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Soil erosion monitoring at small scales: Using close range photogrammetry and laser scanning to evaluate initial sediment delivery

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Introduction

Soil erosion represents one of the most significant environmental problems of the 21st century with severe impacts on terrestrial ecosystems.

Traditionally, soil losses by water are determined by runoff plots in situ. Micro-scale devices (<1 m length) are commonly used to monitor soil erosion rates in comparative field studies. This is especially the case in ecological-pedological experiments, investigating e.g. the effect of plant characteristics on erosion processes.

The small plot size allows to focus precisely on interrill processes with the smallest possible set of confounding factors and a high replication.

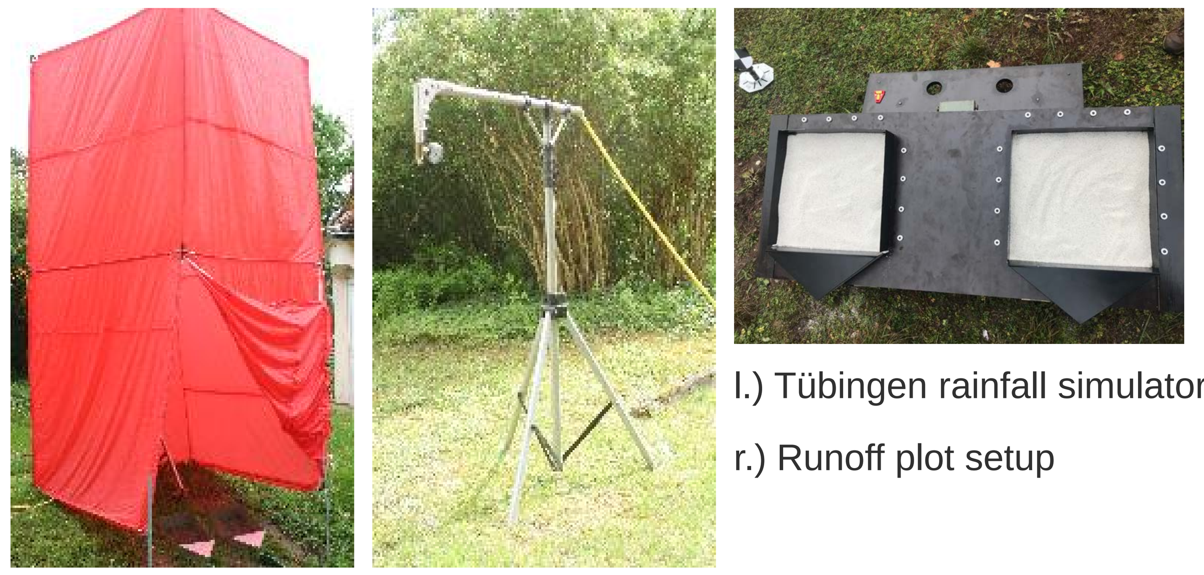
However, the runoff plot method is labor- and time-intensive, sediment handling can be challenging and the measurement accuracy varies importantly with set-up maintenance and control. To optimize the acquisition of erosion data from splash and interrill processes, digital methods become more and more of interest.

Thus, the objective of this study was to transfer those approaches to smaller scale and

I. **to compare different methods to create repeatable 3D point clouds of soil surfaces with sub-millimeter resolution**

II. **to evaluate their accuracy and the reliability of measurements.**

Material & Methods



l.) Tübingen rainfall simulator

r.) Runoff plot setup

Rainfall Simulation: Tübingen Rainfall simulator intensity 60 mm h^{-1} , drop fall height 3.8 m

15 replications for every treatment and substrate

Runoff Plots: micro-scale (0.4 m x 0.4 m) with hortic anthrosol or sand (0.1-0.45 mm) substrate

Reference frame with 24 ground control points and 4 laser scan targets

Discharged sediment weighed for ground-truth

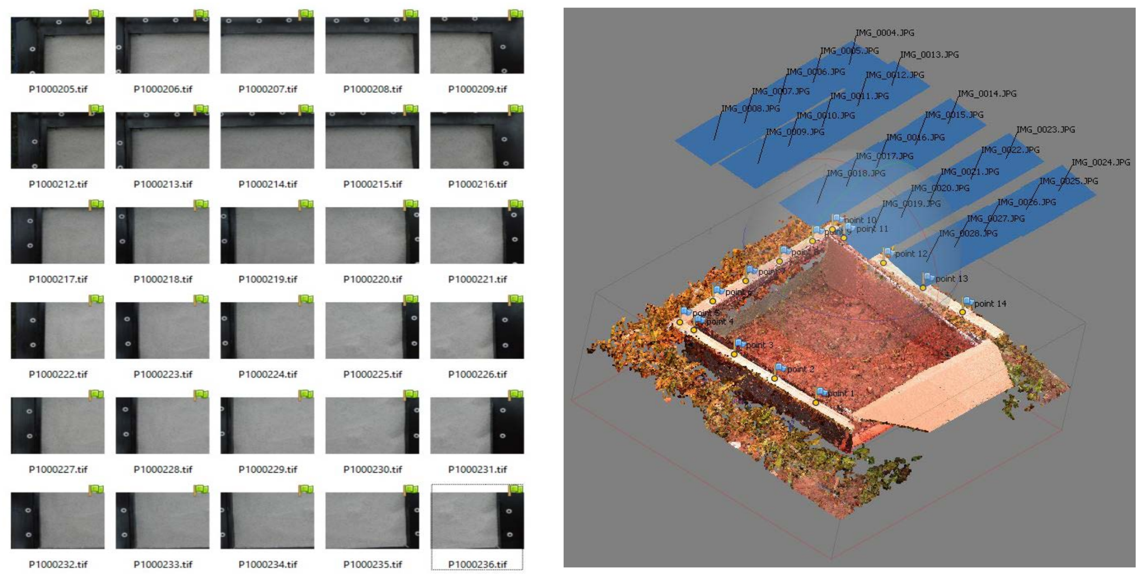
Treatments: a) terrestrial (TC) and b) airborne camera (AC) and c) terrestrial laser scanner (TLS)

l.) Camera rack, m.) UAV with camera and r.) terrestrial laser scanner

Image Creation:

Digital camera: Panasonic Lumix DC, 24 MP mounted on rack or UAV, respectively

Terrestrial laser scanner: Leica ScanStation P40



l.) Block of stereo-images and r.) dense point cloud of the reference DEM for a hortic anthrosol

Image Processing:

Referencing, image matching, processing of digital elevation models (DEM) and photogrammetry (Structure from Motion) with AgiSoft PhotoScan 1.5.1 (a, b) and calculation of 3D point clouds with Leica Cyclone (c)

DEM refinement, calculation of volumes, Cut&Fill, evaluation with ESRI ArcGIS 10.5 and CloudCompare 2.8.1

Results

Erosion Rates and Surface Changes:

Mean discharge weighed (mean surface change):

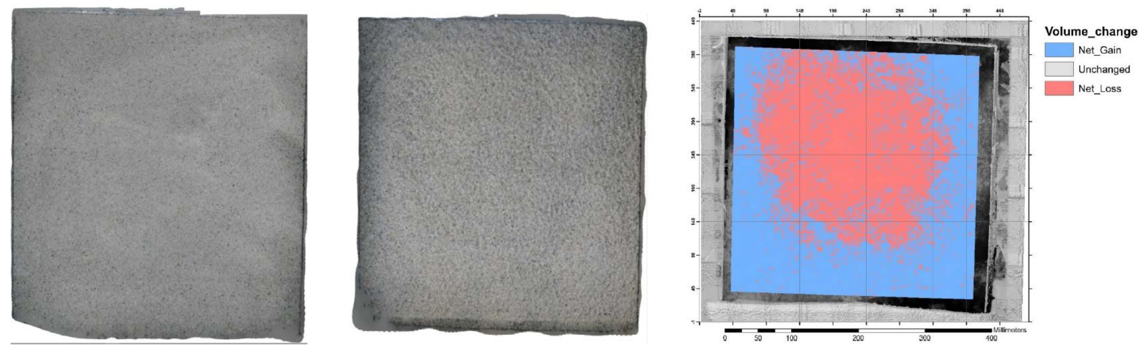
	137.8 g (sand)	48.6 g (anthrosol)
	(0.542 mm)	(0.167 mm)

Mean discharge calculated:

a) TC	118.5 g (sand)	/	36.2 g (anthrosol)
c) TLS	161.6 g (sand)	/	70.5 g (anthrosol)

Treatment b (AC) strongly overestimated erosion rates and results could not be used

- TC underestimated, whereas TLS over-estimated sediment discharge
- Calculated erosion rates differed from weighed sediment discharge (TC and TLS) up to 45 %
- Accuracy was higher for uniform sand than for the hortic anthrosol treatment
- Increasing accuracy of volume calculations with increasing sediment losses



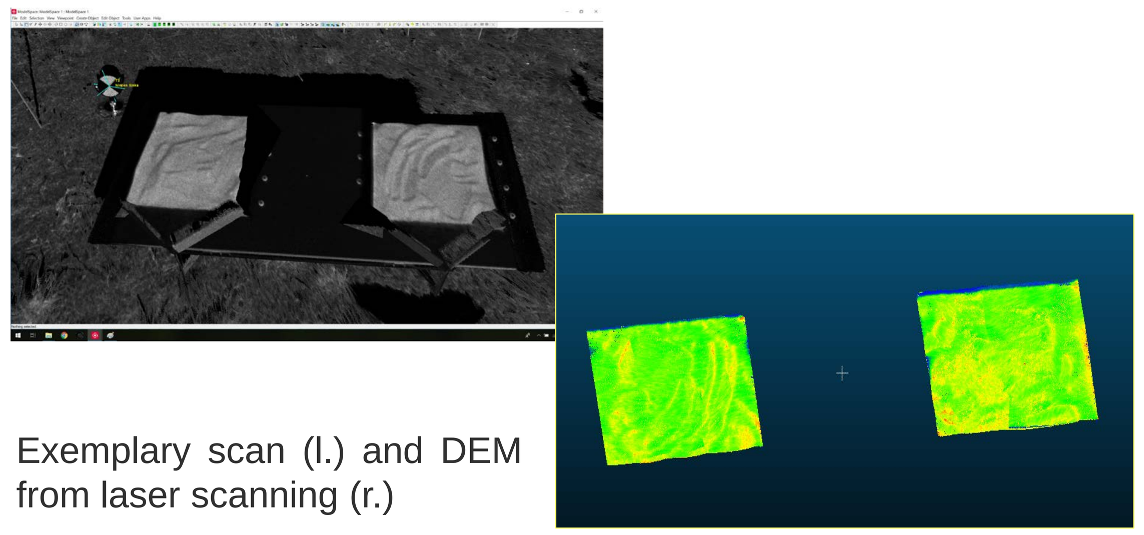
Calculated DEM before (l.) and after (m.) rainfall simulation; result of an exemplary Cut&Fill operation with ArcGIS (r.)

Workflow and Suitability of the Methods:

- Standardized workflows for every method could be derived
- The processing with common software systems proved to be prone to error
- TC approach with digital cameras derived higher image resolution (1.4 mm) and more accurate erosion rate estimation than the laser scanner (1.6 mm) used in this study
- The airborne camera was not suitable for this small-scale setup, as the flight altitude had to be set to 10 m, to avoid air turbulences on the soil surface (image resolution 5 mm)

Sources of Error:

- Resolution of images to capture sub-millimeter surface changes
- Precision of measurements in the field (e.g. accurate positioning of the camera)
- Precision of software processing (e.g. linking of ground control points)
- Conditions of (artificial) illumination
- Compaction of investigated substrates by raindrop impacts



Exemplary scan (l.) and DEM from laser scanning (r.)

Conclusion & Outlook

The presented methods appear to be promising tools for process studies on small-scale soil erosion. Suitable small-scale 3D point clouds to map topography differences from initial soil erosion could be derived. Nevertheless, the precise quantification of sediment loss still needs further refinement. In particular, an exact application of techniques in the field, higher resolution of images as well as improved and more reliable software processing is needed.

In particular, further experiments with light-weight and high resolution laser scanners are regarded as promising.

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