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Monitoring of rill formation

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Abstract Formation of rills can cause transport of sediment and associated nutrients and pesticides over longer distances. This project aims at a better understanding of rill formation and evolution under Danish conditions. A system for monitoring erosion and sediment delivery continuously from a plot with winter wheat tilled up and down is designed. Total weight and volume is recorded and used for triggering of transport proportional sampling with a newly developed sampler. A video-recording system is also operated. Manual measurements are used for control and for computation of rill volume. Preliminary results from the first field season are discussed.

INTRODUCTION AND AIMS

Soil erosion has until recently been considered a minor problem in the northern part of Europe. Chischi & Morgan (1986), however, have demonstrated that in certain areas quite severe erosion can take place. Severe erosion is very often found to be caused by rill erosion (Govers, 1987; Alstrøm & Bergman, 1988). In Denmark erosion has been studied within the framework of the NPO (Nitrogen, Phosphorus and Organic matter) programme. Results from this investigation (Hasholt, 1991) confirm the findings of the authors mentioned above. It was shown that the development of rills could be responsible for long-term transport of both sediment and nutrients, and that rills often are found on fields with winter wheat tilled up and down the slope. A new Danish environmental programme, the strategic environmental programme, STM, aims at a further understanding of the processes leading to eutrophication. The effect of tillage was studied earlier (Sibbesen *et al.*, 1994; Hasholt & Hansen, 1993) using plot studies; these investigations are continuing within the new programme. Because of the development of soil erosion models, the project in this phase is more process orientated and a better time resolution is used in order to validate models and to create a better understanding of cause and effect. In the nine plots with different crops and tillage typical for Danish conditions, the developed rills are registered after larger events, approximately once a month. One plot is equipped in order to study rill development and related sediment transport in detail. Lay out and instrumentation of erosion plots were studied within the STEP programme and by visiting research stations in different parts of the world; however, none of the plots was able to fulfil the requirements of this investigation. Besides the manual monitoring of rills, it is the aim of this project to construct a system for continuous/semicontinuous registration of the flow of water and sediment from a plot in order to investigate the conditions under which rills are initiated and further developed. The collected data should also be used for testing of erosion models such as EUROSEM and erosion models included in the SHE model (Hasholt & Styczen, 1993). The system has to fit into the existing research set up and the measuring routines; therefore, certain specifications stated below must be fulfilled.

Requirements for the plot installation

(a) The system should allow manual registration and collection of sediment after each runoff event, as in the other plots. Therefore, a collecting tank should be placed in the measuring cellar.
(b) The inlet should be sedimentation free so that all aggregates and grain size fractions released from the plot are carried to the measuring system without delay caused by sedimentation.
(c) The groundwater level around the measuring cellar should follow the natural level as at the other plots.
(d) The volume of water and sediment in the collecting tank should be measured continuously.
(e) The weight of water and sediment in the collecting tank should be measured continuously.
(f) Flow-proportional samples of water and sediment should be collected.
(g) The runoff and erosion on the plot during an event should be recorded on a video-recorder.

DESCRIPTION OF THE CONSTRUCTION OF THE RECORDING SYSTEM

The recording system is shown on Figs 1 and 2. The description follows the order stated in the listing of the requirements.

The area of a single plot is 57.5 m^2 (22.1 × 2.6 m). Water and sediment are collected in plastic tanks with a volume of 1.4 m^3; their depths are 0.9 m. They are emptied before spill over during an event or after a major event. The system collecting tank is constructed of 4-mm stainless-steel plates welded together as a cube with inner dimensions of 1000 mm; the bottom area is therefore 1 m^2 and a 1-mm increase in stage corresponds to 1 l. The cube is reinforced with flanges so that the volume is stable during filling and the tank can be lifted by a crane. If the water level rises above 1 m, the surplus water is carried to an overflow tank via a Thompson weir. The tank is emptied for water by use of an electric pump and the settled sediment is collected manually and dried and weighed as for the other collecting tanks.

The inlet is constructed of stainless steel and the sides slope towards a tube leading to the cellar; the dimensions are shown on Fig. 1. The structure is covered by a plate of corrugated steel in order to prevent rain on the inlet reaching the cellar. All water and sediment leaving the lower edge of the plot enters the cellar after a few seconds.

The cellar is 2.5 m deep, 3 m long and 2 m wide; it is buried 2.4-2.1 m below the surface to obtain sufficient slope from the inlet to the collecting tank so that sediment will not accumulate before reaching the tank. The natural groundwater will normally rise

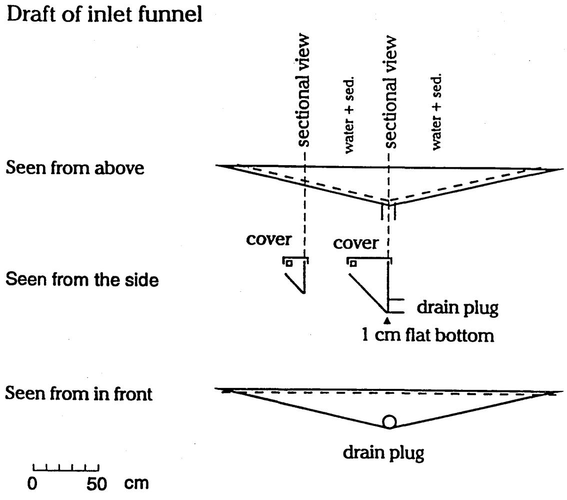

Fig. 1 Sketch of inlet trough.

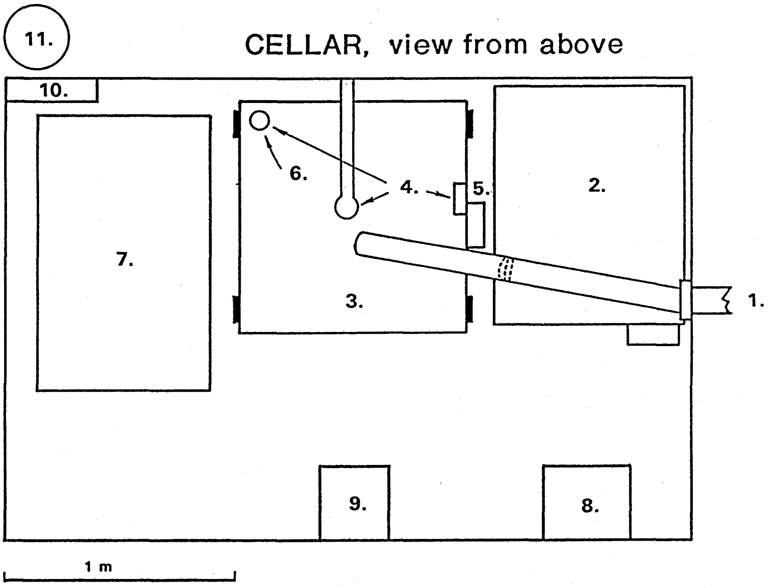

Fig. 2 Layout of instrumentation in cellar: 1: connection tube; 2: sampling system; 3: Collecting tank with Thompson weir; 4: water level sensors; 5: balance; 6: sensors for water and air temperature; 7: overflow tank; 8: steering system (dataloggers) with housing; 9: manuals and spare parts; 10: pump for flood protection; 11: rainfall recorder.

to approximately 1 m below the surface during the winter. This rise can cause significant buoyancy on the cellar. The cellar is kept in place by flanges on the bottom held down by the weight of the overlying soil. The cellar is build of steel and the construction is watertight so that groundwater can rise without the need of pumping to keep the cellar dry. The intent is to measure volume and weight of water and sediment in the collecting tank continuously.

Assuming a density of the sediment of 2.65 t m^{-3}, the volume of water and sediment accumulated during a time step is computed by solving the two equations with two unknowns. The total volume is measured by recording the stage in the tank. Two to three independent systems are used including a Campbell pressure transducer with a resolution of 1.3 mm, a TDR sensor (Thomsen & Thomsen, 1994) with a resolution of 1.4 mm, and an ultrasonic sensor manufactured by Endress and Hauser with a resolution of 1 mm. Theoretically the accuracy could be improved to 0.1 mm by averaging frequent samplings of the stage.

The total weight is measured by an electric balance consisting of three load cells manufactured by Bizerba, the maximum capacity of which is 2 t with a resolution of 0.1 kg. The resolution, however, put restraints on the minimum length of the time step, depending on the amount of sediment in the water, because the computation involves a difference measure.

Sampling of water and sediment, therefore, is also applied, and measurements of the actual sediment concentration can be used as a control of the computed concentrations and to calibrate the computations. Furthermore, this alternative system may provide a better time resolution if the computation procedure is not satisfactory. The best way to obtain samples is to be at the site and to collect them manually at the outlet from the plot. This procedure is well suited in studies using artificial rainfall; if, however, as in the present case, natural conditions are to be studied at a remote location, automation is needed. A survey showed that no commercially available sampler meets the demands for this investigation and it was decided to construct a new one. The sampler should be designed to collect a large number of "in stream" samples within a short time without causing sedimentation and cross contamination. External triggering and choice of sampling time should be possible.

The resulting sampler (Fig. 3) allows water and sediment to enter the cellar through a tube from the inlet structure. The tube is connected to a flume sloping toward the collecting tank. The lower part of the flume can swing to an upright position, so that the water/sediment mixture is led into a funnel instead of the collecting tank. When the sampling ends, the flume swings back and flow to the collecting tank continues. Water and sediment run from the funnel into a 250-ml PVC bottle placed below; after a drip of time of 8 s, a new bottle moves into position within 30 s, thereby allowing a sample to be collected each 30-60 s. The bottles are attached to a chain that moves on a table. The capacity is 149 bottles.

To monitor the system and to collect flow-proportional samples, the steering is programmed with a Campbell 21X datalogger. A scan interval of 30 s is chosen because of the execution time of the programme. Every 10 min on average the maximum and minimum of water level and weight are recorded. For each scan the water level and/or weight is compared with that of the previous scan, and the difference is computed. If the accumulated difference is larger than a pre-chosen increment (e.g. 7.5 l or 7.5 kg), the datalogger computes an opening time for the sampler so that the bottles are filled without overflow. The actual time, sampling time, weight, and water level are recorded. Simultaneously, a video-recorder and a car headlight are triggered. A modified Canon E60 video-recorder is used; a "grey box" overrides the autofocus mechanism and copies date and time into the images. As a security procedure the water level measured by the

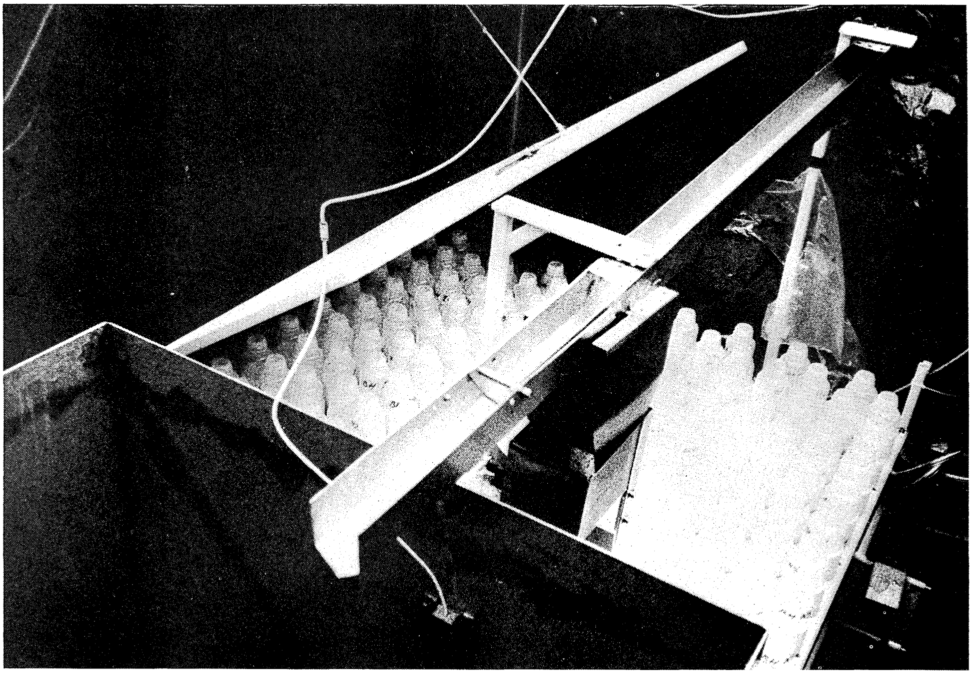

Fig. 3 Sediment sampler: tipping flume, funnel, and bottles.

pressure transducer is recorded independently on a Grant 12-bit datalogger. As an experiment, water levels were recorded using TDR by the Danish Institute of Plant and Soil Science in connection with the measurements of soil water. Rainfall and temperature are also recorded on the Grant logger at 5-min intervals.

The installation is visited every two weeks in the winter half year and monthly during the summer. During these inspections the dimensions and spacings of the rills are measured. The Danish Institute of Plant and Soil Science empties the collecting tanks at all plots and collects the accumulated sediment after all large events.

EXPERIENCES AND PRELIMINARY RESULTS

The project was ready to start September 1993. Normally tillage and sowing of winter wheat take place early after the harvest in July to August, and the "erosion season" starts. Due to the late start, operation of parts of the installation began as soon as they were constructed. The first field season, therefore, was partly a pilot study. The cellar and the collecting tank were installed in early October, together with the pressure transducer. The first balance and the ultrasonic sensor were installed in late October. The prototype sampler was installed in late November.

Not surprisingly, many system failures had to be corrected. The first problem was that the cellar seemed not to be watertight. The reason was that heavy rainfall caused preferential flow where the tube from the plot entered the cellar; after tightening, this problem disappeared. The plastic roof of the cellar caused condensation, a problem that was solved by the use of plastic folio as a double layer. Together, these moisture problems caused erratic readings of the balance and the ultrasonic sensor. After thermostatic heating of the logger box, the readings stabilized. The cellar endured a groundwater level about 1.5 m above its floor, but the welding of the floor did not prevent minor swelling and the balance had to be placed on iron bars attached to the walls of the cellar. The first balance proved not to be able to keep the resolution of 0.1 kg as promised by the manufacturer, and a new one was installed in late December. The system functioned well in January and February. In early March several cases of stochastic sampling occurred that were caused by periodic breakdowns of the ultrasonic sensor. The sensor was repaired. Accurate water level measurements with a resolution of better than 1 mm, however, seem impossible with this technique, partly because the water causes oscillations of the surface. The triggering is now steered by the balance, which appears to be a more stable set up.

The total volume of water and sediment recorded from the plot from 1 October to 20 April was 2089 l, or 36.4 mm. The surface runoff was approximately 10% of the precipitation. In all, 20 surface runoff events were recognized; the number of events by month were: October, 1; November, 0; December, 10; January, 5; February, 1; March, 2; and April, 1. The largest event occurred on 3-5 March and accounted for 1190 l, whereas the second largest event occurred on 18 January, accounting for 150 l. Both events were combinations of rain and snowmelt. The total sediment load was 16 495 kg, corresponding to a mean concentration of 7850 ppm. Mean concentration was 29 449 ppm during the period 4 January through 10 February, but was only 3097 for the period 10 February through 7 March. Concentrations based on sampling during runoff of 18 January are shown in Fig. 4. The measured concentrations were almost all lower than the mean concentrations indicated above. The first occurrence of rills was recorded on 14 December, when two small rills with a total volume of 0.0012 m^3 formed. The rills grew during snowmelt periods in January and March. At the end of the field season the total rill volume was 0.0045 m^3, or approximately 6.7 kg; the resulting sediment had

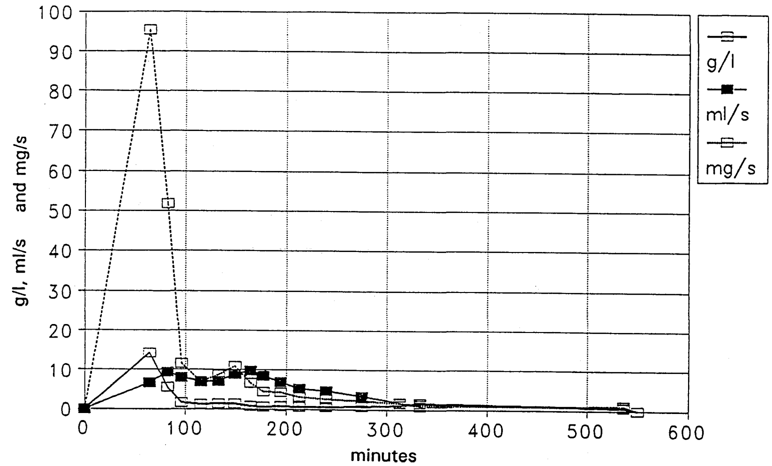

Fig. 4 Surface runoff, sediment concentration and sediment transport during snowmelt of 18 January 1994.

a dry soil density of 1.5 t m^{-3}. Rill erosion accounted for 41% of the total sediment eroded from the plot.

DISCUSSION AND CONCLUSION

The monitoring system is a prototype that is not yet tested to its limits. Many problems have emerged and have been solved. The measurements of accumulated water level will not facilitate computation of flow for smaller time steps because the accuracy (±2 mm) is not sufficient. Accumulated weight seems to be more accurate (±0.2 kg) and these recordings, therefore, are suited for steering of the sampling and as test values for erosion models. The low values of sediment concentration in the water samples from the period that could be compared with the bulk sample from the tank are remarkable. A possible explanation is that a separation of water and sediment occurs because the tipping flume is too long. This possibility will be tested in the near future. Altogether, the system gives a good time resolution that is useful for the study of rill processes.

The number of rills formed was fewer than in earlier investigations (Hasholt & Hansen, 1993). Also, the eroded volume was smaller. This observation is curious because surveys on selected fields showed that the number of rills and their volumes this year were larger than in previous years. Rills were formed on newly tilled seedbeds during rainstorms in September and early October. As the plot studies started late, these events were not included. This indicates that early tilling increases the risk of rill formation due to more frequent rainstorms. On the other hand, the rills on the plot did not develop much during the two snowmelt periods, as was the case on surveyed fields. The reason for this was that a snow drift covered the lower end of the plot. Runoff from the upper part of the plot was filtered through the snow, and meltwater from the drift flowed only a short distance to the outlet. This process was clearly revealed on the video-recorder. It is concluded, therefore, that results from the plot during this study underestimated the amount of rill erosion.

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