Transactions on Ecology and the Environment vol 13, © 1997 WIT Press, www.witpress.com, ISSN 1743-3541

Rainfall Intensity and Soil Texture Effects on Water, Sediment, and Pesticide Losses

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Abstract

The objective of this paper is to evaluate the effect of rainfall intensity and soil texture on the transport behavior of three pesticides (2,4-D, metolachlor, and chlorpyrifos). We compared water, sediment, and pesticide losses from two soils (Greenville sandy clay loam from Georgia, USA, and a silt loam from Austria), and for two simulated rainfall intensities (40 and 60 $mm.h^{-1}$) under laboratory conditions. Pesticides were applied to air dry soils at rates of 1.0, 2.0, and 1.5 $kg.ha^{-1}$ for 2,4-D, metolachlor and chlorpyrifos, respectively. One day after pesticide application, erosion pan was placed at a 7.5% slope and rainfall was simulated. Runoff, wash, splash, and infiltration were measured at 5 min intervals throughout the rainfall event. Pesticide concentrations were determined in selected runoff, splash water and infiltration samples, and analyzed using enzyme-linked immunosorbent assay (ELISA). Depending on soil texture, time until steady-state runoff was reached varied. Higher silt content of Pyhra soil led to surface sealing, increased runoff, and high splash water rates. Interrill erosion from Pyhra soil was high for air dry surface and decreased when soil surface was sealed or crusted. 2,4-D losses by runoff were higher for Greenville soil with lower organic carbon and lower susceptibility to raindrop detachment. Metolachlor and 2,4-D showed similar transport behaviour. Transport of chlorpyrifos was small.

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1 Introduction

Models can are efficient tools to simulate pesticide transport under different climatic, pedologic, and management conditions. Continuous simulation models have been developed to simulate pesticide fate and transport in soils. With these models pesticide transport can be calculated on a daily storm event basis. When evaluating the impact of agricultural management practices on aquatic eco-systems, extreme single event values may be more important than long-term averages (1).

We investigated the impact of rainfall intensity and soil texture on runoff, sediment yield and pesticide transport.

2 Materials and methods

Soil was obtained from the A horizons of a Greenville sandy clay loam from Georgia, USA, and a silt loam soil from Pyhra, Austria. Physical and chemical properties of each soil (Table 1) were determined with the following methods: dispersed particle size distribution, measured with a combined wet sieving and pipette method (2) or a hydrometer method (3); organic carbon, measured by the modified Walkley-Black method (4); pH in H_2O for Greenville soil and in $CaCl_2$ for Pyhra soil (5); cation exchange capacity (CEC), determined by barium chloride dihydrate method (6); exchangeable cations, determined by the NH_4OAc Method (7).

Table 1 Physical and chemical properties of Pyhra and Greenville soil

property	Pyhra	Greenville
Texture	silt loam	sandy clay loam
Sand (%)	37	64
Silt (%)	41	15
Clay (%)	22	21
OM ($g.kg^{-1}$)	28	12
pH	7.4	5.0
CEC ($cmol.kg^{-1}$)	12	9.0
Ca ($cmol.kg^{-1}$)	10	1.0
Mg ($cmol.kg^{-1}$)	1.0	0.2
K ($cmol.kg^{-1}$)	0.2	0.4
Na ($cmol.kg^{-1}$)	0.1	0.1

Laboratory rainfall/erosion method was similar to that described by Truman and Bradford (8). The erosion pan had an area of 1,47 m^2 and a central test area of 0,32 m^2. Soil was air dried and sieved through a 19 mm sieve. A 100 mm-layer of air-dried soil was placed over a 50 mm-layer of sand in the central and border test areas of the pan. Initial bulk densities were 1,42 $g.cm^{-3}$ for Pyhra soil and 1.28 $g.cm^{-3}$ for Greenville soil.

Before simulating rainfall, pesticides (Table 2) were surface applied conventionally with a nozzle type, laboratory sprayer. On the Greenville soil, atrazine and chlorpyrifos were applied, whereas on Pyhra soil 2,4-D, metolachlor and chlorpyrifos were sprayed.

One day after pesticide application the erosion pan was placed at a 7% slope for the sandy clay loam and 7.5% slope for the silt loam, and then placed under a multiple-intensity rainfall simulator (9). The simulator used 80100 Veejet nozzles that produce median drop size of 2.3 mm. Nozzles were 2.4 m (Austria) and 3.0 m (USA) above the soil surface.

Rainfall simulations were carried out with intensities of 40 and 60 $mm.h^{-1}$, respectively. Deionized water (Greenville) and chloride free tap water (Pyhra) was used as rainwater. Rainfall durations ranged from 90 min for Pyhra soil to 240 min for Greenville. Runoff (R), wash (W), splash water (Sw), splash sediment (Ss), and infiltration (INF) were measured at 5 min intervals throughout all rainfall events. Infiltration was defined as the amount of water which drained through the drain holes in the bottom of the erosion pan. Pesticide concentrations were measured in R, Sw, and INF at every other 5 min interval using enzyme-linked immunosorbent assay (ELISA). Pesticide concentration in runoff and splash samples were corrected for amounts of added destilled water to clean collectors. Runoff samples included runoff and splash collected in runoff collector.

Table 2 Pesticide characteristics and application rates

property	pesticide		
	2,4-D	metolachlor	chlorpyrifos
t ½ (days)	10	100	30
K_{oc} ($ml.g^{-1}$)	20	100	6070
solubility ($mg.l^{-1}$)	890	530	0.4
application rate (kg $a.i.ha^{-1}$)	0.4* / 1.0**	1.9	1.5

* Pyhra soil
** Greenville soil

3 Results

3.1. Runoff, infiltration, and erosion measurements

Runoff (R) and splash water (Sw) losses for Pyhra and Greenville soil are given in Figs. 1 and 2, while sediment losses (W and Ss) are shown in Figs. 3 and 4. For both intensities, runoff from Pyhra soil started within the first 15 min and increased rapidly. Steady-state R was reached 35 min after beginning of rainfall with constant R rates of 29 $mm.h^{-1}$ and 46 $mm.h^{-1}$ for rainfall intensities of 40 and 60 $mm.h^{-1}$, respectively (Table 3). During the second (95-150 min) and third rainfall event (155-210 min), slightly higher R rates can be observed. At the end of the experiment steady-state runoff rates were 35 and 55 $mm.h^{-1}$ for 40 and 60 $mm.h^{-1}$ intensity. Runoff for Greenville soil started about 50 to 60 min after beginning of rainfall depending on rainfall intensity. Runoff rate increased slowly until constant runoff (32 and 57 $mm.h^{-1}$) was reached after 160 min.

Intensity induced differences can also be seen in splash water rates. Pyhra soil showed higher splash water rates than Greenville soil. Highest values for Pyhra soil were measured during first rainfall with air dry initial conditions (Table 3), and were 39 and 73 $mm.h^{-1}$, respectively. During this time period, splash rates were higher than corresponding runoff rates. Rainfall (60 $mm.h^{-1}$) on a sealed soil surface showed lower splash water rates regardless the surface was wet (95-150 min) or dry (155-210 min). For the lower rainfall intensity, such differences were not observed. For Greenville Sw values ranged between 6 and 13 $mm.h^{-1}$ for lower rainfall intensity and between 10 and 21 $mm.h^{-1}$ for higher intensity.

No infiltration (INF) was measured during experiments with Pyhra soil. With Greenville soil infiltration started 65 min and 35 min, respectively, after beginning of rainfall (Fig. 11). Maximum INF rates were 29 and 69 $mm.h^{-1}$. Afterwards INF decreased for both rainfall intensities until steady-state INF of 10 and 17 $mm.h^{-1}$ was observed at same time as constant runoff.

Figs. 3 and 4 show wash (W) and splash sediment (Ss) for Pyhra and Greenville soil. Pyhra soil is more susceptible to detachment by raindrops and runoff than Greenville. For Pyhra, maximum W occurred for both intensities shortly before maximum runoff. With increased rainfall duration and accumulated kinetic energy of rainfall, soil surface was sealed which decreased soil losses by runoff until steady-state W rates were reached at the end of first rainfall event. For Greenville soil, W rates increased slightly during the first 160 min when constant rates of 0.3 and 0.5 $kg.m^{-2}.h^{-1}$ were measured.

For both intensities, Pyhra soil showed high splash erosion (Ss) during the first rainfall event (0-90 min; Fig. 4). Maximum Ss values were 2.5 times higher than maximum W. Due to surface sealing, Ss rates decreased steadily to constant rates of about 1.1 and 1.8 $kg.m^{-2}.h^{-1}$, respectively. Ss rates increased slowlier for Greenville soil reaching maximum rates (1.5 and 2.6 $kg.m^{-2}.h^{-1}$) about 120 to 140 min after beginning of rainfall. For lower rainfall intensity, Ss rates were nearly constant (1.4 $kg.m^{-2}.h^{-1}$) whereas Ss rates decreased slightly to a final rate of 2.0 $kg.m^{-2}.h^{-1}$ at end of experiment for 60 $mm.h^{-1}$ rainfall intensity.

Table 3 Peak and steady-state runoff (R), wash (W), splash water (Sw) and splash soil (Ss) rates

	Pyhra		Greenville	
rainfall intensity ($mm.h^{-1}$)	38.1	57.0	37.2	59.0
bulk density ($g.cm^{-3}$)	1.42	1.42	1.28	1.28
steady state R ($mm.h^{-1}$)	29.5	46.5	32.0	57.3
steady state Sw ($mm.h^{-1}$)	39.1	72.6	10.0	17.0
peak INF ($mm.h^{-1}$)	n.m.	n.m.	28.5	69.0
steady state Inf ($mm.h^{-1}$)	n.m.	n.m.	10.1	17.3
peak W ($kg.m^{-2}.h^{-1}$)	0.85	1.86	0.27	0.53
final W ($kg.m^{-2}.h^{-1}$)	0.34	0.70	0.26	0.52
peak Ss ($kg.m^{-2}.h^{-1}$)	2.17	4.60	1.53	2.63
final Ss ($kg.m^{-2}.h^{-1}$)	1.09	1.77	1.41	1.99

3.2 Pesticide measurements

Figs. 5 and 6 show 2,4-D concentrations in runoff and splash water samples. For the Pyhra soil, pesticides were sprayed on air dry soil surface whereas the surface of Greenville soil was prewet before applying pesticides. Despite higher Sw rates for Pyhra soil, 2,4-D concentrations in Sw samples were up to one order of magnitude higher than in R samples. Threefold application rate of 2,4-D on wet Greenville soil surface led to higher concentrations in R than in Sw, although R rates were higher than Sw rates. Concentrations of 2,4-D in infiltration from the prewetted Greenville soil were determined 10 and 15 min after infiltration started (Fig. 12). For lower rainfall intensity, concentrations ranged between 5 and 1 ppb. For the 60 $mm.h^{-1}$ rainfall intensity treatment, breakthrough of 2,4-D started 75 min after rainfall started. During steady state infiltration, 2,4-D concentration increased from about 2 to 35 ppb.

Due to a higher application rate, metolachlor concentrations in Sw and R samples from Pyhra soil were always higher than 2,4-D concentrations (Figs. 7 and 8). Values were similar to 2,4-D concentrations from Greenville soil. Higher application rate and lower solubility of metolachlor led to these results. After 40 min, steady-state runoff conditions were reached, and constant metolachlor concentrations were observed in R and Sw. Final metolachlor concentrations were about 35 ppb for both intensities.

Because of rapidly increasing runoff from Pyhra soil, chlorpyrifos concentrations decreased for both intensities from 96 (60 $mm.h^{-1}$) and 56 ppb (40 $mm.h^{-1}$) within the first 20 to 40 min to constant concentrations of about 1 ppb (Figs. 9 and 10). Lower R and Sw rates for Greenville soil resulted in higher concentrations. Rate of decrease in concentration was less for Pyhra soil than for Greenville soil. Initial concentrations in runoff of 147 (40 $mm.h^{-1}$) and 418 ppb (60 mm.h^{-1}) dropped to 0.7 (40 mm.h^{-1}) and 1.8 ppb (60 mm.h^{-1}), respectively. Chlorpyrifos concentrations in infiltration of Greenville soil did not change significantly throughout the whole experiment (Fig. 12).

Depending on intensity and soil texture, between 0.5 and 15.8 % of total applied 2,4-D was lost by runoff (Table 4). Greenville soil showed higher losses than Phyra soil. Sorption in Pyhra soil, with 2.8% organic carbon content (OC), seems to be higher than in Greenville soil. For Pyhra soil, runoff losses were about 10% of splash values whereas for Greenville soil, runoff values were 2 times higher than splash results. Calculations for metolachlor showed slightly lower values. Relation between runoff and splash is similar to 2,4-D. Increased rainfall intensity increased surface seal development and possibly increased depth of soil surface-runoff water interaction and pesticide extraction into runoff. Chlorpyrifos has a relatively large K_{oc} (≈ 6000) and small solubility (0.4 mg.l^{-1}), and should be transported mostly attached to sediments. Therefore, runoff, splash water and infiltration losses were very small (Table 4).

Table 4 Pesticide losses by runoff, splash and infiltration in % of applied amount during 90 min.

	Pyhra		Greenville	
rainfall intensity (mm.h^{-1})	38.1	57.0	37.2	59.0
2,4-D				
losses by runoff	0.5	2.6	7.2	15.8
losses by splash	31.5	39.4	3.6	6.1
losses by infiltration	0.0	0.0	0.1	0.1
total losses	***32.0***	***42.0***	***10.9***	***22.0***
metolachlor				
losses by runoff	1.2	3.3	---	---
losses by splash	18.3	33.9	---	---
losses by infiltration	0.0	0.0	---	---
total losses	***19.5***	***37.2***	---	---
chlorpyrifos				
losses by runoff	0.04	0.04	0.06	0.33
losses by splash	0.14	0.19	0.18	0.29
losses by infiltration	0.00	0.00	0.02	0.02
total losses	***0.18***	***0.23***	***0.26***	***0.64***

4 Summary and conclusions

In a laboratory study, we investigated the effect of rainfall intensity and soil texture on water, sediment and pesticide losses. One day after applying 2,4-D, metolachlor and chlorpyrifos on air-dry soils (a Greenville sandy clay loam and a

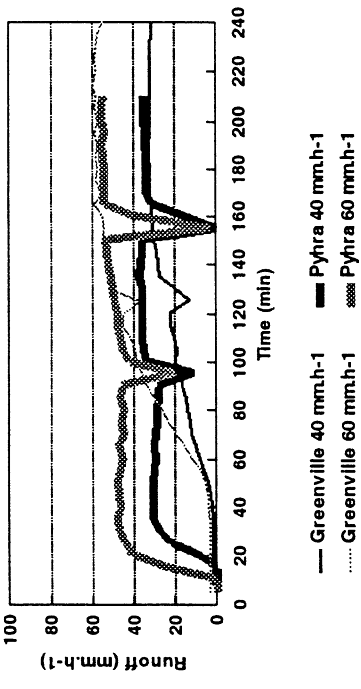

Fig.1: Runoff from Pyhra and Greenville soil for two rainfall intensities

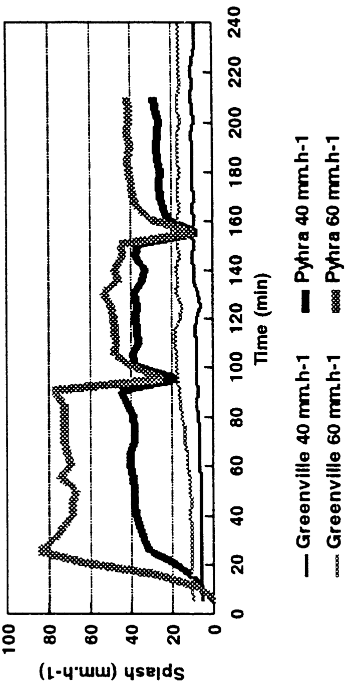

Fig.2: Splash water from Pyhra and Greenville soil for 2 rainfall intensities

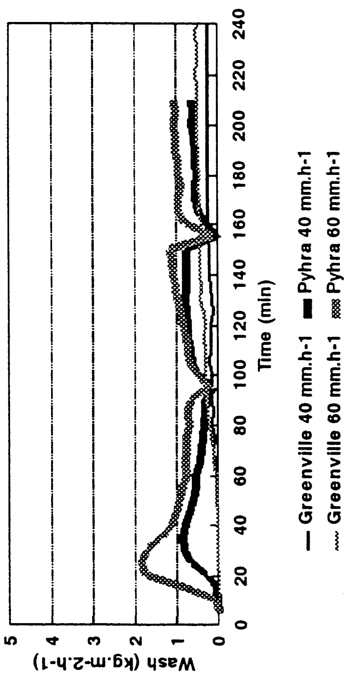

Fig.3: Wash from Pyhra and Greenville soil for two rainfall intensities

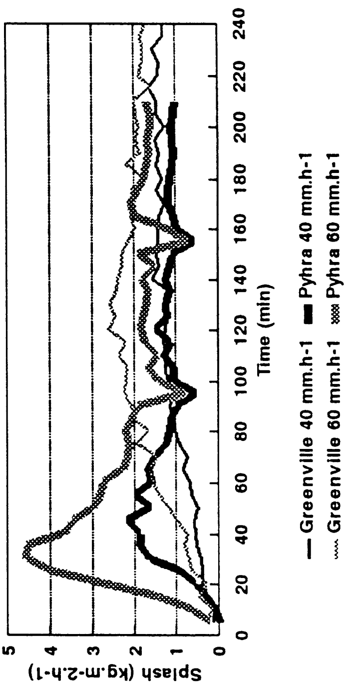

Fig.4: Splash sediment from Pyhra and Greenville soil for two rainfall intensities

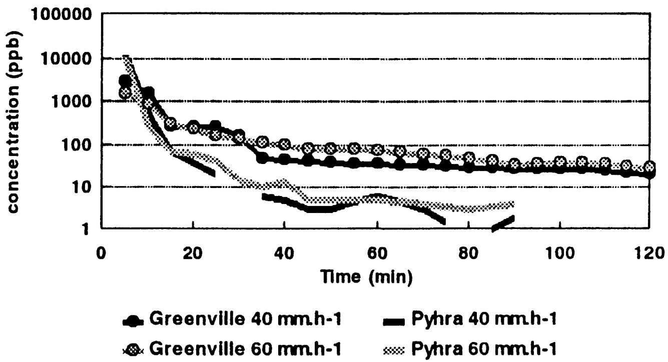

Fig. 5: 2,4-D concentrations in runoff (in ppb)

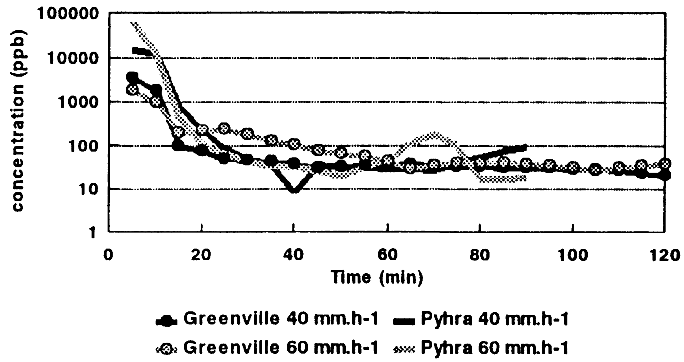

Fig. 6: 2,4-D concentrations in splash (in ppb)

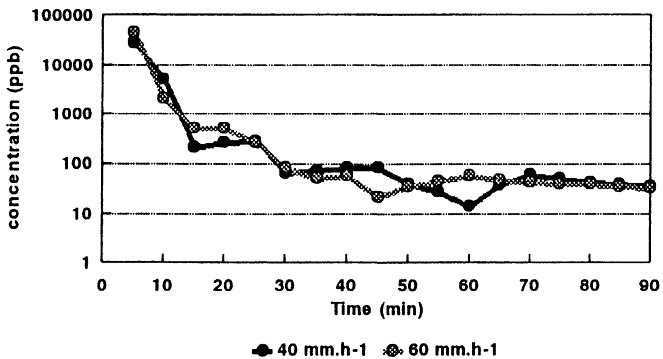

Fig. 7: Metolachlor concentrations in runoff from Pyhra soil

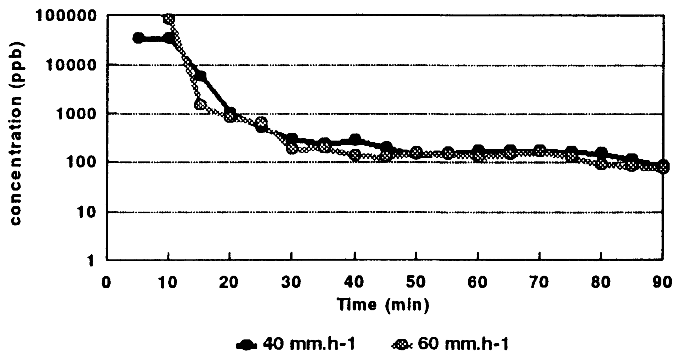

Fig. 8: Metolachlor concentrations in splash from Pyhra soil

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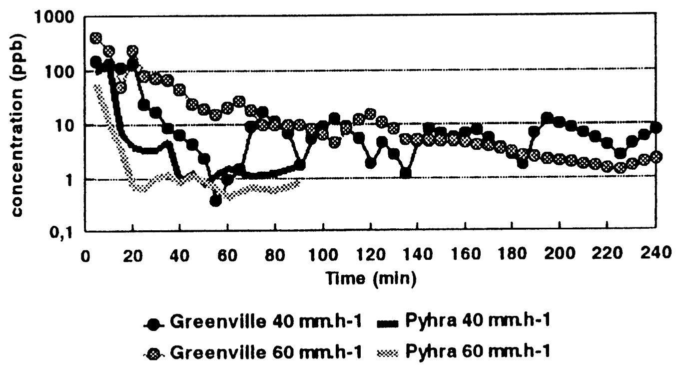

Fig. 9: Chlorpyrifos concentrations in runoff (in ppb)

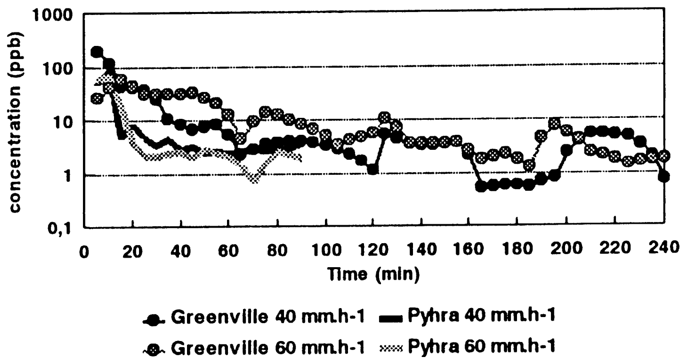

Fig. 10: Chlorpyrifos concentrations in splash (in ppb)

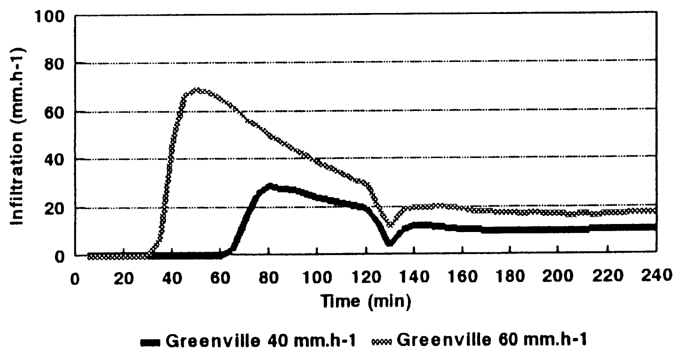

Fig. 11: Infiltration in Greenville soil

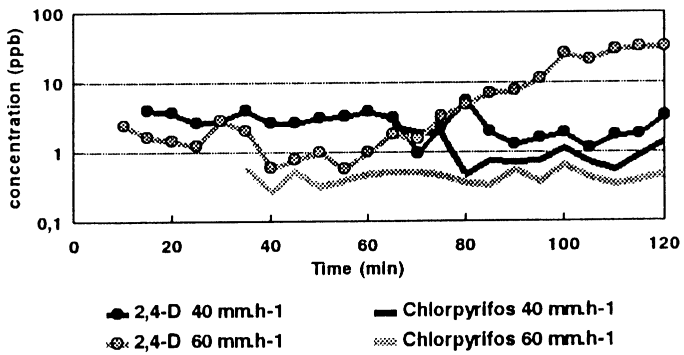

Fig. 12: 2,4-D and chlorpyrifos concentrations in infiltration

Pyhra silt loam), soils were exposed to simulated rainfall with 40 and 60 $mm.h^{-1}$ intensity. Runoff, sediment yield, splash, and infiltration were measured and pesticide concentrations were determined in water samples throughout the rainfall event.

Depending on soil texture, time until steady-state runoff was reached varied. Constant runoff was similar for both soils. Higher silt content of Pyhra soil led to surface sealing, increased runoff, and high splash water rates. Interrill erosion from Pyhra soil was high for air dry surface and decreased when soil surface was sealed or crusted. Wash from Greenville soil correlated with runoff. 2,4-D losses by runoff were higher for Greenville soil with lower organic carbon and lower susceptibility to raindrop detachment. Metolachlor and 2,4-D showed similar transport behaviour. Transport of chlorpyrifos was small.

References

1. National Research Council. *Soil and water quality - an agenda for agriculture.* National Academy Press, Washington, D.C., 1993.
2. Önorm L 1061. Physikalische Bodenuntersuchungen - Bestimmung der Korngrößenverteilung des mineralischen Feinbodens. Österreichisches Normungsinstitut, September 1988, pp. 4.
3. Day, P.R. Particle fractionation and particle size analysis. p. 545-567. In: Black, C.A. (Ed.) Methods of soil analysis. Part 1. Agron. Monogr. 9. ASA and SSSA, Madison WI, 1965.
4. Nelson D.W. & Sommers, L.E. Total carbon, organic carbon, and organic matter. p. 539-579. In: Black, C.A. (Ed.) Methods of soil analysis. Part 1. Agron. Monogr. 9. ASA and SSSA, Madison WI, 1982.
5. McLean, E.O. Soil pH and lime requirement. p. 199-224. In: Black, C.A. (Ed.) Methods of soil analysis. Part 1. Agron. Monogr. 9. ASA and SSSA, Madison WI, 1982.
6. Rhoades, J.D. Cation exchange capacity. p. 149-157. In: Black, C.A. (Ed.) Methods of soil analysis. Part 1. Agron. Monogr. 9. ASA and SSSA, Madison WI, 1982.
7. Thomas, G.W. Exchangeable cations. p. 159-165. In: Black, C.A. (Ed.) Methods of soil analysis. Part 1. Agron. Monogr. 9. ASA and SSSA, Madison WI, 1982
8. Truman, C.C. & Bradford, J.M. Laboratory determination of interrill soil erodibility. *Soil Sci. Soc. Am. J.*, 1995, 59: p. 519-526.
9. Foster, G.R., Neibling, W.H. & Nattermann, R.A. A programmable rainfall simulator. 1982. *ASAE Paper No. 82-2570.*