CHANNEL EROSION THRESHOLDS FOR DIFFERENT LAND USES ASSESSED BY CONCENTRATED OVERLAND FLOW ON A SILTY LOAM

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Abstract
Flow resistance and sediment transport measurements are needed from different land uses to evaluate surface wash erosion and channel incision by over land flow. In arid and semi arid pastures, channel incision is limited by vegetation cover but there is the lack of enough data to evaluate erosion processes. An experiment was conducted in the Lamerd watershed located in the southwest of Iran to investigate the channel incision threshold in pasture with different vegetation covers. A flume (15 m length, 0.3 m width and 0.4 m height) was used. Flume experiments are conducted on dense, medium and poor pastures with >40, 20-40 and <20% surface vegetation density. The depth of surface runoff was varied by increasing discharge from one run to the next. Results indicate that critical shear stress for channel incision varied from 38 dyne cm^{-2} for dense pasture, 30 dyne cm^{-2} for medium pasture and 29 dyne cm^{-2} for poor pasture. There was no channel head in good pasture (>40% vegetation cover). Eight channel heads appeared in the poor pasture and it was doubled in bare land. Results show that vegetation cover provides substantial resistance to erosion by overland flow. The stems provide the greatest flow resistance and protect the bed from local concentration of flow and channel incision. Thre threshold for channel incision is higher than that for wash erosion and is set by soil cohesion provided by the root mat. The strength of the root mat must be reduced for incision to occur and topographic concentration of flow is needed to exceed the threshold for incision. Surface wash erosion will increase with decreasing vegetation cover and will reduce critical shear stress for channel initiation.

Additional Keywords: incision, critical shear stress, pasture

Introduction
Vegetation appears to modify erosion processes strongly in the natural grassland. Dense root mats and thick stands of grass carpet the ground and reduce or prevent rainsplash and overland flow erosion. Overland flow can reach a depth of several centimeters and a velocity of 1 m s^{-1} or more, but as long as the valley floors are well vegetated, the flows are unable to cause channel incision (Wilson, 1988). In south eastern Australia, for example, valleys with drainage areas of at least 10 km^2 contained no channels in prehistoric times and almost all the sediment eroded from upstream was stored in valley bottoms (Prosser *et al*.,1994). Land use influences the condition of grasslands and thereby forms a link to geomorphic processes. Intense grazing has reduced ground cover and it has been argued that this caused widespread channel incision by overland flow (Prosser and Slade, 1994). The argument is based on the theory that the vegetated surfaces have a high resistance to scour, which can be expressed as a threshold boundary shear stress bellow which sediment transport by overland flow is ineffective (Dietrich and Dunne,1993).

The reduction of vegetation cover lowers the resistance to erosion, so that frequently occurring flows are able to incise channels. It may be widely recognized that vegetation cover limits erosion by overland flow, but there are little data with which to evaluate the erosion processes. Flow resistance data are required to express overland flow discharge in terms of flow velocity and depth and to quantify shear stress on plant stems. We conducted some flume experiments in a grassy catchment of the Lamerd city located in the southwest of Iran. Our experiments were designed to investigate the effect of grass cover on flow resistance, sediment transport and channel initiation. The experiments were conducted on the natural grassed surface with different vegetation cover, to investigate the flow resistance. Measurements of sediment yield were used to identify the threshold for sheet wash under each condition. The data show that vegetation cover provides substantial soil cohesion, which ultimately limits sheet erosion and prevents channel incision.

Materials and Methods
Flume experiment were conducted on the undisturbed plots , by increasing discharges from one run to the next. The experiments were then repeated for dense, medium and poor pastures with >40%, 20-40% and <20% vegetation cover respectively.

The flume was 15 m long , by 0.3 m wide and 0.5 m high (Figure 1). The flume width was greater than the spacing between individual bunches of grass. Water was supplied to the flume through an upslope holding pond and regulating pond. Dissipating ponds were placed at the head of the flume to dissipate the flow and supply the plot with it without scour. The regulating pond was holding water surface and discharge constant for each experiment. Flow discharge was measured by Parshall flumes that were installed at the head and the end of the flume. Flow depths were measured from a datum (leveled flume walls) using a fine–pointed steel rule. Measurements were taken across a grid of 36 points in the central 9m of the flume. Mean flow velocity was calculated from the flow depth and discharge measurements. Flow resistance was characterised by the Darcy-Weisbach friction factor (f), calculated from mean flow velocity (u) and depth (d) as:

$$F=8g\ d\ s/u^2$$

where g is the acceleration due to gravity and s is the sine of the plot gradient. The Reynolds number of the flow (R_e) was calculated from:

$$R_e= u\ d\ /v$$

where v is the cinematic viscosity of the flow assumed to equal 0.01 $cm^2\ s^{-1}$. Sediment yield from each experiment was collected in a 50 ml container at the outlet of the flume. The samples were initially collected every 0.5 minute and finally every one minute during each run test (15 minutes). Sediment yield was related to boundary shear stress (τ_b) defined as t_b=ρgds where ρ is the density of the flow, assumed to be 1 g cm^{-3}.

Results and Discussion

Flow hydraulics

Mean values of flow depth, discharge measured during each run are given in Table 1, together with calculated hydraulic parameters. During the first of each experiment, velocities were visibly much slower within bunches of grass that stood erect through the flow. As the discharge was increased , bunches of grass were deflected blew the water surface and limited the development of velocity profile, creating sub critical flow (Fr<1). Nowell and Church (1979) recorded a similar result denoting that large roughness elements limit the development of the logarithmic velocity profile. This produces a lower layer of slow flow at a similar scale to the size of the roughness elements.

In this study specially for poor and medium pastures where there were spaces between bunches, flow plunged towards the bed over each bunch, before rising up within the dense stems of next bunch. Shooting flow and Renold's number (Re>3000) indicated turbulent flow for all runs. Prosser and Diethrich show by flume experiments in a grassed valleg of coastal California that Reynold 's number was greater than 3000 and the flow was turbulent in all runs (45000>Re>3000). Flow resistance is conventionally characterised by Moody diagram of (f) plotted against (R_e) as:

$$f= a\ R_e^{\ B}$$

where a and B are constant factors and for turbulent flow over planar surface B=-0.25 to 0 and for laminar flow B=-1. Figure 2 shows the flow resistance relations from the experiments. Dense pasture has higher flow resistance than medium and poor pastures the differences reflect relative vegetation cover and micro topography between plots. Differences in flow resistance between treatments are more pronounced at low (R_e) but at high (R_e) poor and medium pastures still reduces resistance by an order of magnitude. In this study values for exponent B are –0.17, 0.28, -0.21 for poor, medium and dense pastures respectively. However, the exponents decrease systematically with vegetation cover and are in the range of turbulent flow over planar surfaces.

Sediment

The considerable resistance of the plots to sediment transport can be expressed as a critical sheer stress (t_c), below which sediment transport is negligible. Definition, of (t_c) is largely arbitrary (eg Lavelle and Mofjeld, 1987) but it is still a useful concept for quantifying resistance to erosion on a cohesive surface. We calculated (t_c) from the cumulative sediment yield during each treatment. Critical shear stress was defined as the x- axis intercept by linear regression through the data (Figure 2).

Critical shear stress values are 38, 30 and 29 dyne/cm^2 for dense, medium and poor pastures, respectively. This indicates the differences in flow resistance in plots with different vegetation covers. Merz and Brayan (1993) recorded 6-44 dyne cm^{-2} for critical shear stress in bare, poorly cohesive soils.

Critical shear stress for channel incision is higher than that for sheet wash and is set by soil cohesion provided by the root mat. In this study the concentration of flow in spaces between bunches exceeds the threshold for incision and the number of channel head in poor, medium and dense pastures are 8, 5 and 0, respectively (Table 2). This indicates that degradation of vegetation cover has and enormous impact on channel initiation and the extent of channel network.

Figure 1. Experimental flume in Lamerd

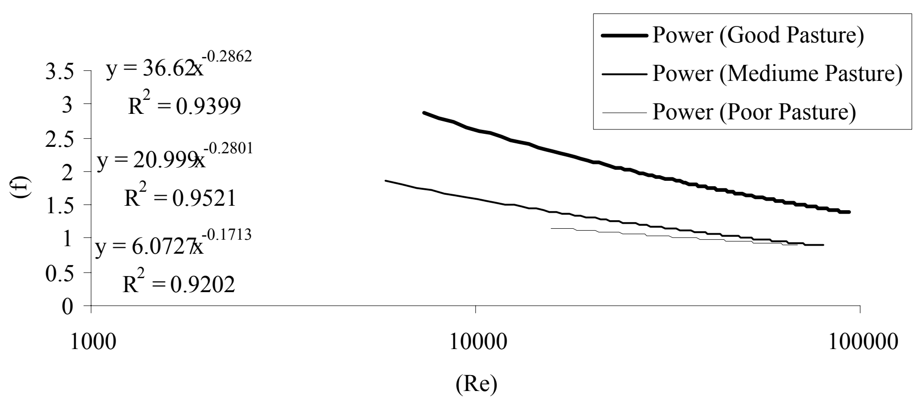

Figure 2. Flow resistance (f) as a function of Reynolds number (Re)

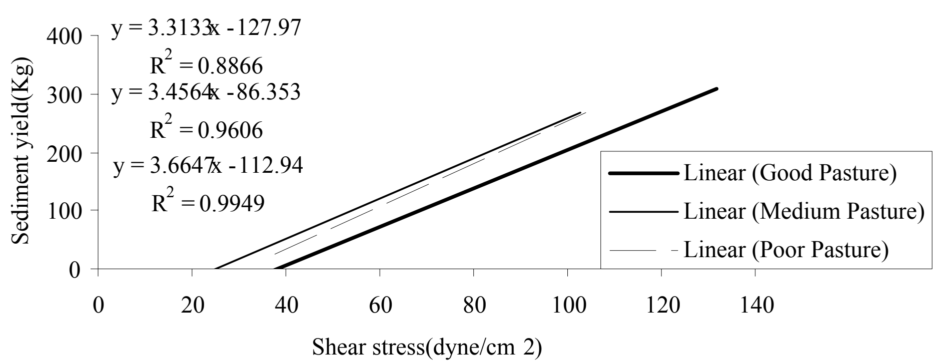

Figure 3. Cumulative sediment yield as a function of shear stress

Table 1. Hydraulic parameters

Pasture Quality	Num. Of Exp.	Discharge ($l\ s^{-1}$)	Depth (cm)	Velocity ($cm\ s^{-1}$)	Reynold Number (Re)	Resistance Coef.(f)	Shear Stress(t)	Sidement (kg)
Poor	1	5.00	9.58	16.31	15625	1.13	37.59	28.79
Poor	2	7.25	12.34	18.36	22656	1.15	48.42	37.09
Poor	3	8.95	13.71	20.40	27968	1.03	53.8	47.58
Poor	4	18.85	21.71	27.13	58899	0.92	85.19	75.77
Poor	5	22.1	23.95	28.83	69047	0.90	93.98	87.25
Medium	1	10.74	5.71	10.16	5801	1.74	22.41	16.09
Medium	2	4.80	10.74	14.91	16013	1.52	42.14	23.40
Medium	3	6.50	12.62	17.17	21668	1.34	49.52	45.17
Medium	4	11.00	16.83	21.79	36672	1.11	66.04	46.57
Medium	5	14.30	19.18	24.85	47662	0.97	75.26	61.02
Medium	6	24.00	26.22	30.51	79997	0.88	102.89	83.42
Good	1	2.20	7.32	10.00	7320	2.3	28.72	11.42
Good	2	6.35	14.26	14.84	21162	2.03	55.95	28.58
Good	3	14.00	21.54	21.66	46655	1.44	84.52	52.41
Good	4	17.45	24.82	23.43	58153	1.42	90.39	72.17
Good	5	25.40	32.38	26.15	84674	1.48	127.06	100.63
Good	6	28.21	33.58	28	94024	1.34	131.77	102.02

Table 2. Number of channel heads

Land Use	Num. of Exp.	Discharge ($l\ s^{-1}$)	Depth (cm)	Velocity ($cm\ s^{-1}$)	Shear stress(t)	Number of channel heads
Poor	1	5.00	9.58	16.31	37.59	0
Poor	2	7.25	12.34	18.36	48.42	1
Poor	3	8.95	13.71	20.40	53.8	3
Poor	4	18.85	21.71	27.13	85.19	6
Poor	5	22.1	23.95	28.83	93.98	8
Medium	1	10.74	5.71	10.16	22.41	0
Medium	2	4.80	10.74	14.91	42.14	1
Medium	3	6.50	12.62	17.17	49.52	2
Medium	4	11.00	16.83	21.79	66.04	3
Medium	5	14.30	19.18	24.85	75.26	5
Medium	1	2.20	7.32	10.00	28.72	0
Good	2	6.35	14.26	14.84	55.95	0
Good	3	14.00	21.54	21.66	84.52	0
Good	4	17.45	24.82	23.43	90.39	0
Good	5	25.40	32.38	26.15	127.06	0
Good	6	28.21	33.58	28	131.77	0

Conclusions

The experiments show that vegetation cover provides substantial resistance to erosion by overland flow. Resistance can be expressed as a threshold shear stress below which sediment transport is insignificant .On the dense pasture most of the shear stress is exerted on individual plant stems deflected beneath the flow and on dense bunches of grass. In this study a mean threshold shear stress of 29-38 dyne cm^{-2} required to transport the sediments that are very low, indicating that the soil is very cohesive. Shear on the plant produces lower flow velocities near the bed and mean flow velocity increase greatly as the plots are submerged (Fr<1).

It was also observed that there was no channel incision in dense pasture and with reduction in vegetation cover it reached to 8 channel heads for poor pasture.

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