From rills to gullies: how do we measure them?

Sheng Li
Agriculture and Agri-Food Canada
Fredericton, New Brunswick, Canada
Sheng.Li@agr.gc.ca

Fangzhou Zheng, Zisheng Xing, Fanrui Meng
University of New Brunswick
Fredericton, New Brunswick, Canada

Rene Wackrow
Loughborough University
Loughborough, Leicestershire, United Kingdom

David Lobb
University of Manitoba
Winnipeg, Manitoba, Canada

Abstract—***Water erosion can take the forms of inter-rill (sheet), rill and gully erosion. Although gully erosion has been recognized as a major form of water erosion in many agricultural lands, studies on water erosion have focused on inter-rill and rill erosion. There is a gap in knowledge about how gullies are formed and how this process can impact surface runoff, sediment yield and nutrient losses from the landscape. In this study, we propose to conduct a plot study to examine the initiation of channels and the development of channels from rills to gullies.***

The study was carried out on six plots in the research farm of the Potato Research Centre in Fredericton, Canada. Three management treatments were applied to the plots: cropped and up-down-slope tillage, cropped and contour tillage, and fallow and up-down-slope tillage (serving as the control). The formation and development of channels are monitored using three methods: 1) manual measurement, 2) a total station scanner, and 3) photogrammetry. Preliminary results showed that the resolution and accuracy of data obtained using the total station scanner varied substantially, depending on the view angle and the distance of the measurements whereas the photogrammetry method was capable of detecting fine elevation changes across the plots.

Introduction

In many regions, accelerated soil erosion is a major cause of soil degradation on agricultural landscapes (Lobb et al., 2010). Major forms of soil erosion on cultivated lands are water, wind and tillage erosion, categorized based on the force involved in the erosion processes (e.g., Li et al., 2008). Among these three major forms of soil erosion process, water erosion is most intensively studied. Many of the early studies on water erosion are within the framework of the Universal Soil Loss Equation (USLE), which focuses almost entirely on sheet and rill erosion at the plot-scale, while not accounting for erosion that occurs in large channels, especially in classical gullies (Renard et al., 1997). Channels occupy only a small portion of the land area and were often considered only as pathways for water and sediments transportation. Since then, many BMPs developed to reduce sediment and nutrient loadings in receiving waterbodies (e.g., rivers, lakes and wetlands) were aimed at controlling water erosion in agricultural fields (Chow, 2010). However, studies have shown that as water flows along channels, it may interact with channels and these interactions may have profound impacts on hydrology, soil erosion and the transportation of sediments and nutrients. For example, previous studies have found that gully erosion is an important form of water erosion and can contribute up to 94% of the total sediment yield due to water erosion (Poesen et al., 2003).

Our literature review suggests that there is a lack of knowledge on how the channels are formed and evolved, especially those lower-order channels at the plot- and field-scale, in agricultural landscapes. Therefore, we propose a plot study to investigate the initiation and development of channels and the effects of channels on hydrology, soil erosion and nutrient losses in agricultural land.

Materials and Methods

Study site and plot layout

A field located in the farm of the Potato Research Centre (PRC) in Fredericton, New Brunswick, Canada was used in this experiment. The field is situated on an east-north facing slope with a slope gradient of about 10% and a slope length of about 100 m (Fig. 1). A 110 m wide and 80 m long area in this field was used to establish 6 plots. Each plot was approximately 78 m long and 6 m wide (the width of a typical potato seeder) with 5 m wide space between plots for machine operations. Three management treatments were applied to the plots: cropped and up-down-slope tillage, cropped and contour tillage, and fallow and up-down-slope tillage (serving as the control). The three treatments, each with two repeats, were randomly assigned to the 6 plots. Lidar topographic data (point density of about 2 m^2 per point with accuracy at the level of ~0.3 m) were obtained for the study site and were used to determine the plot orientation. The up-down-slope tillage plots were oriented along the direction of the steepest slope. The contour tillage plots were oriented at the direction of ~3 degree included angles to the contour lines. This created a slope for the plots to shed water away, which is a common setup for contour tilled fields in this region. A set of reference points was established around the plot area. These reference points were permanently marked with 1 m long iron sticks buried into the ground and their absolute coordinates were surveyed using a Trimble GeoXH GPS system with a real-time accuracy at the level of 0.1 m.

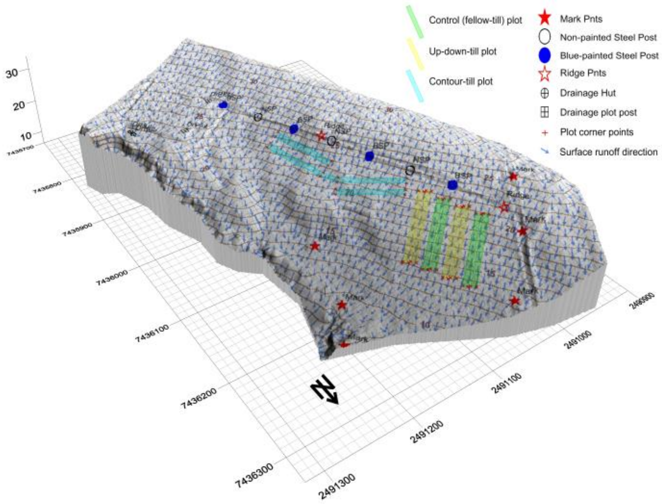

Figure 1. Maps of the study site and the plot layout.

Monitoring of channel initiation and development

Channel initiation and development are determined morphometrically in this study, using three methods. The first method (M0) is to measure the density and geometry of channels manually. To facilitate the measurement, a platform of ~6 m wide is built. The platform is put on wheels and going across the plot at about 1 m height from the ground. The measurement is done by standing on the platform so that the plot is not disturbed. The measurement is conducted along eight transects across each plot. The transects are 10 m apart, located using permanent markers as references. The channels along the transects will be counted and numbered systematically. The location, depth and width of each channel will be recorded. This manual measurement will be carried out after every major rainfall or snowmelt event. Although crude, M0 is applicable year round. The other two methods described below use remote sensing technologies and will not work during periods of snow coverage and crop canopy. The first remote sensing method (M1) is to use a total station scanner (Fig. 2). Total station is easy to operate and can scan the entire plot area within a few hours. However, the accuracy (< 1 cm) is not ideal for capturing small changes after every erosion event. So the entire study area will be scanned for only four times per year: after snowmelt but before cultivation (T1), after seeding (T2), before 10% crop canopy coverage (T3) and after fall tillage (T4). Comparison between T2 and T3 will be used to characterize the effect of rainfall erosion and the comparison between T4 and T1 in the following year will be used to characterize snowmelt erosion.

Another remote sensing method is photogrammetry (M2). A pair of cameras is installed on top of two poles welded to the platform (Fig. 3). Pairs of overlapping images of the plot surface are taken while the platform is moving along the plot. Overlapped pictures are imported into a photogrammetry software (Photomodeler Scanner 2012) to generate a three dimensional image of the soil surface. Data collection using photogrammetry is fast, efficient and cost effective and can be seen as an advantage of this method. Collected data will be compared with data acquired in methods M1.The timing for taking the photos will match those for the total station scanning.

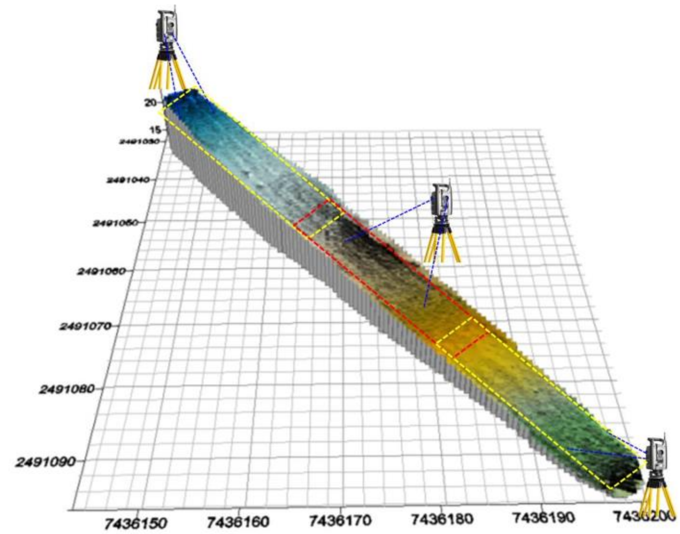

Figure 2. Illustration of the total station scanning method (M1). The total station is set up at multiple locations for scanning. The coordinate systems for the scanning are based on the same reference points so that the data can be merged and used to generate the 3D map for the entire plot. Raw data points obtained from the scanning are shown as black dots on the map.

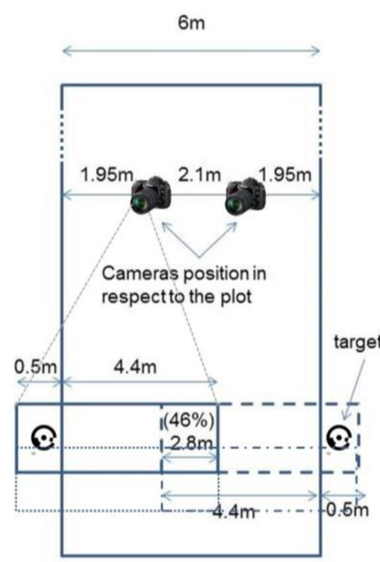

Figure 3. Illustration of the photogrammetry method (M2). The pair of cameras are mounted on top of poles (welded on a platform) at positions ~5 m above the ground. There are overlaps between the pair of pictures in the same row. Along the plot, pictures are taken every two meter to ensure sufficient overlaps between adjacent rows of pictures. The overlapped pictures are used to generate the 3D surface of the ground using a photogrammetry software. Targets are installed along both sides of the plot and are used as reference points to bring together pictures taken at different time periods.

Monitoring runoff water

A 6 m wide flume will be installed at the bottom of each plot to collect surface runoff. Flow rate and discharge will be monitored and recorded in a datalogger. An auto-sampler will be connected to the datalogger and water sampling will be triggered by the initial rise of water level (> 1 cm) in the flume. Hourly samples will be taken after the first sample until the water level is lower than 1 cm. Additional samples will be taken whenever the water level change from the last sampling is > 5 cm. All water samples collected will be analyzed in the hydrological lab in PRC for total sediment (TS), particulate nitrogen (PN), nitrate and nitrite (NOx), ammonium (NH3), total dissolved nitrogen (TDN), total nitrogen (TN), particulate phosphorus (PP), total dissolved phosphorus (TDP) and total phosphorus (TP). A weather station located about 700 m south-east of the plot will provide hourly or more detailed data on precipitation, air temperature, evaporation, wind direction and speed, solar radiation and soil temperature.

PRELIMINARY RESULTS

The plots were prepared in the spring of 2012. The GPS reference points were surveyed and marked. A first set of total station scanning were conducted in the fall of 2012 after harvesting. A grid DEM was generated for each plot based on the total station scan data (Fig. 2). Tillage furrows can be identified on these DEMs so that it was expected that large channels/gullies should be identifiable using this method. However, it was found that the resolution and accuracy of the data obtained using the total station scanner varied substantially, depending on the view angle and the distance of the measurements. Point cloud was extremely dense near the total station and was becoming increasingly sparse at further distances. Beyond ~20 m, the points were too sparse to reflect the shape of ridges and furrows. Also, when the total station was set up at the side of the plot, there were blind areas behind the ridges. This created errors for the elevation data, especially for those high ridges or deep furrows.

The photogrammetry photos were taken at about the same time as the total station scanning. Firstly, the camera geometry was determined following a calibration procedure. The photo image block of each plot was imported into the PhotoModeller software, which uses these camera parameters in a bundle adjustment for image restitution. When the exterior orientation parameters of all images are determined, PhotoModeller can measure a vast number of 3D points on the surface which can then be used to generate a digital elevation model (Fig. 4). With the number of data points provided by the photogrammetry method, subtle changes in elevation can be detected. Therefore, the shapes of ridges and furrows in the plots can be precisely determined.

FUTURE PLANS

In this coming spring, another set of total station scanning will be conducted, as well as another set of photos will be taken. The generated DEMs will be compared against the ones obtained in last fall to determine the shape and volume of channels. Also, a flow monitoring station will be established at the bottom of each plot to monitor the runoff and sediment and nutrient yields during critical periods of water erosion. Weather data will also be collected at a nearby weather station. The effects of topographic, climatic and hydrologic factors and the interactions between these factors will be investigated.

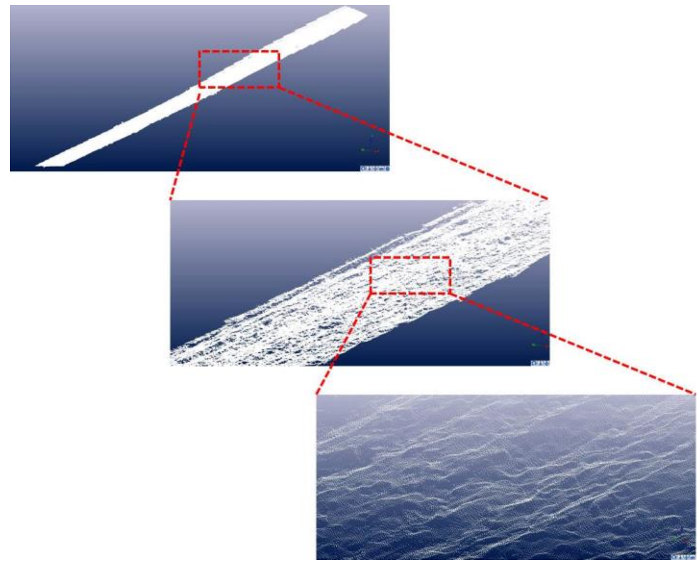

Figure 4. Illustration of the DEM generated using the PhotoModeler scanner software.

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