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Evaluating the Erosion Impact of Irrigation Water at Three Positions on a Rectangular Furrow Shape at the Greenville Farm in Logan, Utah (Usa).

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ABSTRACT: *An experiment was conducted on a rectangular shaped furrow (180 m long) at the Greenville farm in Logan, UT to investigate the impact of irrigation on soil erosion. A furrow profilometer instrument was used to measure the changes in cross sectional area of the furrow. The trapezoidal rule was used to calculate the furrow geometry. An increase in furrow geometry was found to be at the upper part of the furrow and a decrease in geometry from the middle of the furrow towards the end. It was concluded that the upper parts of the furrow experience erosion and the lower parts deposition. The magnitude of deposition at the end of the furrow was however lower that in the middle. This could be due to the change in stress going down the furrow caused by soil deposition resulting from changes in furrow slope.*

KEY WORDS: *Furrow shape, soil erosion, irrigation, flow rate.*

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I. INTRODUCTION

Furrow irrigation is probably the oldest and most widely used method for applying irrigation water to many field crops and vegetables worldwide (Walker and Skogerboe, 1989; Nie et al., 2018). It is an effective means of applying water to many row crops, though also considered effective in removing top soil (Berg and Carter, 1980; Everts and Carter, 1981). Dibal et al. (2014) observed that it is preferred over other surface irrigation methods due to its simplicity and low capital cost. One of the main problemswith these methods of irrigation is soil loss through erosion, which is a by-product of the erosive forces of water over therow, which brings soil loss and therefore decreases in crop yield (Carlos et al., 2011).Soil erosion impacts negatively both on the environment and on crop productivity. Carlos et al. (2011) observed that soil erosion is the main source responsible for the gradual decrease in fertility and thereforethe loss in productive capacity of many soils.

According to Yu et al. (2003) the movement of water along a furrow carry with it small soil particles that tend to form a seal due to the physical disintegration of surface soil aggregates and the physicochemical dispersion of clay moved to the deeper soil layers by the infiltrating water. Dlamini (2001, 2021) noted that this movement of soil along the furrow, combined with soil swelling and consolidation may influence the furrow geometry and thus potentially the soil infiltration rate via changes in flow depth, wetted perimeter, and infiltrating velocity.

Graf (1971) observed that the effort hydraulic radius of the grains is responsible for the erosion and sediment transport. The total soil hydraulic effort being a combination of grain roughness and form, with the form roughness larger than the grain roughness. For detachment in a channel it is necessary to know the stress (Ʈ) distribution along the length of the furrow which for uniform flow, is given by equation (1) (Carlos, et al., 2011).

$$\text{Ʈ} = \gamma_w * \mathrm{R}_{\hbar} * S_o \qquad (1)$$

where
γ_w = the specific weight of water [M L^{-3}],
R_h= the hydraulic radius [L] a characteristic of the furrow shape; and

S_o = the furrow slope [L L^{-1}].

Infiltration is an indicator of the soil's ability to allow water movement into and through the soil profile. The soil temporarily stores water, making the water available for root uptake, plant growth and as habitat for soil organisms. Furrow infiltration increases with wetted perimeter and this effect strongly influence water distribution along furrows (Trout, 1991, 1992). Wetted perimeter and flow velocity vary across a furrow irrigated field and may influence the infiltration. If however, their effects are known, the influence of the flow rate, slope and roughness on infiltration can be predicted (Dlamini, 2001, 2021).

Soil infiltration characteristics are important for the evaluation, design and management of surface irrigation systems (Dedrick et al., 1985; Silahou et al., 2020; Walker, 2003). Irrigation cannot be practiced without the knowledge of the soil infiltration rate. Knowledge of the basic infiltration rate is needed when selecting a method of irrigation (Hargreaves and Merkely, 2004). Infiltration rates are also useful for estimating the amount of effective rainfall in hydrology studies. While there are standard values available for different soil types, land cover also has a documented influence on infiltration rates. This makes infiltration highly variable across spatiotemporal scales and as such, difficult to measure in field, thus selection of an appropriate measurement technique is important to consider (Söderberg, 2015).

Measurement of infiltration rates is difficult (Akhavan and Mahdavi, 2015) because of the soil heterogeneity and soil spatial variability influence on the measurements. With the adoption of empirical infiltration models, the ability to describe the distribution of waterin the subsurface is lost (Furman et al., 2006). Soils infiltration rates can be measured using cylinder ring infiltrometers (Rodríguez-Juárez et al., 2018;Salahou et al., 2020), ponds, inflow-outflow furrows, blocked (ponded) furrows, and through the use of special equipment such as recycling (flowing) furrow infiltrometers (Walker and Willardson, 1983; Walker and Skogerboe, 1987).

A number of mathematical models have been developed to simulate the movement of water along furrows (Walker and Humphreys, 1983; Schmitz and Seus, 1992; Valiantzas, 1997; Strelkoff and Katapodes, 1977; Walker and Busman, 1990). These models simulate the depth of flow, advance, recession, infiltrated volume, runoff, and deep percolation volume but not the impact of flowing water on soil erosion. It should be understood that the hydraulics of surface irrigation has all the complexities of the unsteady open channel flow plus the added major complication of a variable intake (Tabuada et al., 1995; Or and Walker, 1996). Direct solution of this complex problem is not possible, making all surface irrigation models to be based on the principle of continuity and the conservation of mass.

This paper reports on a study done to measure the change in furrow cross sectional area after irrigation as a measure of soil erosion or deposition along a furrow.

II. MATERIALS AND METHODS

Experimental area

The research was carried out at the Utah State University Greenville farm (Logan, UT: Latitude 41°46′ N, longitude 111°48′ W, and elevation of 1405 m absl). The site is located at 1800 North, 800 East. The cross sectional area of a triangular furrow configuration (Dlamini, 2021) measuring 180 m long, 0.50 m wide (top width), and about 0.15 m deep was evaluated at three points to determine the impact of irrigation on erosion. The soils were predominately a Millville silt loam soil.

The Millville series consist of well-drained and moderately well drained very strongly calcareous soils. These soils are formed in alluvium derived from dolomitic limestone. They are on alluvium fans deposited on high and medium lake terrances. The top soil (20 cm) is a dark grayish brown silt loam, very dark grayish brown when moist, weak, medium, granular structure, slightly hard, friable, slightly sticky and slightly plastic (United States Department of Agriculture, 1974).

Experimental procedure

A V-shaped tractor implement was modified to make the rectangular-shaped furrows. Three furrows each 180 m long were formed 1.4 m apart. The measurement furrow was at the center and the other two acted as guard furrows. Stakes were placed at three positions along the furrow; at 00 m, 120 m and 140 m were marked. The furrows were at a slope of 0.000833.

The measurements were carried out on a rectangular furrow shape (Dlamini, 2001, 2021) that was 180 m long. Erosion measuring stations were placed at three points along the furrow; at the inlet (point 0,0), at 120 m and at 140 m downstream. The measurements were taken after each irrigation event using a furrow profilometer instrument (Walker and Skoggerboe, 1987; Dlamini, 2001, 2021). A total of four irrigations were administered to the furrow. There were two guard furrows irrigated simultaneously with the measured furrow, one on either side bordering the furrow of interest. It was essential to ensure that the inflow was not erosive and did not vary with time. It was kept constant at 60 liters per minute (Dlamini, 2001; Walker, 2003).The water was supplied from a sprinkler hydrant and controlled to the desired flow rate using a 25 mm globe valve.After the water had reached the end of the furrow, it was allowed to runoff for a fixed interval (a period of 15 minutes) the same applied to the guard furrows.

A furrow profilometer instrument (Walker and Skoggerboe, 1987; Dlamini, 2001; Dlamini 2021) was used to measure the changes in furrow shape profile before the first irrigation and after each irrigation event to determine any changes in furrow geometry caused by irrigation. This device uses vertical rods to indicate relative soil surface elevations across a section of the furrow. Changes within the furrow were assumed to be due to the effect of irrigation and determined by calculating the cross sectional area changes of the furrow using the trapezoidal rule (Bird, 2010).

III. RESULTS AND DISCUSSION

The furrow perimeter was considered a function represented by equation (2) with the top width of the furrow taken as the limit of the function between two points “a” and “b” being the range of integration for the function.

$$Y = f(x) \qquad (2)$$

The cross sectional area of the function (2) can be calculated by using the Trapezoidal rule represented by equation (3)

$$Area = \int_a^b Y\,dx \qquad (3)$$

If the range of integration is divided into “n” equal intervals each of width d, such that;

$$n\,d = b - a \qquad \text{or} d = \frac{b-a}{n} \qquad (4)$$

Labeling the ordinates y_1, y_2, y_3, …,y_{n+1} and noting that each interval became a trapezium, then the total area can be given by equation (5);

$$Area = \int_a^b Y\,dx = \frac{1}{2}(Y_1 + Y_2)d + \frac{1}{2}(Y_2 + Y_3)d + \frac{1}{2}(Y_3 + Y_4)d + \cdots + \frac{1}{2}(Y_n + Y_{n+1})d \qquad (5)$$

By opening the brackets and collecting like terms, equation (5) reduces to the following equation (6);

$$Area = \int_a^b Y\,dx = d[\frac{1}{2}(Y_1) + (Y_2) + (Y_3) + \cdots + (Y_n) + \frac{1}{2}(Y_{n+1})] \qquad (6)$$

A summary of the changes in cross sectional area at the three measurement positions along the furrow are shown in Table (1). Figure 1 illustrates the furrow profile as measured with the furrow infiltrometer instruments at the inlet positions.

Table 1. The cross sectional area changes observed along a furrow after three irrigation events at USU Greenville Farm, Logan, UT.

Position along the furrow (m)	Cross-sectional area change of the furrow with irrigation (cm^2)			
	Before Irrigation	1st Irrigation	2nd Irrigation	3rd Irrigation
0.0	346.4	418.4	444.4	423.0
120	326.8	281.1	227.7	211.1
140	337.7	277.6	273.5	268.2

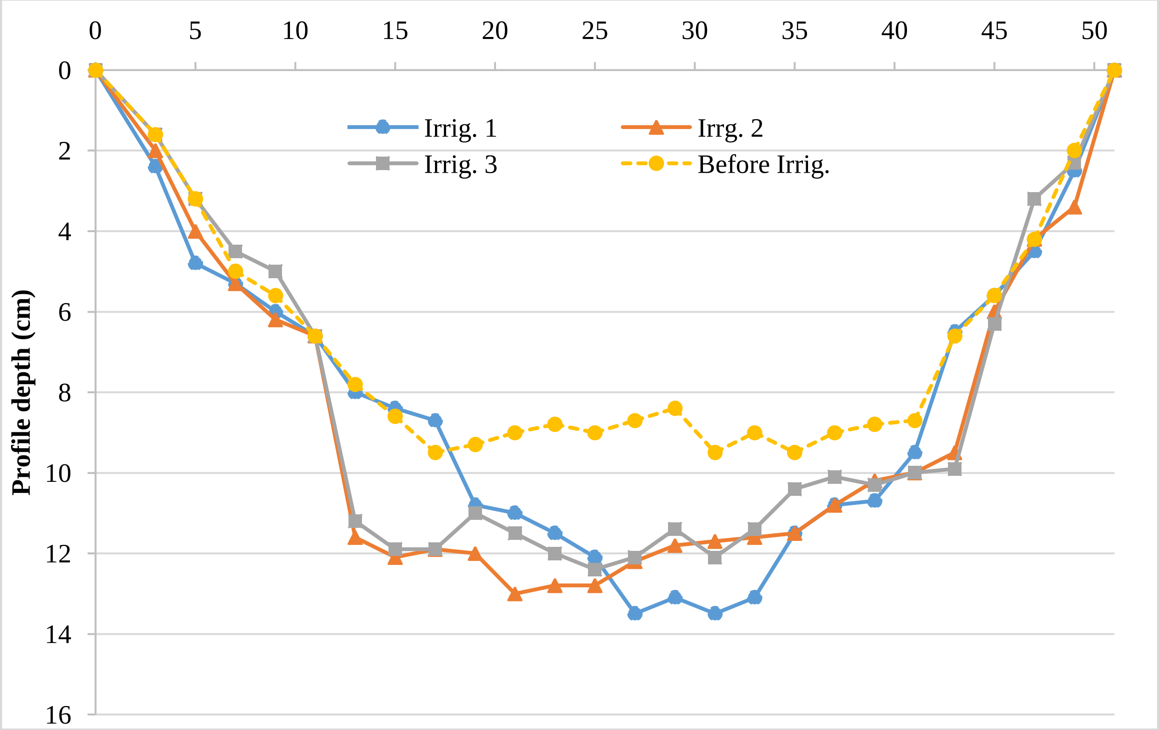

Fig. 1. Changes in furrow cross sectional area with irrigation at the inlet of the furrow, measured at USU Greenville Farm, Logan, UT.

At the inlet of the furrow (position 00) the cross sectional area of the furrow before irrigation was smaller than after each of the three irrigations. This indicates that the irrigation caused soil movement making the cross sectional area to increase. There was erosion at this point. At position 120 m down the furrow, the cross sectional area of the furrow before irrigation was larger than after irrigation. This indicates that soil was deposited making the cross sectional area smaller. At position 140 m a similar trend to that at position 120 m was observed.

Studying the cross sectional area behavior along the furrow, one can notice that before irrigation there were no cross sectional area differences in the three positions. This means that the soil was more stable during furrow forming and the consistency of the furrow forming implement highly commended. After each irrigation, there was a noticeable decrease in cross sectional area going down the furrow indicating soil deposition. The highest deposition was observed at position 120 m. This observation was similar to that of Carter et al. (1985) who noted that furrow irrigation erosion redistributes topsoil by eroding upper ends of fields and depositing sediment on downslope portions causing a several fold topsoil depth difference on individual fields.

The soil deposition at position 140 m down the furrow was slower that at 120 m. This could be due to a lower stress as indicated by equation (1) caused by the change in furrow slope as soil gets deposited. Long irrigation runs are especially susceptible to excessive erosion at the head of the field because of the large stream sizes generally used.A furrow stream's size and velocity decreases as it advances down the furrow due to a decrease in energy. As a furrow stream's energy decreases, so does its ability to carry soil. This clearly shows that most sediment eroded at the head of the field settles out before reaching the end of the furrow. The furrow stream continues to pick up sediment until its energy equals the energy needed to carry the soil particles.

The results also clearly show that early season irrigations generally cause more erosion than later irrigations after crop roots are established, after plant leaves and stems have fallen into furrows and cultivations have ended. Reducing the number of cultivations or maintaining crop residues on the surface can help reduce furrow erosion.

IV. CONCLUSION

Furrow-irrigated fields often have different slopes along a furrow, which tend to cause different water intakes and erosion rates.From the results of this studyit was observed that there was erosion at the upper end of the furrow that resulted in deposition towards the center of the furrow and slight erosion towards the end. It was concluded that the upper parts of the furrow experience erosion and the lower parts deposition. The magnitude of deposition at the end of the furrow was however lower that in the middle. This could be due to the change in stress going down the furrow caused by soil deposition resulting from changes in furrow slope.

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