IRRIGATION EROSION PROCESSES

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INTRODUCTION

Irrigation is important to global food production. About 15% of cropland (1) and 5% of food production land, [F1] which includes rangeland and permanent cropland (2), are [F2] irrigated. However, irrigated land produces more than 30% of the world's food (3), which is 2.5 times as much per unit area compared with nonirrigated production (1). In the U.S., approximately 15% of the harvested cropland is irrigated; however, almost 40% of the total crop value is produced on irrigated land (4).

Although sprinkler- and drip-irrigated areas are increasing, most of the world's irrigated land uses surface or flood irrigation. The countries with the large irrigated areas are India (59,000,000 ha), China (52,580,000 ha), U.S. (21,400,000 ha), and Pakistan (18,000,000 ha) (2). These countries account for 55% of the world's irrigated land; all other countries have less than 10 million ha each of irrigated land (2). About 50% of the irrigated land in the U.S. is surface irrigated (5), although 95–99% of the irrigated land in India, China, and Pakistan is surface irrigated (6).

Soil erosion from irrigated fields has been discussed previously (7, 8); this article focuses on unique aspects of irrigation-induced soil erosion that are important when managing and simulating soil erosion on irrigated lands.

Soil erosion mechanics can be divided into three components: detachment, transport, and deposition. Water droplets and flowing water detach soil particles; flowing water then transports these detached particles downstream; deposition occurs when flowing water can no longer transport the soil particles because flow rate decreases as water infiltrates or as rill slope or roughness changes. Some particles are deposited within a few meters although others are transported off the field with runoff water. These mechanisms are the same for surface irrigation, sprinkler irrigation and rainfall; however, there are some systematic differences between irrigation and rainfall erosion and especially between surface irrigation and rainfall.

SURFACE IRRIGATION

Soil erosion is often a serious problem on surface-irrigated land (Figs. 1 and 2). Erosion rates as high as 145 Mg/ha in 1 h (9) and 40 Mg/ha in 30 min (10) were reported in some early surface irrigation erosion studies. These extreme losses do not represent a sustained seasonal rate. Annual soil losses of 1–141 Mg/ha from surface-irrigated fields were reported in a 1980 southern Idaho study (11). Within-field erosion rates on the upper quarter of a furrow-irrigated field can be 10–30 times more than the field average erosion rate (12). Some soil eroded from the upper end of a field is deposited on the lower end, whereas some soil leaves the field with runoff. Losing topsoil from the upper end of the field can decrease crop yields by 25% when compared with the lower end of the field (13).

Sediment cannot be transported without runoff. Runoff is planned with many surface irrigation schemes in order to irrigate all areas of the field adequately. Under ideal conditions, properly designed and managed sprinkler irrigation systems will not have any runoff from the irrigated area. However, economic and water supply constraints, along with variable slope and soil conditions, often force compromises in sprinkler irrigation design.

SPRINKLER IRRIGATION

Runoff is rarely a problem with solid-set sprinkler irrigation systems because stationary sprinklers uniformly apply water at low rates (e.g., 2 mm/h). At the other end of the spectrum are systems with continuously moving laterals (center-pivot and lateral-move systems), which apply water to smaller areas (5–20 m wide) at higher rates than solid-set systems (e.g., 80 mm/h). Traveling lateral systems must irrigate large fields to reduce cost per unit area; this necessitates high instantaneous application rates to meet crop water requirements over the entire field. Application rates for center-pivot and lateral-move irrigation systems often exceed the soil infiltration rate; therefore, runoff is

Q1 Fig. 1

Q1 Fig. 2

almost always a potential problem. Sprinkler type, nozzle pressure, and nozzle size influence runoff and soil erosion by affecting application rate, wetted area, and droplet size. Low-pressure sprinklers, which reduce energy costs, have smaller pattern widths and therefore greater application rates. Lower pressure also produces larger drops with greater impact energy on the soil.

Sprinkler systems, particularly center pivots, operate on variable slopes and topography. Slope direction relative to the lateral affects how runoff accumulates. If the lateral is perpendicular to the slope direction, runoff will tend to move away from the lateral where water is being applied, allowing water to infiltrate before traveling very far. However, if the slope is parallel to the lateral, runoff can accumulate downslope and begin flowing in erosive streams. Furthermore, if the lateral is traveling upslope, runoff will flow onto a previously wetted area, whereas with downslope travel, runoff can flow onto dry soil. These factors are further complicated by wheel tracks from moving sprinkler systems that create compacted channels for water flow.

SURFACE IRRIGATION AND RAINFALL EROSION DIFFERENCES

The most obvious difference between soil erosion from rain or sprinkler irrigation and from surface irrigation is the lack of water droplets impacting the soil during surface irrigation. This fundamental difference is important because droplet kinetic energy affects both erosion and infiltration (14). When rain begins, droplets wet the soil surface and detach soil particles; as runoff begins, rills form in wet soil. Water flowing in rills is also exposed to falling raindrops, which affects detachment, transport, and deposition in the rills.

For furrow irrigation, rills are mechanically formed in dry soil before irrigation begins. Water is applied to only a small portion of the soil surface. As water advances down the field, it flows over dry, loose soil on the first irrigation and dry consolidated soil on subsequent irrigations. Irrigation water instantaneously wets the soil, rapidly displacing air adsorbed on internal soil particle surfaces (15). The rapid replacement of air with water breaks apart soil aggregates (7), increasing the erodibility of the soil. Preliminary results from a southern Idaho field study showed that soil erosion from initially dry furrows was greater than erosion from furrows that were prewet by drip irrigation.

The hydraulics of rill flow from rain differ from furrow irrigation. Rill flow rate tends to increase downstream as additional rainwater plus sheet and rill flow combine. During furrow irrigation, flow rate decreases with distance down the furrow as water infiltrates and increases with time as infiltration rate decreases, which changes sediment detachment and transport capacities with distance and time. The duration of furrow irrigation runoff (typically 12 h or more) is generally longer than most rain runoff events. Temporal changes in infiltration, soil and water temperature, rill size and shape, and soil erodibility become more important for longer runoff events. Sediment concentration tends to decrease with time during furrow irrigation. Flow rate, however, increases with time, which should increase sediment detachment and transport. This indicates that soil erodibility decreases during furrow irrigation by phenomena such as armoring, surface sealing, or other unrecognized processes.

Predicting small erosion events is important for irrigation. Seasonal irrigation-induced erosion occurs during numerous controlled and often small events rather than during one or two large erosion events. In southern Idaho, for example, a cornfield may be sprinkler irrigated 15–20 times or furrow irrigated 6–8 times during the growing season. The magnitude of a single irrigation erosion event is usually much smaller and less dramatic than erosion from a single 50–mm thunderstorm occurring on freshly tilled soil without an established crop. However, the cumulative soil loss from irrigation during the growing season may be substantial.

Chemical quality of rainfall varies less from location to location than surface water and groundwater quality. Irrigation water quality can also vary during the season as return flow is added to surface water sources or as groundwater and surface water sources are mixed. Water quality can significantly impact erosion from furrow and sprinkler irrigated fields. Increasing electrical conductivity (EC) tends to decrease erosion, whereas increasing sodium adsorption ratio (SAR) tends to increase erosion (16, 17). Interactions among EC, SAR, clay flocculation, soil chemistry, rainfall application rate, etc. influence the effects of water quality on infiltration and erosion.

REFERENCES

1. Kendall, H.W.; Pimentel, D. Constraints on the expansion of the global food supply. Ambio **1994**, *23* (3), 198–205.
2. Food and Agriculture Organization, *FAOSTAT—Agriculture Data*; on-line database, apps.fao.org (accessed Sept. 2000) Food and Agriculture Organization.
3. Tribe, D. *Feeding and Greening the World, the Role of Agricultural Research*; CAB International: Wallingford, UK, 1994.
4. National Research Council, *A New Era for Irrigation*; National Academy Press: Washington, DC, 1996; 203.
5. United States Department of Agriculture, *1998 Farm and Ranch Irrigation Survey*; www.nass.usda.gov/census/ (accessed Sept. 2000) National Agricultural Statistics Service.
6. Food and Agriculture Organization, *AQUASTAT—Country Profiles*; on-line database, www.fao.org/WAICENT/-FAOINFO/AGRICULT/ AGL/AGLW/aquastat (accessed Sept. 2000) Food and Agriculture Organization.
7. Carter, D.L. Soil Erosion on Irrigated Lands. In *Irrigation of Agricultural Crops*; Agronomy Monograph No. 30, Stewart, B.A., Nielson, D.R., Eds.; American Society of Agronomy: Madison, WI, 1990; 1143–1171.
8. Koluvek, P.K.; Tanji, K.K.; Trout, T.J. Overview of soil erosion from irrigation. J. Irrig. Drain. Eng. **1993**, *119* (6), 929–946.
9. Israelson, O.W.; Clyde, G.D.; Lauritzen, C.W. *Soil Erosion in Small Irrigation Furrows*; Bulletin 320, Utah Agric. Exp. Station: Logan, UT, 1946.
10. Mech, S.J. Effect of slope and length of run on erosion under irrigation. Agric. Eng. **1949**, *30*, 379–383, (see also page 389).
11. Berg, R.D.; Carter, D.L. Furrow erosion and sediment losses on irrigated cropland. J. Soil Water Conserv. **1980**, *35* (6), 267–270.
12. Trout, T.J. Furrow irrigation erosion and sedimentation: on-field distribution. Trans. ASAE **1996**, *39* (5), 1717–1723.
13. Carter, D.L.; Berg, R.D.; Sanders, B.J. The effect of furrow irrigation erosion on crop productivity. Soil Sci. Soc. Am. J. **1985**, *49* (1), 207–211.
14. Thompson, A.L.; James, L.G. Water droplet impact and its effect on infiltration. Trans. ASAE **1985**, *28* (5), 1506–1510, 1520.
15. Kemper, W.D.; Rosenau, R.; Nelson, S. Gas displacement and aggregate stability of soils. Soil Sci. Soc. Am. J. **1985**, *49* (1), 25–28.
16. Lentz, R.D.; Sojka, R.E.; Carter, D.L. Furrow irrigation water-quality effects on soil loss and infiltration. Soil Sci. Soc. Am. J. **1996**, *60* (1), 238–245.
17. Kim, K.-H.; Miller, W.P. Effect of rainfall electrolyte concentration and slope on infiltration and erosion. Soil Technol. **1996**, *9*, 173–185.

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