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Effect of riparian vegetation on stream bank stability in small agricultural catchments

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ABSTRACT

The hydrological processes associated with vegetation and their effect on slope stability are complex and so difficult to quantify, especially because of their transient effects (e.g. changes throughout the vegetation life cycle). Additionally, there is very limited amount of field based research focusing on investigation of coupled hydrological and mechanical influence of vegetation on stream bank behavior, accounting for both seasonal time scale and different vegetation types, and none dedicated to marine clay soils (typically soil type for Norway).

In order to fill this gap we established hydrological and mechanical monitoring of selected test plots within a stream bank, covered with different types of vegetation, typical for Norwegian agricultural areas (grass, shrubs and trees). The soil moisture, groundwater level and stream water level were continuously monitored. Additionally, soil porosity and shear strength were measured regularly. Observed hydrological trends and differences between three plots (grass, tree and shrub) were analysed and formed the input base for stream bank stability modeling. We did not find particular differences between the grass and shrub plot but we did observe a significantly lower soil moisture content, lower soil porosity and higher shear strength within the tree plot. All three plots were stable during the monitoring period, however modeling scenarios made it possible to analyse potential differences in stream bank stability under different vegetation cover depending on root reinforcement and slope angle.

1. Introduction

Soil moisture content, pore water pressure and frictional properties of the soil are the most important factors influencing slope stability (e.g.: Simon et al., 1999; Bogaard and van Asch, 2002; Krzeminska, 2012). Slope stability is determined by the balance of shear stress and shear strength. Gravity, mobilised friction, buoyancy and seepage are the forces that work on soil body. The potential soil movement is resistant by the shear strength of the soil that can be mobilised along the slip surface. Negative pore water pressures reflect the surface tension of pore water in the voids, creating a suction effect on surrounding particles and contribute to the stability of the stream bank. Increase of the soil moisture content within the bank reduces the tension of pore water in the voids and decreases frictional soil strength. Additionally, presence of pore water increases the unit weight of the bank material making the bank more susceptible to failure.

Vegetation effects on slope stability may be broadly classified as either mechanical or hydrological (e.g.: Greenway, 1987; Gray and Sotir, 1996; Abernethy and Rutherfurd, 2000; Genet et al., 2008). The mechanical effect of vegetation on slope stability relates mainly to root reinforcement (positive influence; Thorne, 1990; Abernethy and Rutherfurd, 2000; Genet et al., 2008; Vergani et al., 2012).Roots anchor themselves into the soil to support above-ground biomass, producing a reinforced soil matrix that is less prone to shear failure (Waldron, 1977; Wu and Watson, 1998). The magnitude of root reinforcement mostly depends on root distribution, root mechanical properties (Greenway, 1987; Bischetti et al., 2005; Ji et al., 2012; Naghdi et al., 2013) and root moisture content (Pollen, 2007). Few studies (e.g. Pollen, 2007) talk about the weight of the vegetation mass having negative influence on slope stability. The hydrological effect of vegetation on slope stability relates to altering soil moisture. Presence of vegetation may reduce soil moisture content because of interception and transpiration, and water absorption by roots. On the other hand, riparian zones intent to favor infiltration over surface runoff: these may result in higher moisture contents during and after rainfall events and gives the potential for destabilization (Greenway, 1987; Collison and Anderson, 1996; Andreassian, 2004).

The quantification of coupled hydrological and mechanical effects

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of vegetation on stream bank stability remains difficult due to the complexity of the interactions occurring between riparian vegetation and processes of bank stability (e.g.: Sidle, 1991; Abernethy and Rutherfurd, 2000; Sidle et al., 2006; Pollen, 2007). The beneficial and disadvantageous effects of vegetation presence act against each other (Simon and Collison, 2002) and can vary greatly in time: (1) pore water pressures are transient in response to changes in precipitation and streamflow and (2) root reinforcing depends on the vegetation growth cycle (Pollen-Bankhead and Simon, 2009). There is limited amount of field scale research focusing on coupled hydrological and mechanical influence of vegetation on stream bank stability, and even less dedicated to stream bank stability in small agricultural catchments, accounting for: (1) different vegetation types and (2) temporal changes in hydrological responses observed in both the bank and the stream.

In the framework of the forecasted increase in both the amount and intensity of precipitation events in Norway, all the natural phenomena triggered by water, including soil erosion, floods and landslide, are expected to boost their impact on the anthropic environment (e.g.: Øygarden et al., 2011; Hanssen-Bauer et al., 2015). The area along streams are among the landscape elements that first will be affected by climate change: stream bank failures often occur following floods (Tohari et al., 2007) or during prolonged rainfalls (Midgley et al., 2012). Vegetated buffer zones are one of the most common measures in Norway to improve water quality in agricultural catchments (e.g.: Blankenberg et al., 2016). While these measures aim to slow down the runoff and retain the sediment and nutrient particles from adjacent agricultural fields, they might have significant influence on stream bank stability, depending on the vegetation type.

The main cause of the streambank failures observed in small agricultural catchments in Eastern Norway is undercutting of bank toe and resulting steepening of the slope (Fig. 1; Skarbøvik et al., 2014; Skarbøvik, 2016) while the triggers are either hydrological factors (snow melt, intensive/prolonged rainfall) or human activity (using heavy machinery close to the edge of streambanks). Majority of the erosion events are observed in spring and autumn when the flooding risk is high (Skarbøvik and Bechmann, 2010): during the drawdown phase, the confining pressure of the water in the streams disappears and (partly-) saturated stream banks tent to fail (e.g. Jia et al., 2009). Relatively planar failure surface are commonly observed in the area (Fig. 1).

This paper aims to investigate both hydrological and mechanical effect of vegetation on stream bank stability in an agricultural catchment in Norway. We combine seasonal hydrological monitoring (soil moisture content and pore water pressure under three vegetation treatments, and water level in the stream) with stream bank stability modeling. Monitoring of groundwater level and soil moisture fluctuations accounts for infiltration of precipitation and/or runoff from agricultural field, and influence of changes in water level in the stream. A custom made version of the stream bank stability model (BSTEM) allows for incorporation of monitored hydrological responses.

2. Case study area and monitoring sites

Monitored test plots are located along the Hobøl River, the main tributary of the Morsa catchment system, located in South-Eastern Norway. The catchment area of the Hobøl River is 333 km^2. About 16% of the catchment is agricultural land, about 5% waterbodies, and the remaining 79% forest (Blankenberg et al., 2008). The dominating soil type within the catchment is coarse moraine in the forested areas and marine deposits with silt loam and silty clay loam texture in agriculture areas (Hauken and Kværnø, 2013). Fluvial deposits with silt and silt loam texture are found along the river. The mean annual temperature is 5.6 °C, measured at Rygge meteorological station. The mean annual precipitation is 829 mm (Skarbøvik and Bechmann, 2010). Large differences in water discharge are observed at the Hobøl River (Skarbøvik et al., 2014): from relatively stable discharge (1.0–3.0 m^3/s) in winter and summer periods, to dynamically changing high discharge (7.0–48.0 m^3/s) in spring and autumn.

Hydrological monitoring of two plots representing vegetation typical for Norwegian agriculture areas (Fig. 2): mixed grass (root depth up to 20 cm) and trees (root depth more than 100 cm) were installed. Additionally, on the site with mixed grass, redcurrant berry bushes (*Ribes rubrum* '*Jonkheer van Tets*') have been planted (in July 2016). All plots are located within distance of 50 m to ensure similar soil and environmental conditions. The height of the bank, at all three test plots, is 4 m above riverbed, while the slope varies greatly: 27.5°–32.6° for the grass plot, 39°–54° for the trees plot and 24.7°–39.7° for the shrubs plot. No visible soil stratification was observed within vertical profiles during installation of the equipment.

3. Material and methods

3.1. Monitoring

Hydrological monitoring. Each test plot was installed with two piezometers (Fig. 3): one located close to the river (the bottom of these piezometers reached the average level of the water in the river during the dry summer period, 1.60 m above riverbed) and one located close to the top of the stream bank (the bottom of these piezometers was at c.a.2.30 m above riverbed). The piezometers were made of PVC tubes with 0.90 m filters, covered with standard filter protection, surrounded by filter sand and closed with granular bentonite. Groundwater responses were monitored with the use of automatic recording water pressure devices (Diver; Eijkelkamp, Netherlands) with a 10 min time resolution. Atmospheric pressure was monitored with Baro-DIVER (Eijkelkamp, Netherlands). Each test plot was equipped with soil moisture and soil temperature sensors (FDR, 5TM from Decagon Devices) in combination with EM50 Digital data Logger recording with 30 min time resolution. Based on generic calibration of the FDR the accuracy for the volumetric water measurements is ± 0.03m^3/m^3 while for temperature readings it is ± 1 °C. In order to monitor changes in soil moisture profiles within stream banks, sensors are installed at 5 depths

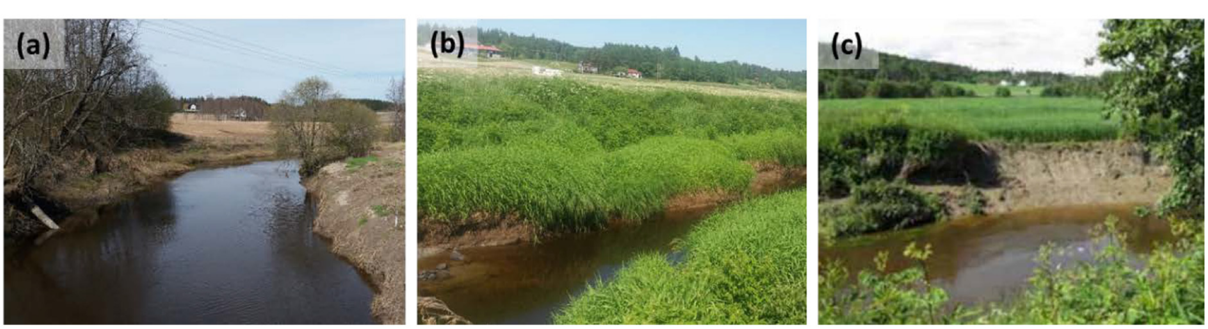

Fig. 1. Examples of observed undercutting processes and associated slope failures in small agricultural catchments in Eastern Norway: (a, b) Hobøl River and (c) Lier River.