INFLUENCE OF SOIL STRUCTURE, PORE-WATER PRESSURE, AND TAILWATER HEIGHT ON HEADCUT MIGRATION IN UPLAND CONCENTRATED FLOWS

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1. Introduction

Soil loss from arable fields caused by surface runoff erosion is composed of several components due to different erosion processes. Bennett *et al.* (2000) reported experimental data showing that actively migrating ephemeral-gully headcuts display steady-state migration and self-similar organization in the absence of hardpans and upstream sediment supply. Alonso *et al.* (2002) combined free and impinging jet theory with mass and energy conservation laws to predict soil losses due to headcut erosion and migration in uniform flows. Headcut erosion and migration rates were shown to depend on upstream flow depth and discharge, tailwater depth, and soil and water properties. The hydrodynamic basis for this model was verified experimentally by Bennett and Alonso (2005a, 2005b).

The preceding studies have improved considerably our understanding of headcut erosion and migration mechanisms. Obviously, there is a critical need for research aimed at characterizing the influence of varying soil structures, tailwater height, pore-water pressure, dirty water inflow, and channel widening on head cut erosion. The primary objective of this study was to determine the impact of soil texture, soil pore-water pressure, and tailwater height on scour hole dimensions, migration rate and sediment yield in headcuts migrating under steady surface runoff conditions.

2. Experimental Methods and Materials

All experimental runs were conducted in a 5.5-m long, 0.165-m wide non-recirculating, tilting flume. The soils used in this study were a fine sandy loam (Ruston series), a silt loam (Atwood series), a silt loam (Dubbs series), and a silty clay loam (Forestdale series).

A subsurface drainage system made out of perforated pipes was installed then covered by a porous fabric and a 0.06m thick layer of 25-35 μm sand. 10 kg soil lifts (0.03 m thick) were sequentially placed in the soil cavity, leveled, and then packed by vibration transmitted through a Plexiglas plate. After packing to a prescribed depth (0.22 m), an aluminum headcut (forming) plate was installed 1.7 m downstream of the rigid floor. Once this headcut plate was in position, soil was packed upstream of the plate in 6 kg lifts, packed, and leveled with the upstream rigid floor, thus producing a preformed vertical step in the bed profile.

Following the rainfall application, two five-gallon Marriott bottles filled with the same water used for overland flow were connected to the subsurface drain. The water was allowed to reach equilibrium at a prescribed height and then maintained 24 hours prior to the release of overland flow. Tailwater height was controlled using an adjustable gate (1mm accuracy) at the downstream end of the soil sample.

3. Results

During each run, clear water was released onto the channel bed at a constant rate (70 L/min). At the brinkpoint of the preformed headcut, water was redirected downward by gravity over the face of the preformed step onto the surface of the soil bed downstream of the preformed step, similar to an impinging jet. As the water impacted the soil surface, the jet split, shearing the soil surface and initiating scour downstream of the preformed step. A hydraulic jump moved upstream from the downstream boundary and became trapped by the impinging jet in the scour hole, initiating upstream migration of the headcut. Two processes control the upstream migration of the headcut: erosion of the basal material (caused by the action of the captured upstream eddy created by the impinging jet) and mass failure by gravity (cantilever failure) of the headcut face following removal of the basal material. These processes occurred continuously, in seamless order, as the headcut began to grow and migrate upstream.

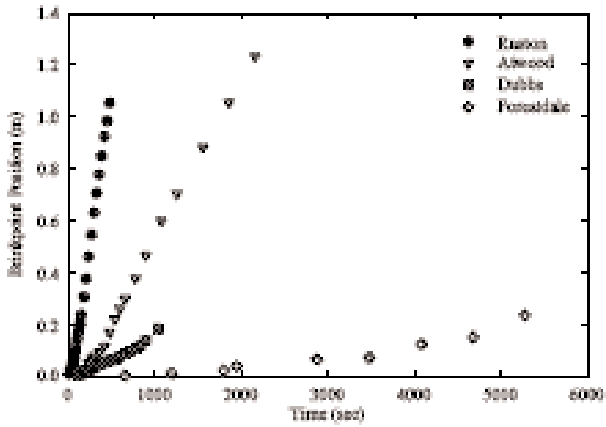

Fig. 1. Comparison of migration rates from four soils.

A significant period of steady state propagation was easily defined with the Ruston and the Atwood soils operating under fully drained conditions. The morphology of the scour hole within each run remained unchanged

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during a substantial portion (>0.5 m) of the available upstream migration length (1.5 m). A second set of morphologically similar responses was obtained from fully drained Dubbs and Forestdale soils. Following initial development of the scour hole, the face of the scour hole became the focal point of erosion. The migration rate in the Ruston soil was greater than those for the Atwood soil, followed by the Dubbs and Forestdale soils (Fig. 1).

The morphological response due to a change in soil pore-water pressure was examined in the Atwood soil. The Atwood soil displayed a tendency for scour hole development similar to that in the full drainage case. However, the maximum scour depth increased with decreasing pore-water pressure (Fig. 2). Both brinkpoint migration and sediment yield attained essentially similar constant rates after roughly 22 minutes into the runs, and in both instances the migration rate was quite similar, although three times slower than observed under full drainage.

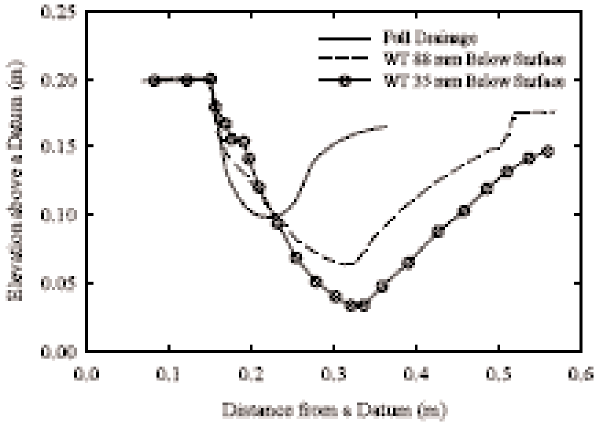

Fig. 2. Scour hole dimensions for full drainage compared to variable water table heights.

The impact of the downstream boundary was examined using the Ruston soil by manipulating the tailwater height at the outlet of the soil flume. After steady-state migration was achieved (asymptotic sediment yield), the gate was raised, samples were taken and the gate was lowered (Fig. 3). Sediment concentrations dropped dramatically each time the gate was raised and the upstream migration rate declined nearly 3 orders of magnitude.

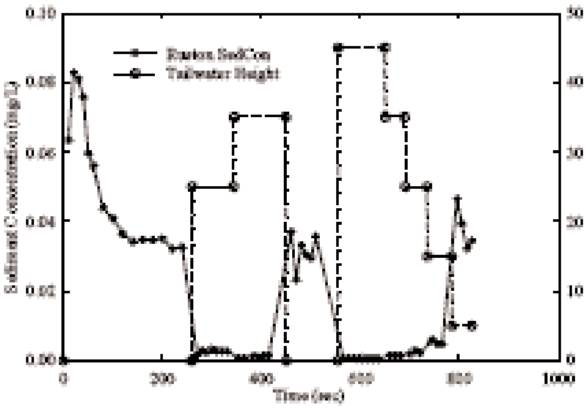

Fig. 3. Impact of tailwater height on sediment concentration.

4. Conclusions

Soil erosion and sedimentation by water are major problems that reduce cropland productivity, degrade water quality, and clog water conveyance structures. The present investigation sought to examine the effect of soil structure, the impact of pore-water pressure and tailwater height on headcut development and migration. These runoff and soil controlling parameters resulted in two distinct modes of headcut growth and migration. The Ruston and Atwood soils attained steady-state morphology, constant upstream migration, and sediment yield. The Dubbs and Forestdale soils developed scour geometries characterized by an eroded brickpoint and tilted back headcut face as the overfall nape turned into an attached wall jet. The resulting scour hole shape is at considerable variance with those exhibited by the Ruston and Atwood soils. Maximum scour depth increased with decreasing pore-water pressures and an increase in tailwater height dramatically lowered the sediment yield and migration rate.

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