 1976, a totally unproductive piece of land located in the Chinteni Valley, Cluj County, severely degraded by landslides, was used as an experimental field in order to study the actual possibilities of agricultural reinstatement of these lands.

Out of a large range of problems studied since then, the present paper shows the most important experimental results concerning the gradual stabilisation and agricultural revaluation of landslides by means of hydro- and agroappropriative works applied.

The presented results emphasise the fact that as a consequence of appropriation works applied to this landslide (drainage and levellment) as well as by using crop technologies specific for slopes, the horizontal and vertical displacements of ground have been significantly reduced. Gradually, there has been noted an obvious tendency of a long term land stabilisation followed by a natural incorporation of this land into the equilibrium condition of the slope to which it belongs.



**KEY WORDS: landslide, appropriation, stabilization, agricultural reevaluation**



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# STABILIZATION AND REEVALUATION OF LANDSLIDES


## DETAILED ABSTRACT

Rigorous experiments were initiated in 1976 in an experimental field located in the hydrographic sub-basin of Chinteni Valley, Cluj County, Romania, on a totally unproductive piece of land, severely degraded by landslides. These experiments have been continued since then, aiming at clarifying the following aspects: technical solutions for rehabilitation of landslides; gradual stabilisation of rehabilitated landslides; possibilities of agricultural reinstatement of these recovered lands; their hydrographic and hydrogeological regime; land and soil evolution as influenced by rehabilitation and agricultural appropriation works.

Out of this large range of aspects studied for more than twenty years, the present paper comprises the most relevant results concerning the gradual stabilisation and agricultural re-evaluation of landslides as a consequence of hydro- and agroappropriative works applied.

On an area of two hectares of landslides, with an average of 2-3 m of depth sliding, two variants of drainage, differing in the actual layout of drainage lines and in the drainage material employed, have been tested. The hydrostatic levels have been recorded through 21 hydrogeological bore holes and for recording the degree of land displacement due to sliding, 30 topographic marks have been planted.

In the first seven years following the landslide appropriation, perennial fodder crops were grown on it. After this period of time the land was ploughed up in narrow, long-stripped sites arranged on contour lines, which were grown to annual crops with different levels of mineral fertilisation.

Based on analysis of displacement values of topographic marks, there can be concluded that the annual horizontal displacement show a positive trend, the cumulated value, on all experimental years, being of 0,930 m, with an annual rate of 2,31 cm. Speaking of annual displacement degree, the highest values were recorded with topographic marks located near the former "glimee" lakes or active springs, as well as in the area of slid banks or of the ravine edge situated in the proximity of landslide. The lowest values were recorded with the marks located near the drainage lines, control wells or hydrological bore holes.

The extent of horizontal displacements varies from year to year, according to years' average rainfalls, the lowest values being recorded in dry years or in years with one of the seasons (cold/warm) showing a droughty trend. It should be mentioned the fact that out of the 21 hydrological years, eight were arid, seven normal and six rainy. Thirteen years were droughty in their warm seasons.

The vertical displacements of topographic marks showed also a positive trend, meaning a tendency of downwards movement of landslide, with an annual rate of 5 mm.

For agricultural re-evaluation of appropriated landslides, perennial fodder crops were tested in the first cycle (pure crops as well as mixtures of grasses and legume fodder) followed by annual crops in several experimental cycles. The results obtained emphasise the fact that, in the first years after landslide appropriation, the most efficient way of its agricultural re-evaluation was by means of grasses and legume mixtures, used as hayfields, regardless of the previous or afterwards intended use of that land.

Due to hydro- and agroappropriative works applied, the landslide was recovered for agricultural use and, by applying crop technologies specific to slopes, high yields as well as a good antierosional protection of the soil were obtained.

## INTRODUCTION

Landslides are natural phenomena known for a very long time as affecting most of the regions of the Earth, in many civilisation they being included into natural catastrophes alongside with earthquakes, floods and volcanic eruptions, due primarily to the high damages inflicted to economic and social objectives and, not in the least, to numerous losses of human lives.

That's why the prevention and control of landslides are, at the present, a permanent preoccupation of political and scientific representatives of most of the countries all over the world. The Symposium dedicated to landslides, during the 28-th International Congress of Geology, Washington D.C., 1989 [3], presented an updated situation of landslides in more than 40 countries, including Romania [6], thus being a very convincing proof of the actual attention given to this subject.

In spite of remarkable progress encountered during the last decades in the technology of landslide stabilisation, the practical solution recommended for protection of social and economic objectives (inhabited settlements, industrial sites, railroads and highways etc.) against landslides are not applicable when agricultural lands are taken into consideration, primarily due to their high cost of investment [1],[8]. Therefore, for agricultural lands affected by these phenomena, it is necessary to find out simpler solutions and at a more reasonable cost of investment, which would gradually re-establish the natural equilibrium of the slopes and reintegrate them into agricultural use. For Romania, such technical and economical solutions are extremely pressing since it is stated [9] that more than 800.000 ha (680.000 ha of agricultural land) are affected by landslides. The recommended solutions should be accepted only after a thorough analysis of casual and conditional factors [7], while in the case of stabilised landslides it is compulsory a general levelling or modelling before they are reintegrated into agricultural use, to prevent afterwards stagnation of rainfalls [2].

In Romania, the experimental results accumulated so far, concerning the stabilization of agricultural landslides are not very numerous [4],[5]. The obvious aggravating trend of these phenomena, in the last two-three decades, make it necessary to continue and enlarge the experiments on their prevention and control.

## MATERIAL AND METHOD

The experiments have been carried out on the experimental field initiated in 1976, on a totally unproductive piece of land, severely affected by landslide, located in the hydrographic subbasin of Chinteni Valley (15 km N-E of Cluj-Napoca). These experiments aimed primarily at testing the efficiency of appropriation methods applicable to this landslide, as well as the technologies to be used for their execution. At the same time, valuable data were recorded concerning the hydrological and hydrogeological regime of the land, the behaviour of drainage network, soil evolution, reintegration of this land into agricultural use.

On the experimental field, the landslide covers an area of about two hectares with an average depth of 2-3 m. The soil is of clino-hydromorphyc type and, in the sites with water excess, soil with surface water gley.

The vegetation cover, existent on land before its reclamation, due to the constant dilapidation through landslide and soil erosion, has evolved into club rush and reed colonies. This development was especially obvious in the area of those 18 "glimee" lakes which were spread on the landslide under study.

Two variants of drainage were performed, according to the way in which drain lines had been placed and to the drainage material used (stone or plastics). The hydrostatic levels have been recorded through 21 hydrogeological bore holes and, for recording the degree of land displacement due to sliding, 30 topographic marks were planted in 1979, on alignments which started in eight topographic stations located outside the studied landslide. The degree of horizontal and vertical displacements was registered be means of Theo 020 A theodolite and Ni 030 levelmeter using provisional topographic marks between 1976-1979 and permanent ones after September 4, 1979.

Subsequent to land drainage and its modelling, in the spring of 1979 temporary grasslands were set up by sowing. These were maintained until 1986 when the land was upturned and used as arable land destined to agricultural crops. Turfed strips of variable width were left among upturned plots for preventing soil erosion. A third experimental cycle was started in 1991 and the forth one in 1996 which is still going on, consisting in testing mixtures of perennial grasses as well as annual crops in arable plots. To annual crops, different levels of mineral fertilisation were applied.

## RESULTS AND DISCUSSION

The analysis of vertical and horizontal displacement values of provisional topographic marks reveals the effect of drainage on land stabilization, starting with the first year of its execution. Thus, in the variant with drainage system made effective in 1976, the average displacement value, registered in 1977, was 17.5 times lower than that of control variant (without drainage). Also, in 1977, in the variant with effective drainage, the "glimee" lakes dried up while in the control variant (without drainage) these lakes were full of water until the fall of 1978 when drainage was performed.

The displacement values of permanent topographic marks, both in horizontal and vertical plane, as compared to their initial position (September 4, 1979) were cumulated and presented in Figure 1 and 2 (as annual average of all marks).

In 20 years of topographic survey, there can be noted a positive trend of horizontal displacement, with a cumulated value of 0.930 m and an annual rate of 2.31 cm. The regression equation shows exactly this trend ( Figure. 1).

Figure 1: Trend of horizontal displacement of tophographic marks as compared to their initial position (Sept. 4, 1979)

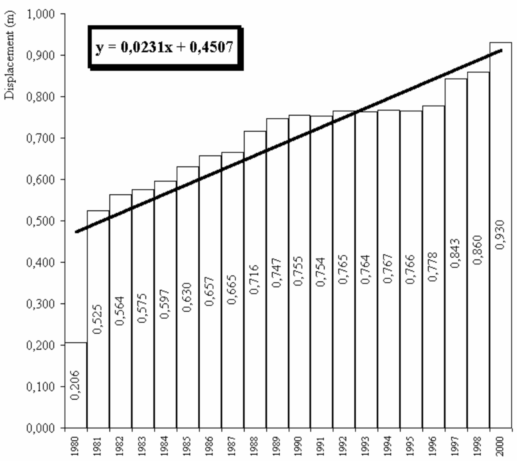
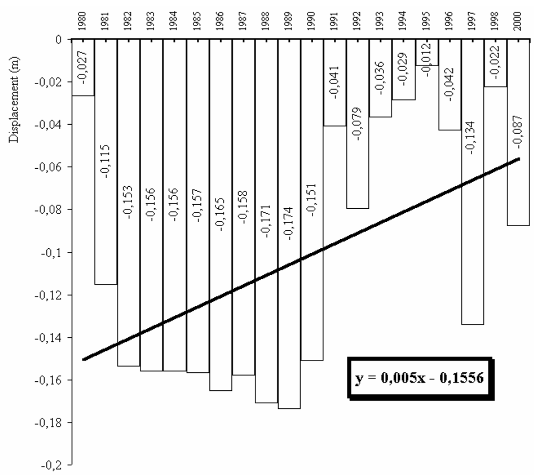



Figure 2: Trend of vertical displacement of tophographic marks as compared to their initial position (Sept. 4, 1799)




Within the measurements of the same year, the largest horizontal displacement values were recorded for topographic marks located near the former "glimee" lakes or active springs, in the area of slid banks or on the edge of nearby ravine. The smallest values were noted with the marks situated near the drainage lines, control wells or bore holes for hydrogeological observations. The extent of horizontal displacements varies from year to year, according to years' average rainfalls (Table 1), and the lowest values being recorded in dry years or in years with one of the seasons (cold/warm) showing a droughty trend.

From climatic point of view, out of the 21 hydrological years, eight were arid, seven normal and six rainy. Thirteen years were droughty in their warm seasons.

The largest horizontal displacement were registered in the spring of 1981 (0.319 m) as a consequence of a very warm and rainy fall of 1980 and of sudden melting of snow in March 1981. After this year, the horizontal displacements were small, indicating a tendency of natural incorporation of this landslide into the equilibrium condition of the slope in which the landslide had occurred.

The vertical displacements of topographic marks showed also a positive trend, meaning a tendency of downwards movement of landslide, with an annual rate of 5 mm.

Table 1: Value of annual average displacement (m) of topographic marks and the characteristics of hydrological years from rainfall point of view

| Specification | | Rainfalls | | | | | | Annual displacement | |
|---|---|---|---|---|---|---|---|---|---|
| | | Cold per. | | Hot per. | | Annual | | | |
| | | mm | calif | mm | calif | mn | calif | Horiz. | Vertic. |
| Hydrological years | 1980 | 138.1 | FS | 511.2 | FP | 649.3 | PMP | 0.206 | -0.027 |
| | 1981 | 283.9 | EP | 299.9 | ES | 583.8 | N | 0.319 | -0.088 |
| | 1982 | 232.4 | EP | 335.9 | FS | 568.3 | N | 0.039 | -0.038 |
| | 1983 | 96.1 | ES | 292.8 | ES | 388.9 | ES | 0.011 | -0.003 |
| | 1984 | 185.4 | N | 466.4 | PMP | 651.8 | PMP | 0.022 | 0.000 |
| | 1985 | 187.0 | N | 411.9 | N | 598.9 | N | 0.033 | -0.001 |
| | 1986 | 184.4 | N | 321.6 | FS | 506.0 | S | 0.027 | -0.008 |
| | 1987 | 124.2 | ES | 339.2 | FS | 463.4 | FS | 0.008 | 0.007 |
| | 1988 | 273.3 | EP | 307.9 | ES | 581.2 | N | 0.051 | -0.013 |
| | 1989 | 93.1 | ES | 625.8 | EP | 718.9 | FP | 0.031 | -0.003 |
| | 1990 | 75.5 | ES | 280.5 | ES | 356.0 | ES | 0.008 | 0.023 |
| | 1991 | 69.4 | ES | 511.8 | FP | 581.2 | N | -0.001 | 0.110 |
| | 1992 | 178.9 | N | 341.1 | FS | 520.0 | S | 0.011 | -0.039 |
| | 1993 | 195.8 | PMP | 381.8 | PMS | 577.6 | N | -0.001 | 0.043 |
| | 1994 | 168.5 | PMS | 363.7 | S | 532.2 | S | 0.003 | 0.008 |
| | 1995 | 145.7 | FS | 384.1 | PMS | 529.8 | S | -0.001 | 0.017 |
| | 1996 | 263.9 | EP | 345.8 | FS | 609.7 | N | 0.012 | -0.030 |
| | 1997 | 131.8 | ES | 567.8 | EP | 699.6 | FP | 0.065 | -0.092 |
| | 1998 | 201.1 | P | 498.3 | FP | 698.4 | FP | 0.017 | 0.112 |
| | 1999 | 164.1 | PMS | 573.8 | EP | 737.9 | FP | - | - |
| | 2000 | 167.2 | PMS | 274.9 | ES | 442.1 | ES | 0.070 | -0.065 |

Legend: EP – excessive rainy; FP – very rainy; P – rainy; PMP – medium rainy; N – normal; S – dry; PMS – medium dry; FS- very dry; ES – excessive dry

It has to be noted that vertical displacements do not always follow the rainfall regime. This means that in very dry years, when horizontal displacements are totally neglect, the values of vertical displacements are significantly higher, some of them even positive (upwards).

This is due, probably, to an excessive drying of deep clay and marl layers which determines the upward pushing of topographic marks. This trend was particularly obvious in the second part of the studied period of time, in which the dry years were predominant.

Figure 3: Dry matter yield (q/ha) as a mean of the 2nd to 5th experimental years (1992 – 1995)

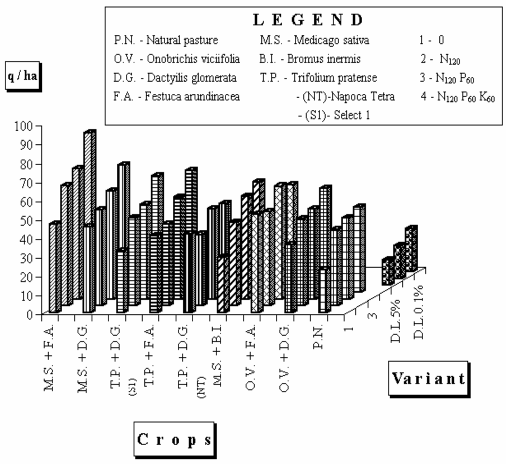
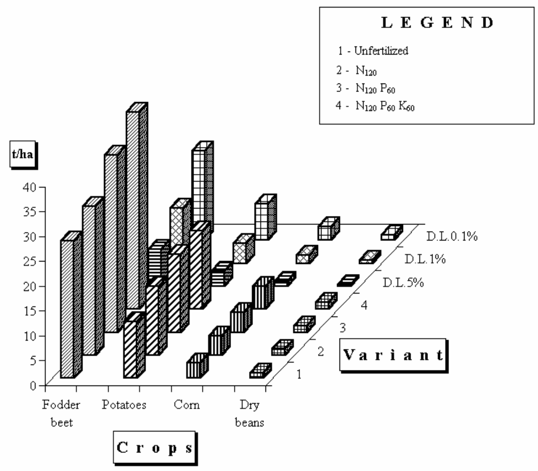



Figure 4: Mean yields (t/ha) of annual crops (1996 – 1999)



As far as the agricultural revaluation of appropriated landslide is concerned, four experimental cycles have already been carried out, with different perennial and annual fodder crops. Out of these results, there are presented the experimental data obtained in the last two cycles, one cycle with perennial fodder crops (1992-1995) and the other with annual crops (1996-1999). There has been considered that these last two cycles are the most illustrative ones since they incorporate the cumulative effects of the previous cycles as well.

In the first year of the third cycle (1991), when a uniform fertilization was applied to all perennial crops ($N_{30}P_{30}$), the highest yield of DM (82.6 q/ha, as an average of all crops) was registered, due to the fact that this year had a vegetation period with an excess of rainfalls. In the second year, when the maximum yields were expected, the mean yield was lower than in the previous one (68.7 q/ha DM), due to a rather dry vegetation period. In the third and fourth years, yields were even lower (38.3 and 38.6 q/ha DM) due to very dry vegetation seasons while in the fifth year, with a rather normal rainfall regime, the average yield increased considerably (50.6 q/ha DM). The average yields in the last four experimental years, on different levels of fertilization, are presented in Figure. 3.

In the next experimental cycle, annual crops reacted less obviously to mineral fertilisation than the perennial grasses did. These data suggested that on rehabilitated landslides perennial grasses more efficiently use the mineral fertilisers, especially in years with excessive rainfalls during the vegetation period. Out of the annual crops tested, the best response to mineral fertilisation was noticed in fodder beet while the poorest one in dry beans ( Figure. 4). It has to be mentioned the fact that dry bean was severely affected by leaf and pod diseases in three years with excess of rainfalls, with significant consequences upon the seed yield of this leguminous crop.

## CONCLUSION

- For landslide stabilisation, solely the ground levelling is technically not a satisfactory arrangement. Collection and evacuation of surface waters and satisfactory arrangement. Collection and evacuation of surface waters and drainage of ascending slope springs are compulsory works. In the last case, drains are to be placed at an adequate depth so as to remove the initial causes which have induced landslides.
- By appropriating landslides through drainage and levelling as well as by applying crop technologies specific for slopes, a sensible decrease of horizontal and vertical land displacements is to be achieved in rather a short time. Gradually, the tendency of landslide towards a permanent stabilisation becomes more evident and this is soon included in the natural equilibrium of the slope to which it belongs.
- Most of landslides (including the present one, under study) are connected to the depth erosion network which diminishes usually the slope base's natural support or of the banks of slope formations. Due to this fact, it is necessary to perform adequate works transversally oriented on the ravine line, in order to cut totally out erosion.
- In the first years after landslide appropriation, the most efficient way of its agricultural re-evaluation is by using it as hayfields which would increase land stabilization by fixing the soil on the depth of roots and by improving the hydrological regime.
- Out of the perennial fodder crops tested on appropriated landslides, the most promising results have been recorded with simple mixtures of grasses and leguminous fodder. These mixtures, even unfertilized, outyielded pure grass lawn or natural grassland fertilised three times a year with 60 kg/ha N.
- After several years of using it as hayfield, the appropriated landslide may be returned to its previous use, including to arable land. The agricultural reevaluation of these lands through annual or perennial crops is both possible and economically efficient. In all tested crops, by applying adequate technologies for slope lands, yields very close to those recorded on "healthy" lands with a medium fertility have been obtained.
- Due to the fact that during the process of landslide, of drainage and levelling, different soil layers have been mingled, on appropriated landslides a special consideration will be given to their fertilisation system.

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