Comparison of German and Swiss Rainfall Simulators - Influence of Plot Dimensions

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This paper is dedicated to Prof. Dr. *U. Schwertmann* on occasion of his 65th birthday

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Summary-Zusammenfassung

The construction and operation of a rainfall simulator becomes easier with decreasing plot size. We studied the effect of plot size on the erosion dynamics and whether it is preferable to decrease plot width or plot length. 22 simulated rainfalls were carried out with Veejet 80 100 simulators and on plots of considerably differing dimensions.

The plot width has to cover a representative width of the field. With the common 3 m wide farm machinery, a plot width of at least 1.5 m containing one wheel track is necessary. Narrower plots are not suited for erosion experiments on agricultural land.

The influence of plot length can be described with the LS factor of the USLE down to a plot length of 4.5 m and with the RUSLE for interrill plots (0.75 m).

With decreasing plot size, the runoff started later (up to 20 min) and the afterflow ended earlier. This is not only a result of the plot length (r = 0.78), but mainly of the plot size (r = 0.92). The large time lag on small plots complicates the interpretation of the results. We recommend to disregard the rain erosivity during the time lag for the determination of USLE parameters. This is in accordance with the procedure of *Wischmeier & Mannering* (1969). Plot sizes have to be selected particularly carefully if the fate of soluble substances is to be studied.

Vergleich deutscher und schweizer Regensimulatoren - Einfluß der Parzellenabmessungen

Mit abnehmender Parzellengröße vereinfacht sich die Konstruktion und der Betrieb von Regensimulatoren. Es wurde untersucht, ob dadurch die Erosionsdynamik verändert wird und ob es vorteilhafter ist, die Parzellenlänge oder -breite zu verkleinern. Dazu wurden 22 Beregnungen mit Veejet-80100-Regnern mit unterschiedlichen Parzellenabmessungen ausgewertet.

Die Parzellenbreite muß einen repräsentativen Ausschnitt des Feldes erfassen. Bei 3 m breiten landwirtschaftlichen Maschinen ist dazu mindestens eine Parzellenbreite von 1.5 m erforderlich, in der eine Reifenspur liegt. Schmälere Parzellen sind zur Untersuchung landwirtschaftlicher Flächen ungeeignet.

Der Einfluß der Parzellenlänge konnte durch den LS-Faktor der ABAG für Parzellen von mindestens 4.5 m Länge beschrieben werden. Für kleine Interrill-Parzellen (0.75 m) war der höhere LS-Faktor der RUSLE für kleine Hanglängen geeignet.

Mit abnehmender Parzellengröße beginnt der Abfluß bis zu 20 min später und der Nachfluß endet früher. Dies ist nicht allein auf die Parzellenlänge zurückzuführen (r = 0.78) sondern vor allem auf die Parzellenfläche (r = 0.92). Die große Verzögerung des Abflusses auf kleinen Parzellen erschwert die Interpretation. Es wird empfohlen, die Regenerosivität bis zum Abflußbeginn nicht zu berücksichtigen, wenn Parameter der ABAG bestimmt werden sollen. Dies entspricht in etwa dem Vorgehen von *Wischmeier & Mannering* (1969). Die Parzellengröße muß besonders sorgfältig gewählt werden, wenn im Abfluß gelöste Substanzen untersucht werden sollen.

Introduction

Erosion research usually has to answer questions on a hectare scale. This makes large plot sizes preferable. The construction and the operation of simulators, however, become more difficult with increasing plot size. The water, for example, can only be adjusted to natural rain water quality when water consumption is low. Otherwise tap water or surface water has to be used, that will have a different influence on nutrient desorption. On the other hand, the influence of plot size on the erosion process has to be known for the extrapolation of simulator results to real field sizes. Both aspects have to be considered when the optimum plot size is selected.

The USLE predicts that the soil loss per unit area increases with increasing plot length, whereas plot width has no influence. It could therefore be concluded that it is preferable to increase the plot length rather than the plot width to approach natural conditions. This has not been proved.

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Materials and Methods

All field rainfall simulators that are currently in use in Germany and Switzerland were tested on the same field during two days (*Auerswald* et al., 1992). Their normal plot dimensions differ considerably (*Kainz* et al., 1992). Further plot dimensions were also included in the survey. To avoid the effect of other variables than plot dimensions, we compare here only the results of the Veejet 80100-nozzle-simulators with a 1 h first run and a 0,5 h second run. Seven plot sizes were rained with the Swanson-type simulator SW (*Auerswald*, 1984), two plot sizes with the simulator KE of *Kainz & Eicher* (*Kainz* et al., 1992) and two plots with the simulator KR of *Kromer & Vöhringer* (1988). Table 1 summarizes the tested plot dimensions.

Table 1: Plot characteristics
Tabelle 1: Parzelleneigenschaften

Parameter		Minimum	Mean	Maximum
Slope steepness	[%]	5.33	5.92	6.60
Plot length	[m]	0.75	6.55	10.60
Plot width	[m]	0.50	1.65	4.00
Length/width ratio	[-]	1.50	4.56	8.08
Plot size	[m^2]	0.38	8.38	42.40
S factor	[-]	0.49	0.56	0.65
L factor	[-]	0.20	0.56	0.70
LS factor	[-]	0.17	0.28	0.44
R factor	[N/h]	28.95	59.87	87.40

Results and Discussion

Erosion behaviour of the research site

The largest plot ($10 \cdot 4$ m^2) is a quasi-standard because of the widespread use of Swanson-type simulators. The runoff behaviour of this plot could be explained by the structure of the soil surface. A shallow (5 cm) seedbed had been prepared with a 3 m wide rotary harrow. This had left a thin layer of small aggregates on the sides and a thicker layer of larger aggregates in the middle of the tilling width. The surface storage was very low and runoff started almost immediately (after 54 s) where the small aggregates formed a thin layer on a consolidated zone (Fig. 1). The runoff increased steadily for the first 20 min because the contributing length increased. The runoff rate then increased abruptly. At this time the surface storage of the area with the larger aggregates was obviously filled, and the whole plot contributed to the runoff. After about 40 min the final runoff rate was almost reached.

The sediment concentrations also reflected this tillage-induced surface structure. During the first increase of runoff the sediment concentration remained constant, because only the contributing area increased but the detachment and transport process did not change. The concentration dropped when the area with the high storage capacity contributed to runoff, because the thick layer of surface water between the large aggregates provided an efficient water mulch. With increasing time of rain, the initial surface roughness was leveled out. This reduced the depth and effi-

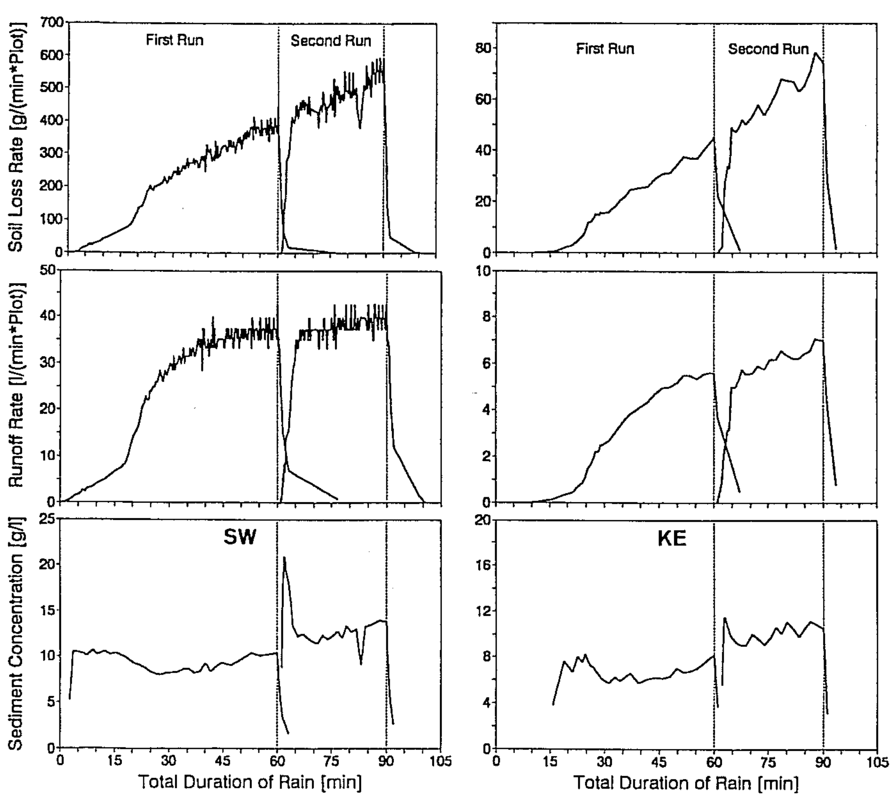

Figure 1: Soil loss rates, runoff rates, and sediment concentrations of SW with a $4 \cdot 10$ m^2 plot and of KE with a $1.8 \cdot 4.6$ m^2 plot
Abbildung 1: Abtragsraten, Abflußraten und Sedimentkonzentrationen auf der $4 \cdot 10$ m^2 Parzelle des Regners SW und der $1.8 \cdot 4.6$ m^2 Parzelle des Regners KE

ciency of the water mulch. The sediment concentrations therefore increased steadily for the rest of the rain. The increasing concentration also caused the soil loss rate to increase. Only the break between the first and the second run produced a short deviation of these trends.

Influence of plot width

With the simulator KE, a plot of only 1.8 · 4.6 m^2 is normally used. This nevertheless produced the same courses of sediment concentration, runoff and soil loss rate as with the 40 m^2 plot (Fig. 1). With a plot width of 1.8 m it was possible to select half the tilling width as a representative part of the area. This was also the case for a 2 · 6 m^2 plot used with the SW simulator.

Some simulators in the test could only be used on 1 m wide plots (*Kainz* et al., 1992). For the comparison of all simulators, a standardized plot width of 1 m was therefore used. This width was too narrow to include a representative sector. Runoff and erosion was different, depending on which part of the surface structure was overrepresented (Fig. 2). With KE, the part with low surface storage was overrepresented on the 1 m plot, whereas with SW the part with high storage was overrepresented.

In spite of a very careful site preparation, small differences in surface storage led to different erosion behaviour. Under normal agricultural use, the differences are far bigger, so that larger differences in erosion can be expected. Even the average of several plots cannot replace a representative plot, because the average does not consider the interaction of different surface situations. A consolidated wheel track, for example, will not erode much because detachment is limited. A freshly loosened soil also would not erode much because the low runoff limits transport. Combining both situations in one plot could lead to high soil losses because neither detachment nor transport is limited.

Comparing all simulators in the test, surface roughness explained to a high degree the soil loss (r = 0.58) and the runoff (r = 0.70) of 1 m wide plots, in spite of large differences in the rain structure of the simulators. The ability of a simulator to cover a representative section is therefore at least of the same importance as the comparability to natural rainstorms.

Influence of plot size

With decreasing plot size, the runoff started later (Fig. 3, see also Fig. 1). Whereas on the 40 m^2 plot runoff began after less than one minute, it took almost 20 min on the 4.6 m^2 plot. This cannot be traced back to a drainage of water to the dry part of the field, because all plots in Fig. 3 were rained with the simulator SW. Its rainfed area of 240 m^2 provides enough buffer area around the plots, especially around small plots.

On larger plots, runoff not only starts earlier but also lasts longer after the rain has been turned off (Fig. 3). Again, this depends more on plot size (r = 0.9195; n = 22) than on plot length (r = 0.7773; n = 22). This is obviously not only due to the longer time the runoff needs on a longer plot to reach the lower end. On larger plots the border per unit plot area is shorter. The 40 m^2 plot has 0.7 m/m^2 border, whereas the

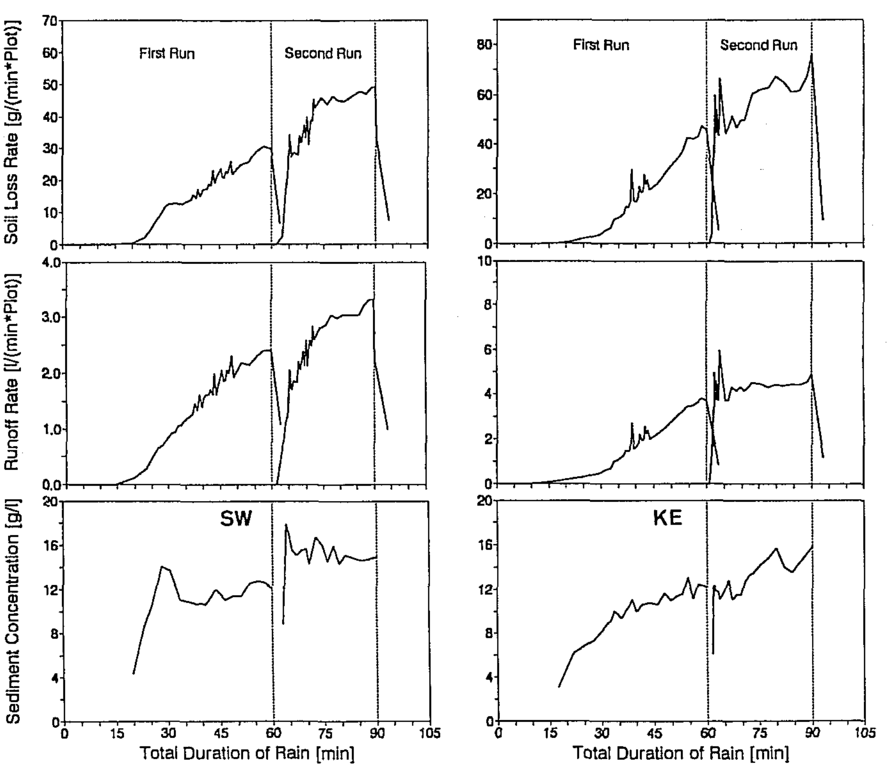

Figure 2: Soil loss rates, runoff rates, and sediment concentrations of 1 · 4.6 m^2 plots with the simulators SW and KE

Abbildung 2: Abtragsraten, Abflußraten und Sedimentkonzentrationen für 1 · 4,6 m^2 Parzellen der Regner SW und KE

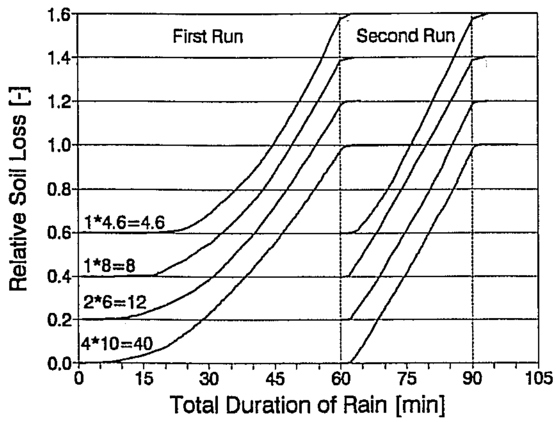

Figure 3: Relative cumulative soil loss of four plot sizes with the simulator SW (shifted by n · 0,2 to improve readability)

Abbildung 3: Relative Abtragssummenkurven von vier Parzellen mit dem Regner SW (jeweils um n · 0.2 verschoben, um die Lesbarkeit zu erhöhen)

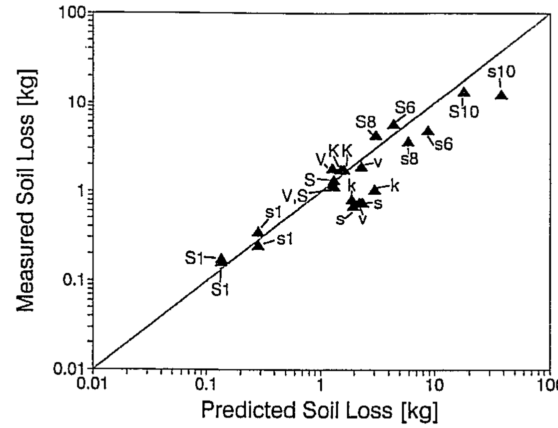

Figure 4: USLE predicted soil loss and measured soil loss for 22 rainfall simulations (small letter = first run, capital letter = second run; rainfall simulator: s/S = SW, k/K = KE, v/V = KR; number = plot length in m; without number = 4.5 m in length)

Abbildung 4: Gemessener Bodenabtrag von 22 Beregnungen in Abhängigkeit vom mit der ABAG berechneten Abtrag (Kleinbuchstabe = Erstberegnung, Großbuchstabe = Zweitberegnung; Regensimulator: s/S = SW-Regner, k/K = KE-Regner, v/V = KR-Regner; Zahl = Parzellenlänge in m; ohne Zahl = 4.5 m Parzellenlänge)

4.6 m^2 plot has 2.4 m/m^2. The probability that runoff, especially at the beginning and at the end of the runoff, is restricted by the border and cannot reach the lower plot end, increases with increasing border length.

Extrapolation of the standardized soil loss curves of Fig. 3 suggests that with regular-sized fields, erosion would have started immediately. On the other hand, erosion had not started after 15 min on the smallest plot, although a soil loss must be expected for a rain of 65 mm/h after this time. The long and high intensity rains used in erosion research, in spite of their low return period in nature, are necessary because of the "unnaturally" small plot sizes.

The large intercept of small plots causes major problems in the interpretation of the data. In the USLE, *Wischmeier & Smith* (1978) defined the Soil Loss Ratio, SLR, as the soil loss per unit erosivity if all other factors are unity. The soil loss on a certain soil should increase to the same degree as the R factor does and thus produce a constant SLR. For a non-zero intercept, the SLR will increase with increasing erosivity. If only the (unnatural) plot size causes the intercept, the correct SLR for farm field should be found if the erosivity during the intercept phase is disregarded. As pointed out by *Wischmeier & Mannering* (1969), the intercept is typical for simulated rains but negligible in natural rains. They had also disregarded the intercept in their K factor determination. The determination of the begin of runoff is not always clear. We propose to start with the determination of the SLR after 5 % of the total runoff has been collected, or to determine the intercept with regression analysis as *Wischmeier & Mannering* (1969) did.

Influence of plot length

The USLE allows to correct different plot lengths with the L factor. To verify this, the soil loss was predicted with the USLE. The R factor was computed from the begin of runoff. The kinetic energy of the simulated rain of the simulators KR and SW was corrected by division with 0,8 after *Wischmeier & Mannering* (1969). *Hassel & Richter* (1992) have shown that the simulator KE, in spite of the use of the same nozzles, produces smaller raindrops than KR and SW. They computed a 20 % smaller kinetic energy per unit rain for this simulator. This was also taken into consideration. The K factor was taken from *Auerswald* et al. (1992). The SLR (0.46) was taken for a small grain seedbed from *Schwertmann* et al. (1987).

The LS factor was computed after *Wischmeier & Smith* (1978) using the continuous function for the slope length exponent of *Murphree & Mutchler* (1981). The USLE is only valid down to a slope length of 4.9 m (*Forster* et al., 1985). For the smaller interrill plots (0.75 m), the S factor was therefore computed with the equation of the RUSLE for this slope length (*McCool* et al., 1989) with the slope length exponent for low rilling intensity. It predicts a 2.8 times higher S factor for this slope length than the S factor according to *Wischmeier & Smith* (1978). The ranges of the variable factors R, L and S are given in Table 1.

The measured soil loss is very close to that predicted (Fig. 4), considering an average error of measurement of 30 % (*Auerswald & Eicher*, 1992). The slope of the logarithmic regression line is 0.8 (r^2 = 0.8483) and just significantly lower than 1. The computation of the R factor from the start of runoff does not account for the slow increase in runoff rate during the first minutes of runoff. For the second runs, this period of increasing runoff rate is shorter than in the first runs. The second runs are closer to the 1:1 line. Also, the use of a constant slope length exponent (m = 0.5) as proposed by *Wischmeier & Smith* (1978) should increase the regression coefficient.

Recommendations

Erosion plots should be as large as possible. With decreasing plot size, longer durations of rain are necessary and the time until runoff starts should be disregarded in the calculation of the USLE Soil Loss Ratios.

Selecting proper plot size is particularly difficult when the fate of soluble substances has to be examined. Large plot sizes (> 40 m^2) are preferable where readily soluble salts like nitrates are a major concern. These salts would be leached during the long intercept phase on small plots and their concentration in natural runoff would be underestimated. On the other hand, smaller plot sizes are preferable where the behaviour of adsorbed substances such as potassium or phosphate are examined. Their desorption is influenced by the chemistry of the rain water (*Holzner*, 1989). Water of a composition resembling natural rain can be used with reasonable effort only on small plots (< 10 m^2) where the water consumption is less than 1000 l/h.

For a given plot size special attention has to be placed on the plot width. The influence of the plot length can be estimated with the L factor of the USLE, but no corrections can be made for a wrongly selected width. This should therefore enclose a representative part of the field. Half the tilling width would usually be the smallest representative width. For the common tilling width of 3 m, an erosion plot should be at least 1.5 m wide although twice this width would be preferable.

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