Environmental conditions of gully erosion in Hungary

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Abstract

Soil erosion research has become very important over the last decades. It is the subject matter of several disciplines, geographers, geomorphologists, soil scientists, hydrologists, agronomists and other scientists publish on this topic and the authors of these publications are members of interdisciplinary and in most cases also international teams. Research on soil erosion by water concentrated, however, mainly on sheet erosion. The role of gully erosion has been recognized only lately. The presence and dynamics of various gully types (permanent, ephemeral and bank gullies) can be observed and their development can be followed under different climatic conditions and various land use types and sheet and rill erosion measurements on runoff plots are not realistic indicators of total catchment erosion (Poesen, J. *et al.* 2003). Another weakness of plot measurements of sheet erosion is that they do not give information about the redistribution of eroded soil within a field (Poesen, J. *et al.* 2003). Gully erosion plays a decisive role in the redistribution of eroded soil on a slope and in delivering it to watercourses (Evans, R. 1993, cited by Poesen, J. *et al.* 2003). All these statements point to the need of intensive research on gully erosion.

Keywords: gully and rill erosion, soil loss, land use change

Introduction

The process of gully erosion generates 20–30 cm to 20 m deep gullies (Bergsma, E. 1996). Although there are contradictory views about the share of gully erosion in the total amount of soil loss our experiences show that gully erosion processes have a bigger share than those of sheet erosion (Jakab, G. *et al.* 2006).

According to the Hungarian classification gully erosion is one of the processes of linear erosion (see e.g. Jakab, G. 2008). Linear erosion is a logical scientific name for this group of processes but it is not used worldwide. Micro-rill, rill and gully erosion belong to the group of linear erosion processes. For the really big gullies, i.e. for those with significant volume and especially deepness the expression of gorge (ravine) erosion is also used. Linearity is included in every definition. E.g. Poesen, J. *et al.* (2003) define gully erosion "as the erosion process whereby runoff water accumulates and often recurs in

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narrow channels and, over short periods, removes the soil from this narrow area to considerable depths".

The definitions of various forms of linear erosion (rill and gully erosion) are given by Jakab, G. (2006) in Hungarian language. In this classification the value of 50 cm (width and depth) separates rills from gullies and deep-cut tracks are defined as a special group of gullies. They were dealt with in detail by Kertész, Á. (1984). Kerényi, A. (1991) applied also the 50 cm value to differentiate between rills and gullies. Various Hungarian and foreign authors use different threshold values and definitions. A detailed analysis and comparison of them will not be given here as it would not bring essential information on the topic.

An important step in gully erosion research was the introduction of the term ephemeral gully erosion (Foster, G.R. 1986). The size of ephemeral gullies is between rills *(Photo 1)* and gullies *(Photo 2),* i.e. these gullies can still be removed by cultivation, while permanent gullies are too deep to ameliorate with tillage machines (Soil Science Society of America 2001). Bank gullies are defined as gullies developed on earth banks, i.e. where concentrated runoff crosses a bank (Poesen, J. *et al.* 2003).

A very clear classification and description of erosion processes is given by Laflen, J.M. (1985, see *Table 1*).

Photo 1. Rills on arable land

Table 1. Classification and description of erosion processes by Laflen, *J.M. (1985)*

Sheet and rill erosion	Ephemeral gully erosion	Gully erosion
Occurs on smooth side slopes above drainageline.	Occurs along shallow drainagelines upstream from incised channels or gullies.	Generally occur in well defined drainagelines.
May be of any size but are usually smaller than concentrated flow channels.	May be of any size but are usually larger than rills and smaller than permanent gullies.	Usually larger than concentrated flow channels and rills.
Flow pattern develops many small disconnected parallel channels which end at concentrated flow channels, terrace channels or in depositional areas.	Usually forms a dendritic pattern along water courses beginning where overland flow, including rills, converge. Flow patterns influenced by tillage, rows, terraces, man made features.	Dendritic pattern along natural water courses. May occur in non-dendritic patterns in road ditches, terrace or diversion channels, etc.
Rill cross-sections usually are narrow relative to depth.	Cross-sections usually are wide relative to depth. Sidewalls not well defined. Headcuts not readily; do not become prominent because of tillage.	Cross-sections usually narrow relative to depth. Sidewalls are steep. Headcut prominent. Eroding channel advances upstream.
Rills normally removed by tillage, usually do not reoccur in the same place.	Temporary feature, usually removed by tillage; reoccur in same place.	Not removed by tillage.
Soil removed in thin layers or shallow channels. Soil profile becomes thinner over entire slope.	Soil removed along narrow flow path, to tillage depth if untilled layer is resistant to erosion, or deeper if untilled layer is less resistant.	Soil may erode to depth of profile, and can erode into soft bedrock.
Low erosion rates not readily visible.	Area may or may not be visibly eroding.	Erosion readily visible
Detachment and transport by raindrops and flowing water.	Detachment and transport by flowing water only.	Detachment by flowing water, slumping of unstable banks and headcut retreat; transport by flowing water.

Photo 2. Gully in a forested area just below an arable field

In order to understand gully initiation and development usually the following questions are asked: (1) What is the importance of surface and near surface lithology? (2) What are the topographic threshold values leading to the formation of gullies? (3) What are the characteristics climatic conditions (first of all rainfall amounts and intensities) to trigger gully development? (4) What is the role of land use and land use change? (5) What socio-economic factors influence gully initiation and extension in a given area? The present paper tries to answer these questions by examining the conditions of gully formation and development in Hungary.

Soil erosion in Hungary

Land degradation processes play an important role in relief formation and development in Hungary. Soil erosion is one of the most significant land degradation processes on agricultural areas. Other land degradation processes, such as: mass movements, extreme soil reaction (including acidification and salinization/alkalization), physical degradation and other chemical, physical and biological degradation processes (see Várallyay, Gy.–Leszták, M. 1990; Kertész, Á. 2001) are also important, but they are not as extended as soil erosion. Soil is one of the most important natural resources in Hungary, therefore soil erosion studies and soil erosion control are very important issues.

25% of the total area of Hungary (more than one-third of agricultural land) is affected by water erosion (on agricultural land 13.2% slightly, 13.6% moderately and 8.5% severely eroded) and 16% is affected by wind erosion (Stefanovits, P.–Várallyay, Gy. 1992, see *Table 2*).

Table 2. Soil erosion in Hungary

Indicator	Thousand hectares	% of the total area	% of the agricultural land	% of the eroded land
Area of the country	9,303	100.0	–	–
Agricultural land	6,484	69.7	100.0	–
Arable land	4,713	50.7	73.0	–
Total eroded land	2,297	24.7	35.3	100.0
strongly	*554*	*6.0*	*8.5*	*24.1*
moderately	*885*	*9.5*	*13.6*	*38.5*
weakly	*852*	*9.2*	*13.2*	*37.4*

The significance of soil erosion processes was recognized half a century ago and a soil erosion map was constructed by Stefanovits, P. and Duck, T. (1964) covering, however, only improved farmland (excluding non agricultural uses, e.g. forests, urban and industrial areas, roads, etc.). The mapping was based upon the analysis of soil profiles. As a consequence of the applied method only areas effected by sheet erosion are identified on the map and the areas of gully erosion were not shown on it. Soil erosion research concentrated mainly on sheet erosion and the assessments were restricted to smaller areas, hillslopes or small catchments.

a) Water erosion. Sheet erosion is an important problem on most of arable land. Before the change of the regime in 1989 large arable fields were created allowing for an even more extensive damage of sheet erosion. Most of the crop is harvested by the beginning of July leaving large surfaces without vegetation during the most sensitive period, i.e. between July and October. Sheet erosion processes are supported by micro-solifluction and by splash erosion (Kerényi, A. 1991). Gully erosion will be dealt with below in detail.

b) Wind erosion is highly extensive on the areas of wind blown sand, which occupy about 20% of the country's territory. The thickness of the sand varies form a few centimeters to 25–30 meters. Damage is primarily caused on sandy soils, where crop yields may be reduced by up to 50%. Improperly cultivated peat soils with decomposed, powdery surfaces also have low resistance to wind erosion.

Gully erosion research in Hungary

As mentioned before, the role of gully erosion processes was not properly recognized until lately and it was believed that it is mainly sheet erosion which causes damage on agricultural land.

This statement is also true in the case of Hungarian research. Gully classification systems will be treated first followed by a short review of scientific publications on gullying.

A gully erosion survey was carried out to characterize gully erosion according to the length of gullies in a given area (Stefanovits, P.–Várallyay, Gy. 1992). Based on this survey the following categories were suggested.

a) weakly gullied area: <200 m/km^2 gullies;

b) moderately gullied area: 200–500 m/km^2;

c) strongly gullied area: >500 m/km^2.

A classification system based on soil loss values was suggested by Thyll, Sz. (1992). According to the method soil loss values will be identified on a 40x40 m test area to give the rate of gully erosion. The categories are weak (<40 t/ha), medium (40–100 t/ha) and strong (>100 t/ha) gully erosion. The selection of the very small test area influences the obtained result very much and therefore this method cannot bring reliable results.

Observations and descriptions of gully erosion date back to the last century (see. e.g. Pécsi M. 1955). The gullies of the Tokaj Hill were investigated by Pinczés Z. (1968, 1980). He used the number and extent of rills to identify the degree of soil erosion. Boros L. (1977) elaborated a simple method for mapping rills and gullies providing also some information on their morphometrical properties.

Hilly areas with thick loess cover or with loose Pannonian sediments have unique geomorphological features and they are prone to rill and gully development (see. e.g. Kádár L. 1954; Ádám, L. 1969). Among them the Tolna and Szekszárd hilly countries were studied in detail by Ádám, L. (1969). Kerényi, A. and Kocsisné Hodosi, E. (1990) reported on the development of erosional forms in vineyards covered by loess. The role of piping was recognized by several authors (Kádár L. 1954; Ádám, L. 1969; Kerényi, A.–Kocsisné Hodosi, E. 1990).

Investigations in Lake Balaton catchment by various authors included also some aspects of gully development. The Department of Physical Geography of the Hungarian Academy of Sciences carried out several research projects on soil erosion forms and processes in the catchment. Tóth A. (2004) analysed the ratio of sheet and gully erosion in the Tetves catchment. Jakab, G. *et al.* (2005) made a very detailed morphometrical survey of gullies in the same catchment. Kertész, Á. (2004a) studied geomorphic processes on collapsible and dispersive soils. Rill initiation and development was part of various rainfall simulation experiments (Csepinszky B. *et al.* 1998; Csepinszky B.–Jakab G. 1999; Sisák, I. *et al.* 2002; Centeri, Cs. 2002; Centeri, Cs.–Pataki, R. 2003, 2005; 2005, Szűcs, P. *et al.* 2006; Jakab, G.–Szalai, Z. 2005; Balogh J. *et al.* 2008).

There is also historical evidence (see e.g. Gábris, Gy. *et al.* 2003) that a very intensive gully erosion activity took place in the nineteenth century when large areas covered by loose sediments were deforested and opened for arable farming.

Conditions of gully development

a) Slope gradient

Stefanovits, P.–Várallyay, Gy. (1992) investigated the effect of *relief* on water erosion (including both sheet and gully erosion) in Hungary according to slope gradient categories. On slopes <5% erosion hazard is negligible. As slopes >25% are generally forested they do not imply a high erosion risk. The 17–25% slopes are either under forest or were deforested in the recent past. Most of the 5–17% slopes are used for agriculture and deteriorated by soil erosion to a certain extent (Krisztián J. 1992). There are no studies carried out on the threshold value of slope gradient for gully initiation. It would be interesting to investigate the relationship between critical slope gradient versus upslope drainage area for (ephemeral) gully initiation (see Vandaele, K. *et al.* 1996).

b) Soil parent material

About two thirds of the total area of Hungary are covered by loose sediments, mainly by loess and loess like deposits, susceptible to soil erosion and mass movement processes in the hilly regions of the country. Soil erosion is the greatest environmental hazard on hillslopes under cultivation. The thickness of slope loess varies between 5 and 25 m. Recent processes acting on loose sediments were mainly dealt with as part of geomorphological mapping activities and geomorphological surveys (Kertész, Á. 2004b). The best conditions for gully erosion are provided in the areas of thick loess cover (e.g. Szekszárd hilly country). Other loose sediments like Pannonian sands are also susceptible to gully erosion.

c) Soil properties

Soils of the loess covered areas are generally highly erodible because the parent material of the soil is a loose sediment. The initiation and development of gullies is in some cases promoted by subsurface erosion, i.e. by piping (called also suffosion in Hungarian literature, see Jakab, G. *et al.* 2005).

Physical and chemical properties of loess and loess-like sediments offer favourable conditions for the development of pipes. Collapsibility is primarily connected with calcium carbonate content (including lime concretions in older loess deposits), with the very high porosity (volume of pores is 40–60%). The most important processes on collapsible/dispersive rocks and soils include sheet erosion, rill erosion, gully erosion, piping (tunnel erosion, suberosion), wind erosion and mass movements.

d) Climatic conditions

Gully erosion is more frequent under arid conditions and less frequent under humid climatic conditions (Poesen J. *et al.* 1996). Recent research concentrates on the occurrence of erosive rainfall events. In most cases the role of rainfall characteristics in SL Gully % (the percentage of soil loss caused by gully erosion in the total soil loss of the catchment. Evidently the amplitude and frequency of rainfall events are the most important rainfall characteristics. It is also evident that any change in rainfall regime (e.g. because of climate change) will lead to the change of the value of SL Gully %.

For the development of sheet and gully erosion, „erosion-sensitive days” characterized by >30 mm daily rainfall are of crucial importance. (Stefanovits, P.–Várallyay, Gy. 1992), which may occur 4–12-times per year in Hungary.

Concerning rainfall characteristics the most informative value is the rainfall threshold leading to the development of gullies in various environments. According to Poesen J. *et al.* (2003) there is not much difference in threshold rains of rills and gullies. There are no data available on threshold rains in Hungary.

Global climate change is very likely to increase gully erosion risk. Extreme events are going to be more frequent. In summer long periods of draught will alternate with storms (high intensity rainfalls). In winter freezing, melting and intensive rainfalls will alternate.

e) Land use change

Land use plays a key role in the development of land degradation processes. Recent studies indicate that (1) gully erosion represents an important sediment source in a range of environments and (2) gullies are effective links for transferring runoff and sediment from uplands to valley bottoms and permanent channels where they aggravate off site effects of water erosion. In other words, once gullies develop, they increase the connectivity in the landscape. Many cases of damage (sediment and chemical) to watercourses and properties by runoff from agricultural land relate to (ephemeral) gullying. There is a huge number of studies on the effect of land use on gully development. Gábris, Gy. *et al.* (2003) reported on a very intensive gully erosion activity in the nineteenth century when large areas deforested. Deforestation and starting agricultural activity on former forested areas increases gully erosion risk also in Hungary.

Conclusions

The hilly countries of Hungary are mainly covered by unconsolidated sediments, with a prevalence of loess and loess like sediments among them. Loess covered areas are prone to erosion and mass movements. The paper provided an analysis of the physico-geographical conditions of gully development in Hungary. Gully erosion risk is present on various landscapes because of the environmental conditions.

a) Great Hungarian Plain. Even lowlands covered by a thick layer of loess and other loose sediments are prone to gullying. Along the banks of rivers (e.g. some sections of the Danube valley) various forms of erosion including gullies are present. Rills and gullies will be formed on sand accumulation areas. These forms are very dynamic, change rapidly and disappear on moving sand (see Boros L.–Boros L.-né. 1980) and on sandy soils.

b) Hilly countries and mountains. Being covered by loess and other loose sediments hilly countries all are prone to gully erosion. Big elevation differences in a small area, i.e. high relative relief values point to a high risk of gullying (e.g. Somogy, Tolna, Szekszárd hilly countries). Deforested areas used by agriculture, especially arable lands and vineyards have an enhanced risk.

Mountains are mostly forested with spots of clearings. Even in the mountain forest there is a risk of gullying. Antropogenous activities (e.g. timber transport tracks, unpaved forest roads etc.) contribute to the risk of gully erosion.

Medium and long term land use planning should ensure a minimum risk of gully erosion with special emphasis on afforestation.

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REFERENCES

Ádám, L. 1969. A Tolnai-dombság kialakulása és felszínalaktana. – Akadémiai Kiadó, Budapest. 83 p.

Balogh J.–Baloghné Di Gléria M.–Jakab G.–Szalai Z. 2008. Talajeróziós vizsgálatok esőszimulátorral. – In: Schweitzer F.–Bérci K.–Balogh J. szerk.: A Bátaapátiban épülő nemzeti radioaktívhulladék-tároló környezetföldrajzi vizsgálata. – MTA Földrajztudományi Kutatóintézet, Budapest, pp. 90–104.

Bergsma, E. 1996. Terminology for soil erosion and conservation. – International Society of Soil Science (ISSS). 313 p.

Boros L.–Boros L.-né. 1980. Hóolvadékvíz által előidézett talajpusztulás a Nyírség északnyugati részén. – Földrajzi Értesítő *29.* (2–3.) pp. 217–232.

Boros L. 1977. A tokaji Nagy-hegy lösztakarójának pusztulása. – Doktori disszertáció, Debrecen. 134 p.

Centeri Cs.–Pataki R. 2003. A talajerodálhatósági értékek meghatározásának fontossága a talajveszteség tolerancia értékek tükrében. – Tájökológiai Lapok *1.* (2.) pp. 181–192.

Centeri, Cs.–Pataki, R. 2005. Soil erodibility measurements on the slopes of the Tihany Peninsula, Hungary. – In: Faz Cano, A.–Ortiz Silla, R.–Mermut, A.R. (eds) Advances in GeoEcology *36.* pp. 149–154.

Centeri, Cs. 2002. Importance of local soil erodibility measurements in soil loss prediction. Acta Agronomica Hungarica *50.* (1.) pp. 43–51.

Csepinszky B.–Csiszár B.–Jakab G.–Józsa S. 1998. A Balaton három vízgyűjtő-területén domináns talajok vizsgálata eső-szimulátorral. – Jelentés, FVM 22.626/96.

Csepinszky B.–Jakab G. 1999. Pannon R-01 esőszimulátor a talajerózió vizsgálatára. – XLI. Georgikon Napok, Keszthely. Agrárjövőnk alapja a minőség. – PATE GEORGIKON, Keszthely. pp. 294–298.

Evans, R. 1993. On assessing accelerated erosion of arable land by water. – Soils and Fertilizers *56.* (11.) pp. 1285–1293.

Foster, G.R. 1986. Understanding ephemeral gully erosion. Soil Conservation, vol. 2. – National Academy of Science Press, Washington, DC, pp. 90–125.

Gábris, Gy.–Kertész, Á.–Zámbó, L. 2003. Land use change and gully formation over the last 200 years in a hilly catchment. – CATENA *50.* pp. 151–164.

Jakab, G.–Kertész, Á.–Dezső, Z.–Madarász, B.–Szalai, Z. 2006. The role of gully erosion in total soil loss at catchment scale. 14th International Poster Day. – Transport of Water, Chemicals and Energy in the Soil-Crop Canopy-Atmosphere System Bratislava, 9.11.2006 Proceedings CD, ISBN 80-85754-15-0

Jakab, G.–Kertész, Á.–Papp, S. 2005. Az árkos erózió vizsgálata a Tetves-patak vízgyűjtőjén. – Földrajzi Értesítő *54.* (1–2.) pp. 149–165.

Jakab, G.–Szalai, Z. 2005. Barnaföld erózióérzékenységének vizsgálata esőztetéssel a Tetves-patak vízgyűjtőjén. – Tájökológiai Lapok *3.* (1.) pp. 177–189.

Jakab, G. 2006. A vonalas erózió megjelenési formái és mérésének lehetőségei. (Gully types and possibilities of their investigation.). – Tájökológiai Lapok *4.* (1.) pp. 17–33.

Jakab, G. 2008. A vonalas erózió folyamatának vizsgálata dombsági vízgyűjtőterületen. – In: Kiss, T.–Mezősi, G. (szerk) Recens geomorfológiai folyamatok sebessége Magyarországon. Szegedi Egyetemi Kiadó–Juhász Gyula Felsőoktatási Kiadó, Szeged. pp. 109–117.

Kádár L. 1954. A lösz keletkezése és pusztulása. – Közlemények a Debreceni Kossuth Lajos Tudományegyetem. Földrajzi Intézetéből *19.* pp. 12–14.

Kerényi, A.–Kocsisné Hodosi, E. 1990. Löszpusztulási formák és folyamatok kvantitatív vizsgálata szőlőterületen. – Földrajzi Értesítő *39.* (1–4.). pp. 29–54.
Kerényi, A. 1991. Talajerózió. Térképezés, laboratóriumi és szabadföldi kísérletek. – Akadémiai Kiadó. Budapest.
Kertész, Á. 1984. The role of deep-cut tracks in linear erosion. – In: Geographical Essays in Hungary. MTA FKI. Budapest. pp. 47–56.
Kertész, Á. 2001. Land degradation in Hungary. – In: Bridges, E.M.–Hannam, I.D.–Oldeman, L.R.–Penning de Vries, F.W.T.–Scherr, S.J.–Sombatpanit, S. (eds). Response to Land Degradation Oxford & IBH Publishing Co.: New Delhi - Calcutta; pp. 140–148.
Kertész, Á. 2004a. Az árkos erózió felszínalakító szerepe Dél-Afrikában. - Földrajzi Értesítő *53.* (3–4.) pp. 203–218.
Kertész, Á. 2004b. Soil erosion and mass movement processes on the loess covered areas of Hungary. – Földrajzi Értesítő. *53*. (1–2.) pp. 13–20.
Krisztián J. 1998. Talajvédelem. (Soil conservation). – GATE Mezőgazdasági Főiskolai Kar, Gyöngyös.
Laflen, J.M. 1985. Effect of tillage systems on concentrated flow erosion. – In: Pla, I.S. (ed.), Soil Conservation and Productivity, vol. 2. Universidad Central de Venezuela, Maracay, pp. 798–809.
Pécsi M. 1955. Eróziós és korráziós völgyek és vízmosások képződése a Duna völgyében Dunaalmás és Nyergesújfalu között. – Földrajzi Értesítő *4.* (1.) pp. 41–54.
Pinczés Z. 1968. Vonalas erózió a Tokaj-hegy löszén. – Földrajzi Közlemények *16.* (2.) pp. 159–171.
Pinczés Z. 1980. A művelési ágak és módok hatása a talajerózióra. – Földrajzi Közlemények *38*. 4. pp. 357–374.
Poesen, J.–Nachtergaelea, J.–Verstraetena, G.–Valentin, C. 2003. Gully erosion and environmental change: importance and research needs. – Catena *50.* pp. 91–133.
Poesen, J.–Vandaele, K.–van Wesemael, B. 1996. Contribution of gully erosion to sediment production in cultivated lands and rangelands. – IAHS Publications *236.* pp. 251– 266.
Sisák, I.–Strauss, P.–Azazoglu, E.–Szűcs, P. 2002. Rainfall simulation experiments to develop an environmental soil P test. 17th World Congress of Soil Science. Transactions. Paper no 1691. 14–21 August 2002, Bangkok, Thailand. p. 7.
Soil Science Society of America, 2001. Glossary of Soil Science Terms. - Soil Science Society of America, Madison, WI, http://www.soils.org/sssagloss/.
Stefanovits, P.–Duck, T. 1964. Talajpusztulás Magyarországon (Soil Erosion in Hungary). – OMMI Budapest.
Stefanovits, P.–Várallyay, Gy. 1992. State and management of soil erosion in Hungary. – In: Proceedings of the Soil Erosion and Remediation Workshop, US – Central and Eastern European Agro-Environmental Program. Budapest, April 27 – May 1 1992, Budapest. pp. 79–95.
Szűcs, P.–Csepinszky, B.–Sisák, I.–Jakab, G. 2006. Rainfall simulation in wheat culture at harvest. – Cereal Research Communications *34.* (1.) pp. 81–84.
Thyll, Sz. (szerk) 1992. Talajvédelem és vízrendezés dombvidéken. – Mezőgazda Kiadó, Budapest. pp. 14–15.
Tóth A. 2004. Egy dél-balatoni vízgyűjtő (Tetves-patak) környezetállapotának vizsgálata a természeti erőforrások védelmének céljából. – Doktori értekezés. ELTE Budapest.
Vandaele, K.–Poesen, J.–Govers, G. van Wesemael, B. 1996. Geomorphic threshold conditions for ephemeral gully incision. Geomorphology *16.* (2). pp. 161–173.
Várallyay, Gy.–Leszták, M. 1990. Susceptibility of soil to physical degradation in Hungary. Soil Technology *3.* pp. 289–298.