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Deposition Diagram studies - The Residual Erosion Potential of Soils

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ABSTRACT

Non-point P sources account for an increasing share of the water quality problems. The aim of our study was to investigate in deposition experiments, the wide range of three major factors, which determine particulate P runoff. The experiment was carried out with soil samples from seven sites of the Hungarian Long-term Fertilization Trials. The soil to water ratios (1, 4, 16, 64 and 264 g L^{-1}), deposition times (100, 1000, 10000 and 100000 s) and soil P contents (25-343 mg kg^{-1} P_2O_5 extractable by ammonium lactate method) covered the possible ranges and combinations of the factors.

The K_A value (a physical indicator of consistency used in Hungary) was better indicator of deposition processes and residual suspended sediment content (from 2 to75 mg L^{-1}) in our experiment than other physical properties, such as clay content. Presumably, consistency indices can be much better indicators for the residual erosion potential of the soils and probably for the sediment yield, as well. Our data reveal that plant available P effects the particulate P runoff in addition to dissolved P runoff . P enrichment was proved at six of the seven sites and two different types of enrichment process were distinguished.

The equations developed are not suitable to predict SS and PP load from different areas during runoff events since time and soil to water ratio as the most important factors, cannot be exactly estimated in real processes. But the equations can be used to study the runoff events themselves. Time and soil to water ratio may be estimated by measuring suspended sediment, dissolved P and particulate P content in the runoff if the deposition properties of the given soils are known. The described deposition method can be a kind of environmental soil tests to determine particulate and dissolved P loading potential of the soils and the method may help us to better understand the underlying processes of runoff and erosion.

INTRODUCTION

The accelerated eutrophication of surface waters is one of the major environmental problems in many countries and also in Hungary. Nitrogen, carbon and phosphorus are the major nutrients responsible for the eutrophication. However, more attention has focused on controlling P inputs because of free air-water exchange of N and C and the fixation of atmospheric N by some blue-green algae (Sharpley et al., 1994). Nonpoint P sources account for an increasing share of the water quality problems due to the easier identification and control of point source pollution (Logan, 1987, Auerswalsd, 1989). Phosphorus is transported in dissolved and particulate forms. Particulate P can provide a long-term source of P to aquatic biota (Sharpley et al., 1992). Its availability for algae according to the papers reviewed by Hegemann et al. (1983) can be as high as 80 % even in short-term bioassays. Recent results point out that large part of the P load may be attributed to a small portion of the watershed (Sharpley et al., 1998) and remediation measures should be focused on these areas.

We need to better understand the major effects influencing particulate P runoff in order to predict more precisely P loading of surface waters and to manage water quality problems. The aim of this study is to investigate in deposition experiments, the wide range of three major factors, which determine particulate P runoff: soil to water ratio, deposition time and P content of soil.

MATERIAL AND METHODS

Surface soil samples (0-10 cm) were collected at seven experimental locations of the Hungarian Long-term Fertilization Trials in 1995, the 28th year of the experiment started in 1967. The selected treatments were 0-0-0, 50-0-0, 50-50-0, 50-100-0 and 200-150-100 kg ha^{-1} yr^{-1} N-P_2O_5-K_2O respectively and the selected crop rotation wheat-corn-corn-wheat. The seven experimental sites Karcag (KA), Keszthely (KE), Kompolt (KO), Mosonmagyarovar (MO), Bicserd (BI), Hajduboszormeny (HA) and Iregszemcse (IR) represent the main agro-ecological regions of Hungary (Debreczeni et al., 1996).

The clay content and the particle size fraction smaller than 0.01 mm were determined with the pipette method described by Day (1965) and Varallyay (1993 a). The K_A value of soils was measured as well (Varallyay, 1993 b). This soil physical test is used in Hungary to characterize soil consistency. It is the water content of the soil (cm^3 100 g^{-1} dry soil) when it gives the "yarn test" (Figure 1) and its value is close to the liquid limit described by Sowers (1965). Its determination procedure is the following: the soil must be thoroughly mixed in a mortar with increasing amount of water. The test is positive when soil yarns form both on the pestle and on the surface of the soil pulp if the pestle is pushed into the pulp and is drawn out quickly. The yarns must lean but must not flow together with the pulp. The available P content of the soil was measured according to Egner et al. (1960) with ammonium lactate extractant at 1:20 soil to extractant ratio. Phosphorus content of the extract

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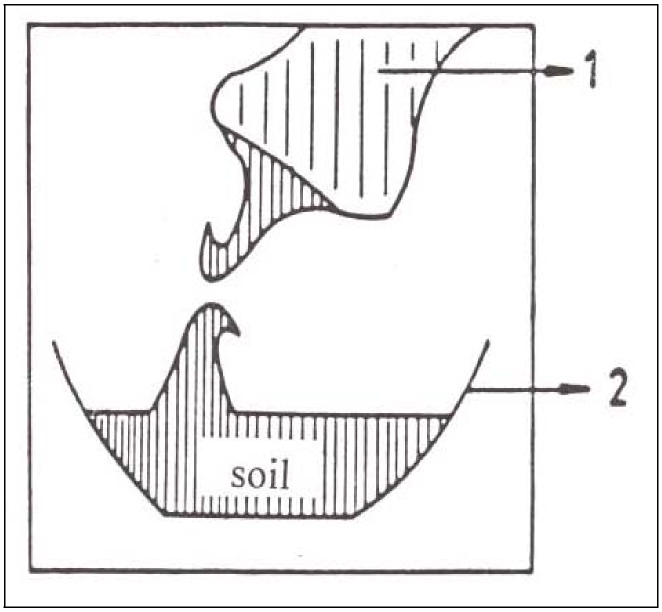

Figure 1. Yarn test for the K_A value. 1-pestle, 2-mortar.

was determined with the photometric method according to Murphy and Riley (1962).

The soils were investigated in deposition experiments (Sisak, 1995, Sisak et al., 1998) using different soil to water ratios (1, 4, 16, 64 and 256 g L^{-1}). Sieved (2 mm mesh size) air-dry samples were suspended in six replicates and gently shaken (10 upside down turns) in a deposition cylinder of 2 L volume. After different deposition times (100, 1000, 10000 and 100000 s), a 20 ml sample was taken with a pipette from 5 cm below the surface of the suspension. Three replicates were used to determine suspended sediment and dissolved P content and three replicates were used to determine total P content.

The suspended sediment content of the suspension was determined by filtering the suspension through a membrane with 0.45 micrometer pore diameter and by drying the filtrate at 105 C. Sampling with pipette and filtering were not possible after 100 seconds when 256 g soil was suspended. Dissolved P content of the suspension was determined on filtered samples and total P content was determined on unfiltered samples following digestion with a semimicro Kjeldahl procedure (Bremner and Mulvaney, 1982) by the colorimetric method of Murphy and Riley (1962). Particulate P content was calculated as the difference between total and dissolved P content.

The suspended sediment content of the suspensions was not influenced by the available P content of the soil and it was described by the following equation:

$$\log SS = A*\log TIME + B*\log SWR + C$$

where

A, B and C = parameters of the fitted equation,
logSS = logarithm of suspended sediment (mg L^{-1}),
logTIME = logarithm of deposition time (s), and
logSWR = logarithm of soil to water ratio (g L^{-1}).

Particulate P content must be a function of the suspended sediment content, the phosphorus content of the original soil, and deposition time. Multiple regression equations were fitted for each site in the following general form:

$$PP = A*SS + B*SS^2 + C*\log TIME + D*ALP + E$$

where

A, B, C, D and E = parameters of the fitted equation,
SS = suspended sediment (mg L^{-1}),
logTIME = logarithm of deposition time (s), and
ALP = plant available P determined with the ammonium-lactate method (P_2O_5 mg kg^{-1}).

RESULTS AND DISCUSSION

Selected physical and chemical properties of soils

Soil test results are shown in Table 1. The measured physical parameters vary considerably among the sites (clay contents between 12 and 41 % , K_A values between 37 and 54, particle size class smaller than 0.01 mm between 22 and 59 %). The available P contents vary according to the fertilizer treatments between 25 and 343 mg kg^{-1} with considerable differences among the sites. The available P content within the site is in close correlation with the P fertilization levels and P balances (Debreczeni and Sisak, 1996)

Suspended sediment

The analysis of variance of the suspended sediment results has shown that the variations in soil to water ratio, in deposition time and in the experimental sites explain 34.18 %, 21.38 % and 1.68 % of the total variance respectively ($p>0.01$). The effect of P treatments was not significant. The soil to water ratio had the strongest effect and this parameter underlines the importance of precise estimation of the effective depth of interaction (Storm et al., 1988) in runoff models. Experimental sites have a small but significant effect.

Equations were fitted for each sites to describe the effects of deposition time and soil to water ratio on suspended sediment content. A multiple linear relationship existed between the logarithms of the variables. The parameters for the different sites are shown in Table 2.

The deposition rates vary considerably (parameter A). It is the lowest at Hajdúböszörmény and the highest at Iregszemcse. The ”A” parameter doesn’t have significant correlation with the clay content and with the particle size fraction smaller than 0.01 mm but it has with the K_A value at $p>0.05$ (Figure 2). The higher amount of soil suspended has always led to an even higher suspended sediment concentration which is consequence of the aggregate dispersion during initial shaking due to the bigger sheering effect. The B parameter has significant correlation with the K_A value as well ($p>0.05$). B values can be regarded as an indicator of aggregate stability, which is the best at Bicsérd ($B \approx \log 4$) and is the worst at Iregszemcse ($B \approx 2 \log 4$). Those soils of which the aggregates tend to disperse easily

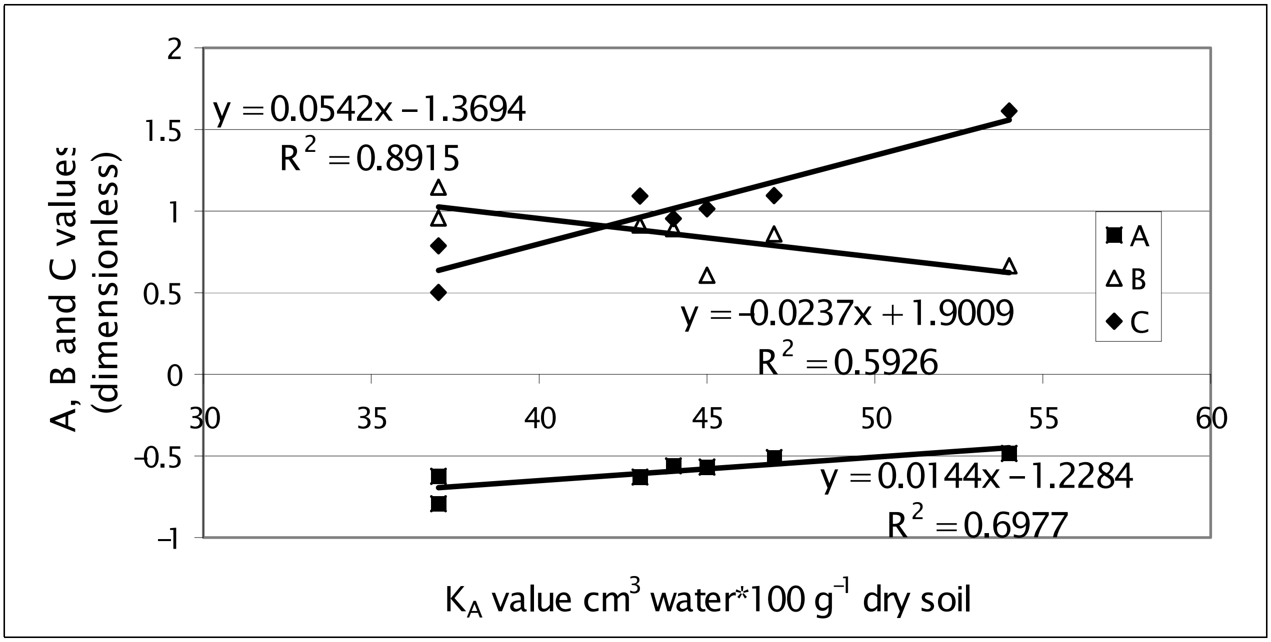

Figure 2. Dependence of the A, B, and C values of the logSS=A*logTIME+B*logSWR+C equation on K_A values.

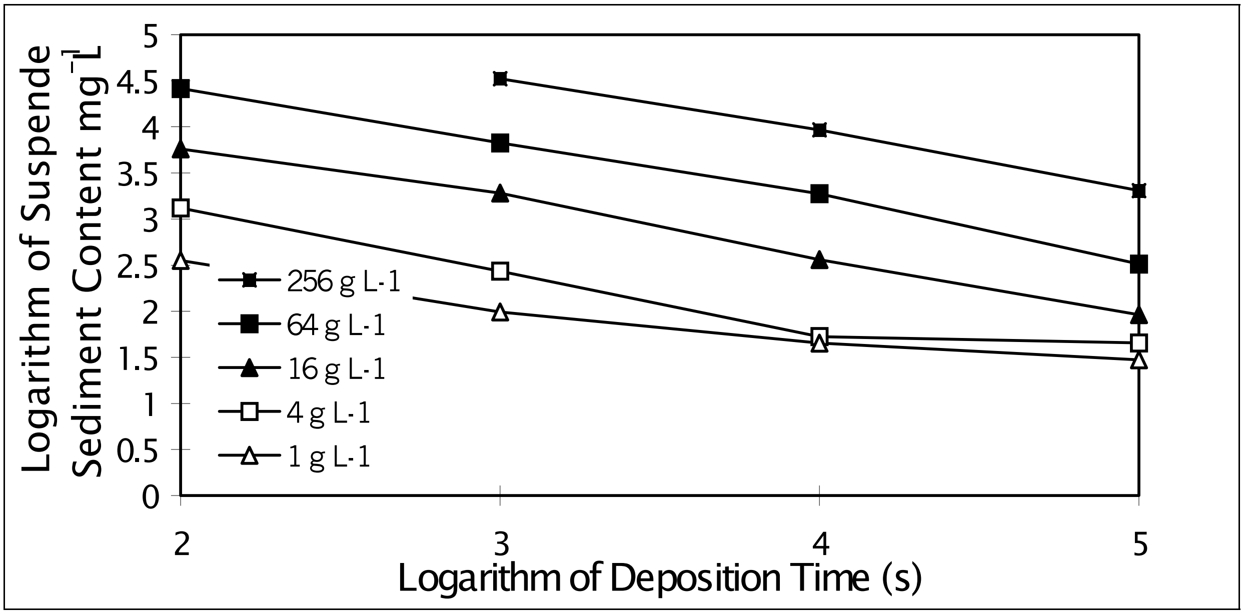

Figure 3. Suspended solid deposition curves (Bicserd).

are prone to erosion and may contribute to the dissolved and particulate nutrient load of surface waters. The C parameter is also strongly dependent on the K_A value.

The results were represented on double logarithmic time-concentration diagrams. The deposition lines at higher soil to water ratios (16, 64 and 256 g L^{-1}) have been consequently linear but those for the lower ratios (1 and 4 g L^{-1}) have leveled out after reaching a bottom in the case of most soils (Fig. 3). The individual lines for the different soil to water ratios can be brought into coincidence by one unit horizontal shift (Fig. 4). Apparent deposition curve for each soil can be determined by averaging the values, which are above each other on the shifted diagram (Fig. 5). The final suspended solid content varied between 2 and 75 mg L^{-1} for the different soils and their values have shown close correlation with the K_A value (Fig. 6) but haven't with the other two physical properties. This final suspended sediment content remains suspended even after long deposition time and may enter surface waters as "residual erosion" carrying considerable amount of nutrients. Based on the data of 11

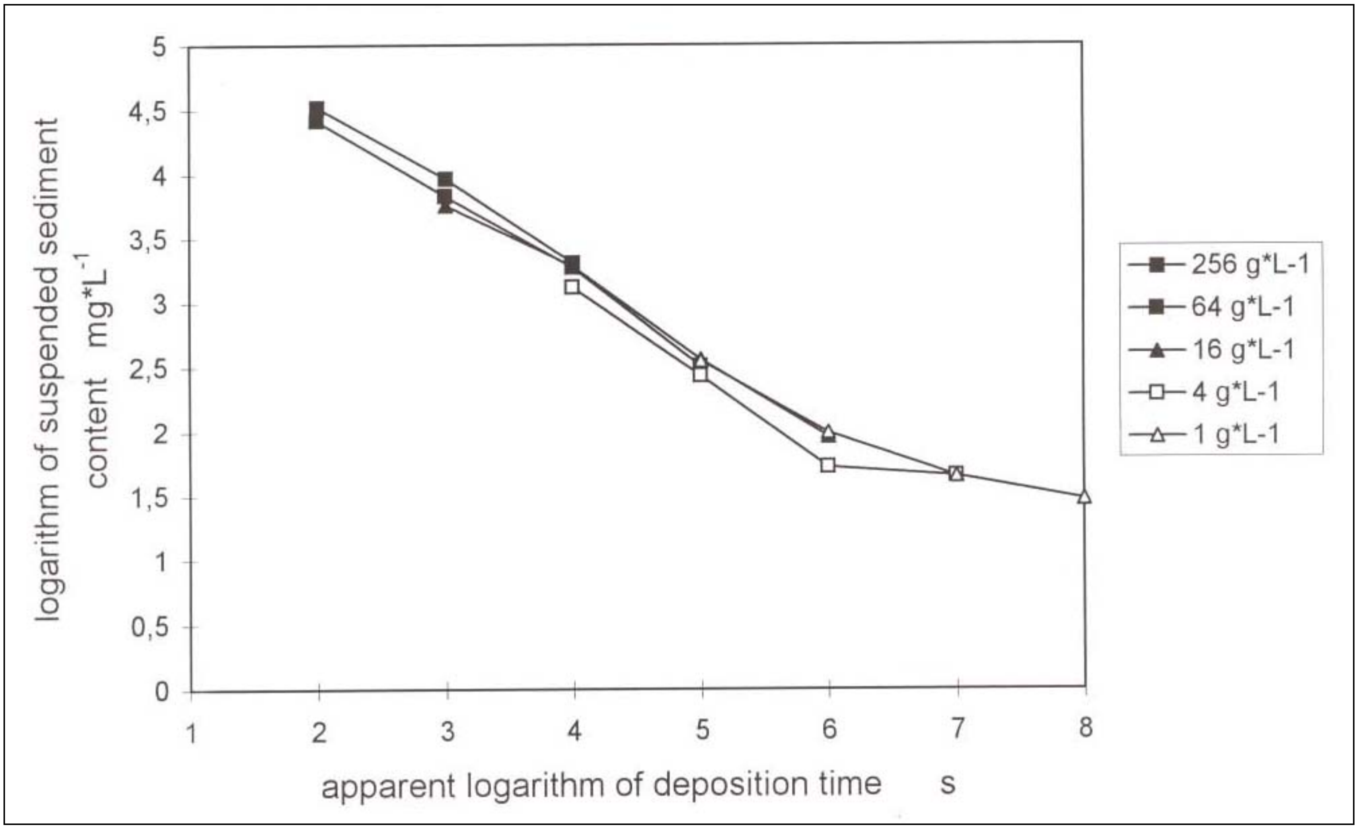

Figure 4. Shifted suspended solid deposition curves (Bicserd).

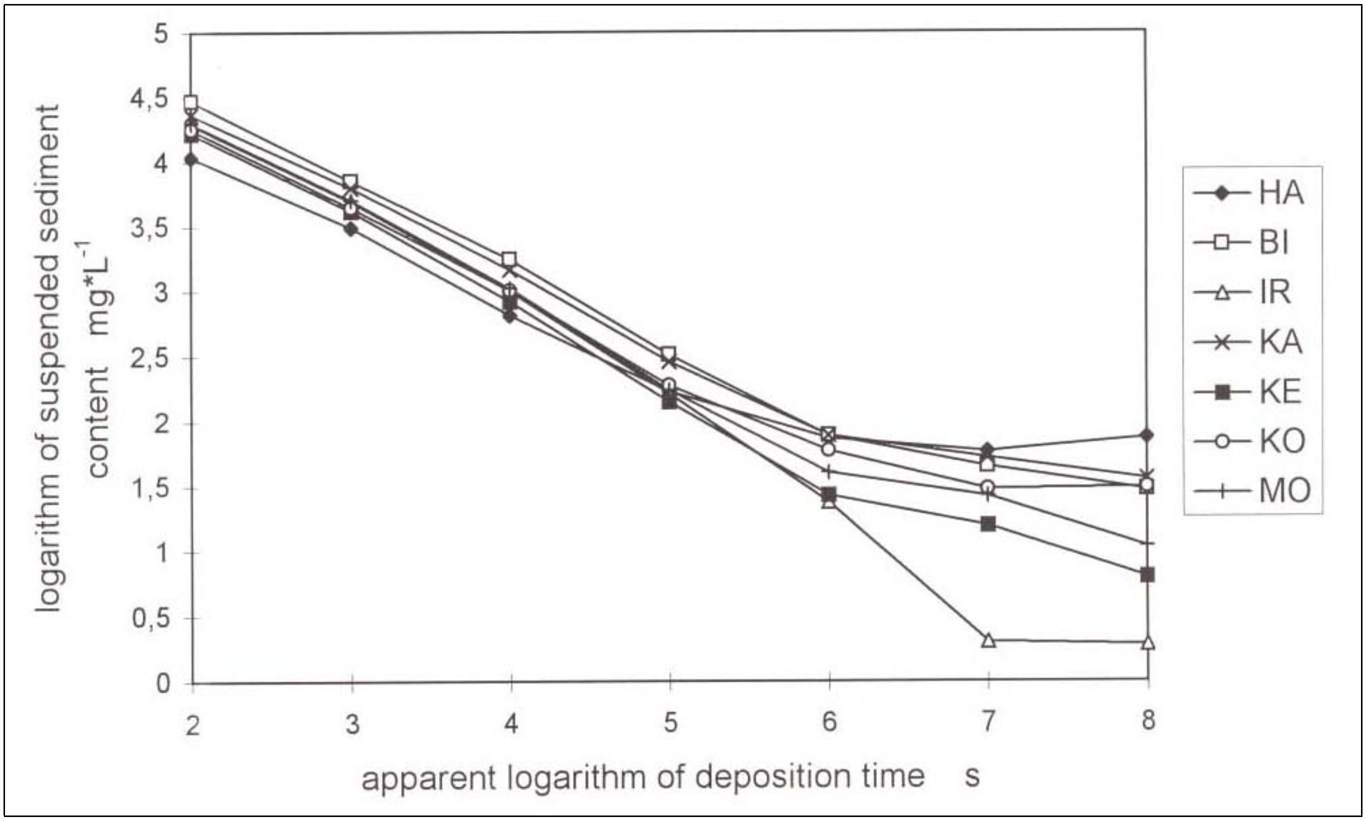

Figure 5. Apparent deposition curves.

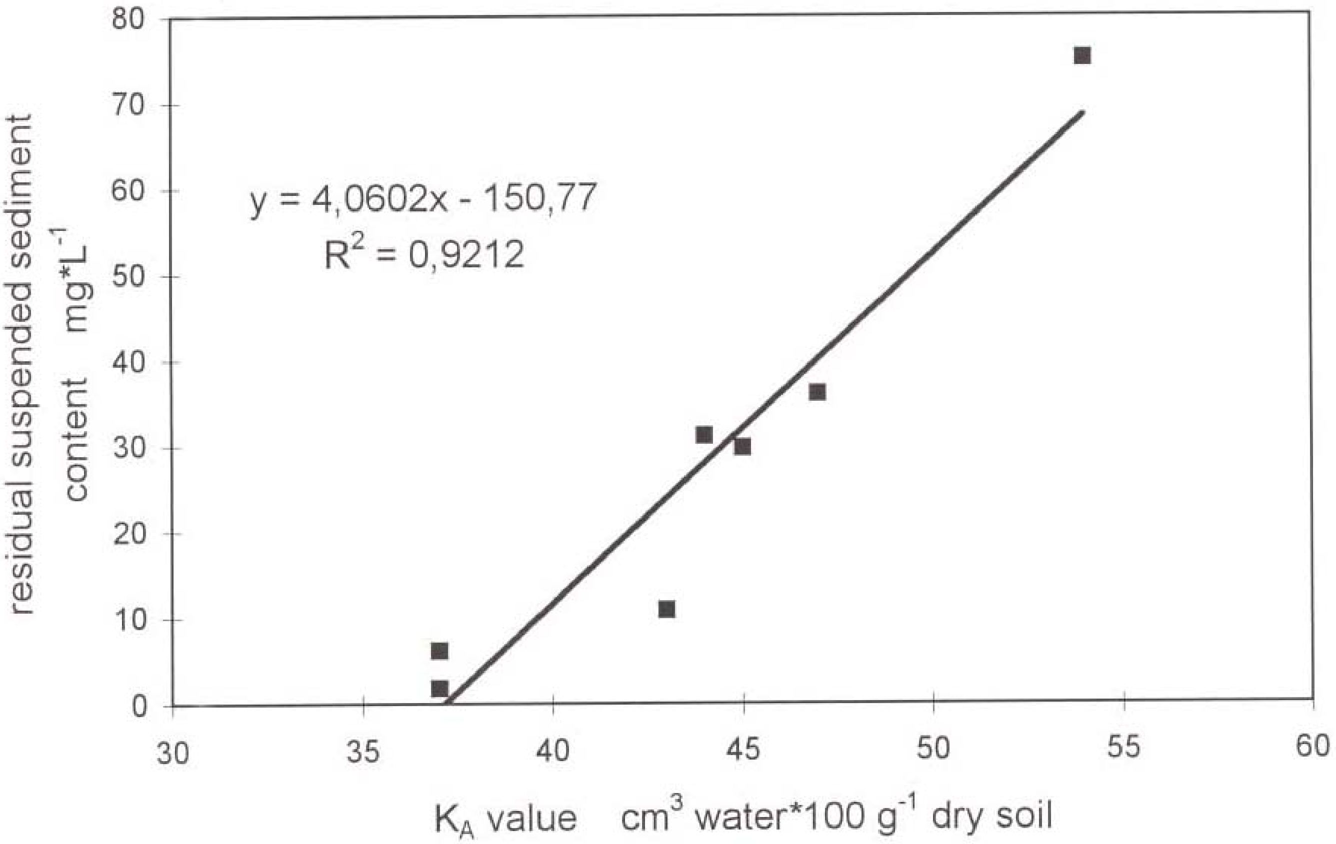

Figure 6. Dependence of the residual suspended sediment content from the K_A value.

Table 1 Selected physical and chemical properties of the experimental soils.

Experimental sites	Clay %	Particles<0. 01 mm %	K_A cm^3 water 100 g^{-1} dry soil	Extractable P_2O_5 with ammonium-lactate method mg kg^{-1}				
				fertilizer treatments for 28 years N-P_2O_5-K_2O kg ha^{-1} yr^{-1}				
				0-0-0	50-0-0	50-50-0	50-100-0	200-150-100
Karcag	37	59	47	55	63	91	125	149
Keszthely	24	37	37	94	92	181	255	294
Kompolt	41	58	44	56	48	118	201	254
Mosonmagyarovar	12	22	43	120	117	180	263	343
Bicserd	33	45	45	42	25	58	108	151
Hajduboszormeny	35	53	54	31	28	71	151	215
Iregszemcse	22	36	37	132	124	178	249	299

Table 2. Parameters, constants and determination coefficients of the logSS = A*logTIME + B*logSWR + C equations ($p>0.01$).

Experimental sites	A	B	C	R^2
Karcag	-0.510	0.860	1.095	0.906
Keszthely	-0.625	0.958	0.787	0.869
Kompolt	-0.560	0.892	0.954	0.878
Mosonmagyarovar	-0.629	0.914	1.092	0.882
Bicserd	-0.568	0.607	1.014	0.894
Hajduboszormeny	-0.484	0.665	1.613	0.809
Iregszemcse	-0.792	1.146	0.502	0.901

agricultural watersheds, Wall et al. (1982) reported that the clay content positively influenced the sediment yield. Our data reveal that consistency indices, such as K_A value can be much better indicators for the residual erosion potential of the soils and probably for the sediment yield, as well.

Particulate phosphorus

The analysis of variance of the particulate phosphorus results has shown that the variations in soil to water ratio, in deposition time and in the experimental sites explain 37.55 %, 16.68 % and 5.03 % of the total variance respectively ($p>0.01$) and the variation in P treatments causes 0,86 % variance ($p>0.05$).

Particulate P content was a function of the suspended sediment content, the phosphorus content of the original soil, and deposition time. Multiple regression equations were fitted for each site, the parameters for the different sites are shown in Table 3.

Based on the equations, three main types of particulate P deposition can be distinguished. In case of Keszthely the particulate P concentration is simple linear function of suspended sediment content and available P content. The sand fraction had settled down at the time of the first sampling (100 s) and the P was uniformly distributed among the remaining aggregate size classes so P enrichment cannot be recognized during the deposition. The second type of deposition is represented by Karcag, Kompolt and Mosonmagyarovar. The logarithm of deposition time has a positive effect on the particulate P content. That means the P content of finer aggregates is higher and enrichment is caused by deposition of coarser aggregates as a single major process. The third type of deposition is represented by Bicserd, Hajduboszormeny and Iregszemcse. At these sites, the particulate P content is a quadratic function of suspended sediment. The particulate P content is not proportionally higher with the higher suspended sediment content, independent of whether the high SS content is caused by shorter deposition time or high soil to water ratio. This indicates that beyond the process described at the second type of deposition another process also reduces PP content. At higher SS concentration the secondary formation of bigger aggregates must be accelerated which settle faster removing P from the upper suspension layer. This is the characteristic process, which overrides the processes described above. Our data reveal that plant available P may also affect the particulate P runoff in addition to dissolved P runoff (Sharpley, 1995).

CONCLUSIONS

The K_A value was better indicator of deposition processes and residual suspended sediment content in our experiment than other physical properties, such as clay content. Presumably, consistency indices can be much better indicators for the residual erosion potential of the soils and probably for the sediment yield, as well. Our data reveal that plant available P effects the particulate P runoff in addition to dissolved P runoff. P enrichment was proved at six of the seven sites and two different types of enrichment process were distinguished.

The equations developed are not suitable to predict SS and PP load from different areas during runoff events since time and soil to water ratio as the most important factors, cannot be exactly estimated in real processes. But the equations can be used to study the runoff events themselves. Time and soil to water ratio may be estimated by measuring suspended sediment, dissolved P and particulate P content in the runoff if the deposition properties of the given soils are known. The described deposition method can be a kind of environmental soil tests to determine particulate and dissolved P loading potential

of the soils and the method may help us to better understand the underlying processes of runoff and erosion.

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Table 3. Parameters, constants and determination coefficients of the $PP = A*SS + B*SS^2 + C*logTIME + D*ALP + E$ equations ($p>0.01$).

Experimental sites	A $*10^{-3}$	B $*10^{-8}$	C	D $*10^{-2}$	E	R^2
Karcag	3.74		2.56*	14.40	-19.85	0.861
Keszthely	5.35			1.76		0.928
Kompolt	3.18		1.81	2.16	-7.71	0.907
Mosonmagyarovar	5.38		1.88*	1.85^{+}	-9.27*	0.939
Bicserd	5.81	-5.25		2.81		0.950
Hajduboszormeny	3.56	-10.83		1.27		0.802
Iregszemcse	11.74	-24.38		1.53		0.905

* = $p>0.05$

\+ = $p>0.1$

Nonsigificant parameters and constants are omitted

REFERENCES

Auerswalsd, K. 1989. Prognose des P-Eintrags durch Bodenerosion in die Oberflächengewässer der BRD. Mitteilg. Dtsch. Bodenkundl. Gesellsch., 59/II. p. 661-664.

Bremner, J.M. and Mulvaney, C.S. 1982. Nitrogen - total. p. 595-624. In: Page, A. L. et al. (Eds.): Methods of soil analysis. Part 2. 2nd ed. Agronomy 9. Am. Soc. Agron., Madison, WI

Day, P. R. 1965. Particle fractionation and particle size analysis p. 545-567. In: C. A. Black et al. (ed.): Methods of soil analysis, Part 1. Agronomy 9:545-567.

Debreczeni K. - Sisak I. 1996. Relationship Between the P Balance of the Hungarian Long-Term Field Trials, the Trend of Yields and the Soluble P Content of the Soils. Comm. Soil. Sci. Plant Anal. 27. 5-8. 1647-1661

Debreczeni, K. - Sisak, I. - Sardi, K. - Csitari, G. 1996. Long-term fertilization trials in Hungary. in: Powlson, D. S.-Smith, P.- Smith, J. O. (Eds.) Evaluation of Soil Organic Matter Models Using Existing Long-Term

Datasets. NATO ASI Series. Series I: Global Environmental Change, Vol. 38. p. 319-324. Springer Verlag. Berlin - Heidelb. - New York.Egner, H., Riehm, H., Domingo, W. R. (1960): Untersuchungen über die chemische Bodenanalyse als Grundlage für die Beurteilung des Nährstoffzustandes der Böden. II. K. Lantbr. Hogsk. Ann. 26:199.

Hegemann, D.A., A.H. Johnson and J.D. Keenan. 1983. Determination of algal-available phosphorus on soil sediment: A review and analysis. J. Environ. Qual., 12:12-16.

Logan, T.J. 1987. Diffuse (non-point) source loading of chemicals to Lake Erie. J. Great Lakes Res. 13(4): p. 649-658

Murphy, J. and J.P. Riley. 1962. A modified single solution method for determination of phosphate in natural waters. Anal. Chim. Acta 27:31-36.

Sharpley, A.N. 1995. Dependence of runoff phosphorus on extractable soil phosphorus. J. Environ. Qual. 24:920-926.

Sharpley, A.N., S.J. Smith, O.R. Jones, W.A. Berg and G.A. Coleman. 1992. The transport of bioavailable phosphorus in agricultural runoff. J. Environ. Qual. 21:30-35.

Sharpley, A.N., S.C. Chapra, R. Wedepohl, J.T. Sims, T.C. Daniel and K.R. Reddy. 1994. Managing agricultural phosphorus for protection of surface waters: Issues and options. J. Environ. Qual. 23:437-451.

Sharpley, A.N., W. Gburek and I. Sisak. 1998. Identifying areas of phosphorus loss in agricultural catchments. In: O. van Cleemput - S. Haneklaus - G. Hofman - E. Schnug - A. Vermoesen (Eds.): Fertilization for sustainable plant production and soil fertility. Volume II. p. 566-573. Proc. World Fertilizer Congress of CIEC. 11th, Gent, Belgium, 7-13 September, 1997,

Sisák, I. 1995. Deposition diagram - a method to study and model the non-point source (NPS) phosphorus loading. In: C. Giupponi - A. Marani - F. Morari (Eds.): Modelling the fate of agrochemicals and fertilizers in the environment. European Society of Agronomy - Unipress. Padova. p. 251-262

Sisak, I., A.N. Sharpley and J. Weld. 1998. Approximating phosphorus release from soils to runoff. In: O. van Cleemput - S. Haneklaus - G. Hofman - E. Schnug - A. Vermoesen (Eds.): Fertilization for sustainable plant production and soil fertility. Volume II. p. 574-580 Proc. World Fertilizer Congress of CIEC. 11th, Gent, Belgium, 7-13 September, 1997,

Sowers, G.F. 1965. Consistency. In: C.A. Black et al. (ed.): Methods of soil analysis, Part 1.Agronomy 9:391-399.

Storm, D.E., T.A. Dillaha III, S. Mostaghimi and V.O. Shanholtz. 1988. Modelling phosphorus transport in surface runoff. Trans. ASAE, 31(1):117-127.

Varallyay, Gy. 1993a. Investigation on particle size distribution In: Buzás, I. (ed): Manual of soil and agrochemical investigations 1. Physical, hydrological and mineralogical investigations of soils. INDA 4231 Press. Budapest, p. 35-44.(in Hungarian)

Varallyay, Gy. 1993b. Investigation on physical type of soil In: Buzás, I. (ed.): Manual of soil and agrochemical investigations 1. Physical, soil-water relationship and mineralogical investigations of soils. INDA 4231 Press. Budapest, p. 45-56. (in Hungarian)

Wall, G.J., W.T. Dickinson, and L.J.P. van Vliet. 1982. Agriculture and water quality in the Canadian Great Lakes Basin: II. Fluvial sediments. J. Environ. Qual. 11:482-486.