Earthworms and Furrow Irrigation Infiltration

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ABSTRACT

Infiltration rates into furrows in southcentral Idaho, after decreasing toward a base rate, sometimes increase. The increase is sometimes sufficient to cause tailwater runoff to cease and the furrow stream to recede up the furrow, resulting in poor water distribution. The infiltration increase is caused by earthworms piercing the furrow wetted perimeter during the irrigation allowing water to enter and infiltrate from their extensive burrow system. Low concentrations of aqua ammonia in the irrigation water prevent the infiltration increase, apparently by repelling the worms from the furrows.

INTRODUCTION

Infiltration into furrows normally begins high and decreases over time as the soil becomes wet and the capillary tension decreases. On some soils the decrease continues for the duration of the irrigation while others more rapidly approach a steady-state rate, as shown in Fig. 1. Decreasing infiltration causes the tailwater runoff from furrows to continually increase from the time runoff begins until the inflow is cut off, as depicted in Fig. 2. Steady infiltration results in steady runoff.

With the Portneuf silt loam soils prevalent in southcentral Idaho, infiltration normally reaches a steady rate quickly and produces a fairly constant tailwater runoff. However, sometimes the tailwater runoff, after increasing to a maximum, decreases. In some cases the runoff decreases to zero creating what local farmers refer to as "back up" — the receding of the furrow stream up the furrow. Furrow stream backup reduces the water application uniformity and often results in inadequate application to the tail ends of the furrows. Figure 3 shows the inflow and runoff hydrographs for three successive irrigation sets on a furrow-irrigated bean field near Twin Falls, Idaho. The runoff rate during each set decreases to less than half its maximum value. Even with the maximum runoff rates of over 50% of the inflow, a few of the furrow streams were observed "backing up" by the end of the 24-h sets.

The runoff rate decrease is caused by increasing infiltration rates during an irrigation such as that depicted in Fig. 1. The runoff decreases shown in Fig. 3 are the result of a 75% increase in infiltration rate. Back up results when the infiltration rate increases above the inflow rate.

Decreasing runoff rate and furrow stream recession is a common occurrence in southcentral Idaho. Sixty furrow irrigations over two years on 35 fields distributed through the area were monitored with automated flow measurement equipment. During one-third of the irrigations, the infiltration increased at least 20%, usually resulting in some furrows with no runoff. Many area farmers consider furrow back up to be a major furrow irrigation management problem.

Figure 4 shows infiltration rate curves measured in several recirculating blocked-furrow infiltrometer tests (Walker and Willardson, 1983) on one field. As the figure shows, the infiltration rate increase in the 6-m long flowing sections was dramatic, but highly variable. The response varied even in adjoining sections of the same furrow. On 25 of 30 tests, infiltration rates increased after reaching a minimum. The time the rate

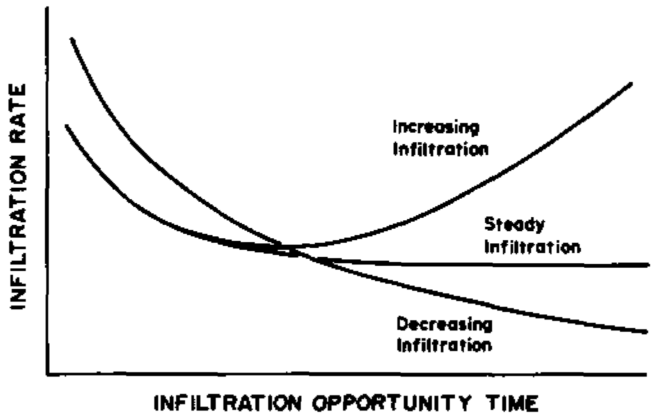

Fig. 1—Typical decreasing, steady, and increasing infiltration rates with time.

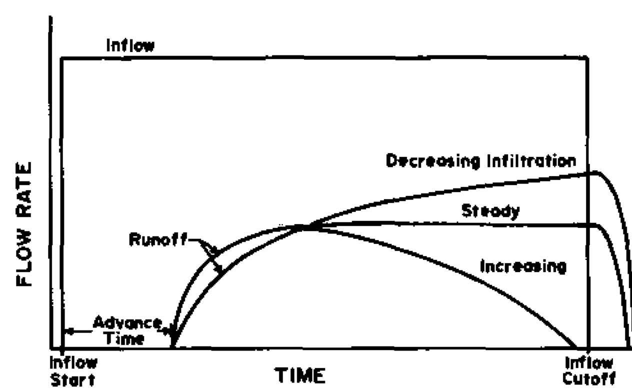

Fig. 2—Typical tailwater runoff hydrographs produced by decreasing, steady, and increasing infiltration rates.

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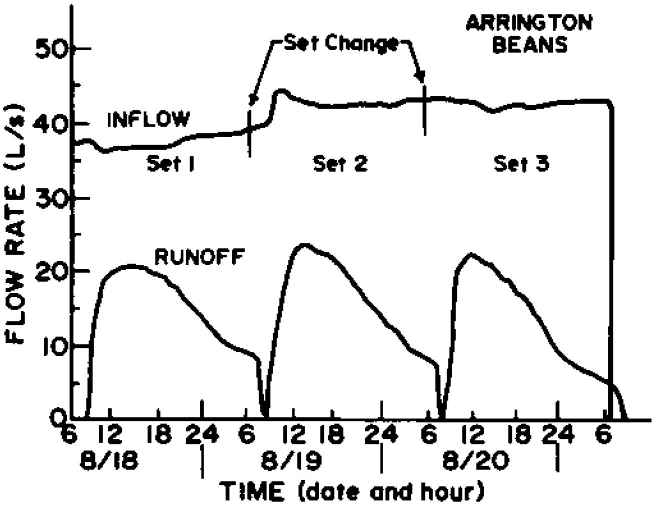

Fig. 3—Inflow and outflow hydrographs during three furrow irrigation sets on a dry bean field in southcentral Idaho.

increase began varied widely but was between 4 h and 16 h on two-thirds of the tests.

The objective of the series of studies reported in this article was to determine the cause of the infiltration rate increase and determine management practices to eliminate it.

CAUSE OF THE INFILTRATION INCREASE

Infiltration theory predicts that furrow infiltration into soil with constant permeability will decrease toward a constant rate. Permeability of the furrow wetted perimeter usually decreases during an irrigation due to structural deterioration (soil consolidation, surface sealing, and soil swelling). An infiltration rate increase would require a permeability increase which requires an increase in the size and/or continuity of water-filled pores. Solubilization or escape of air trapped in the pore space can cause a permeability increase. However, trapped air should not be a significant factor under furrow irrigation since only a portion of the soil surface is wetted. Increasing permeability could also result from flocculation of dispersed clay particles, but this is generally a long term phenomena that does not change significantly during one irrigation event. The clay content of the Portneuf soil is below 20%. Soil swelling could increase the permeability of consolidated layers. However, the Portneuf soil also does not swell significantly when wetted. Furrow permeability would increase if an infiltration-limiting surface is stripped away. Although this does occasionally occur as a result of head-cutting in steeper furrows, it was not observed in conjunction with increasing infiltration.

Permeability will increase if the water viscosity decreases, as occurs when the water temperature increases. Measured infiltration rate increases were not related to the time of day, but occurred both during irrigations begun in the morning and evening. Thus the increases were not related to diurnal temperature changes.

During the field-scale and recirculating infiltrometer measurements, several factors were related to the occurrence of increasing infiltration rates.

1. The increase occurred with all row crops investigated (corn, dry beans, and sugar beets) but not in alfalfa fields. Normal furrow infiltration rates in alfalfa are three to five times greater than those in row crops.
2. The increase occurred erratically throughout the season but was most prevalent late in the season (late July and August).
3. The increase was more prevalent in high organic matter plots and in fields which had been in aflalfa the previous year.
4. The infiltration increase was highly variable — even in short (6-m) adjoining sections. The variability of the infiltration rate in short sections after 12 h of irrigation was two to three times larger than the variability of the base or lowest rate reached. This high variability indicates a factor which strongly affects infiltration and can vary widely over short distances.

Earthworm Activity

A consistent observation in furrows in which the furrow stream is receding due to increasing infiltration is the presence of earthworm holes in the furrow wetted perimeter, as shown in Fig. 5. More than one hole per meter of furrow is common and as many as 20 holes/meter have been observed. Earthworms are sometimes observed floating in the flowing water and lying found in the drained tailwater ditches. During an irrigation with a large infiltration increase, five earthworms per minute were washed out of a furrow with

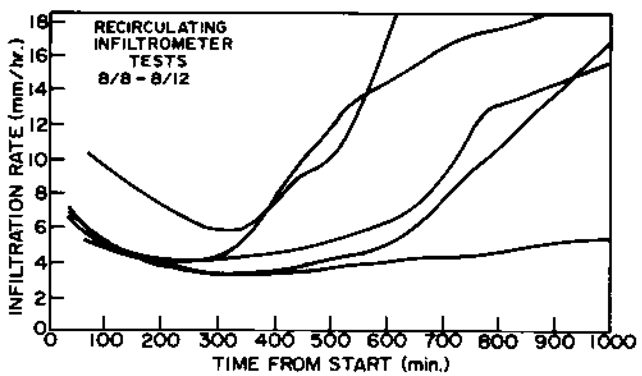

Fig. 4—Infiltration rates into 6-m furrow sections irrigated with a recirculating infiltrometer.

Fig. 5—Photograph of an empty furrow with numerous earthworm holes.

the flow. Up to 50 dead earthworms were found in the recirculating infiltrometer sump following some infiltration tests.

Earthworm populations in the area were measured by excavating 0.18 m^2 x 0.3 m deep volumes of soil and counting the worms. Populations in bean fields generally ranged from 100 to 200 worms/square meter of surface area with the higher populations in fields which had been in alfalfa the previous year. These numbers are higher than those measured in soybean fields in the midwest under tilled conditions (Mackay and Kladivko, 1985). The great majority of the earthworms found in row-cropped fields were small (<60 mm long) subsurface feeding worms (*Aporrectodea tuberculata*). These are distinct from the large, surface feeding "nightcrawlers" (*Lumbricus terrestris*) which commonly inhabit untilled soils with permanent cover.

The dramatic effect of earthworm activity on infiltration under rainfall conditions has been documented by many studies (Zachmann et al., 1987; Germann et al., 1984; Stockdill, 1982; Edwards et al., 1979; Ehlers, 1975). When earthworm holes are open to the surface, they conduct ponded water into their burrow systems from which it infiltrates. Relative increases in infiltration due to earthworm burrows are greatest when the soil surface is covered with a low-permeability seal. Measurements of earthworm burrow water absorption rates (Ehlers, 1975; Bouma et al., 1982) show that they can cause the increase in infiltration rates observed in this study.

Visual observations showed that worm holes in the furrows were conducting water. Near the receding furrow stream front where the flow velocity is very low, water flow into earthworm holes is apparent from fine sediments entering the holes and vortices on the water surface above holes. The small remaining flow at the receding front will sometimes all drain into one earthworm hole. Dye injection into stagnant water in blocked furrow sections showed that much of the water was entering a portion of the visible holes. During a recirculating infiltrometer test in which the infiltration rate had increased from 4 mm/h after 4 hours to 30 mm/h at 16 hours, plugging all visible earthworm holes reduced the rate to 3 mm/h. After 10 additional hours, the rate again began to increase.

A 1.5-m deep pit was excavated at the end of two blocked furrow test sections. During the tests, water began seeping from macropores in three areas on the vertical face of the pit. The seepage areas were all located at least 0.5 m from the furrows — beyond the capillary wetting front. The collectable seepage at the pit face amounted to 10% of the water being infiltrated. Such seepage under positive pressure in the unsaturated soil indicates direct hydraulic contact with the water on the surface, which could occur only with continuous macropores.

STUDIES TO ISOLATE EARTHWORM EFFECTS

Three experiments were carried out to determine whether the increasing infiltration rates are caused by earthworm activity. The experiments were designed to create similar soil environments with and without earthworms. In a greenhouse experiment described in detail by Kemper et al. (1988), 600 mm high x 600 mm wide x 50 mm thick boxes were constructed with one side made of clear acrylic. The boxes were filled with soil and planted to beans. Four earthworms of the type found in local tilled fields were placed in some boxes while others were left as checks. The boxes were irrigated from a half furrow formed at an end of the box with water supplied at a constant head from a Marriotte siphon.

In the boxes with worms, the soils were extensively burrowed by the earthworms. On two occasions, an earthworm moved to the ponded furrow during an irrigation. Water entered the open hole and flooded part of the burrows. Infiltration rates increased 200% until the soil around the holes sloughed and filled the burrow. No infiltration increases were measured in the remaining treated, or in the check soil boxes. Apparently, the box volumes or worm numbers were too small or soil box environment inadequate to result in a worm moving to the furrow and causing an infiltration increase in every treated soil box.

In a field plot experiment, an attempt was made to eliminate earthworms from small plot areas. Chlordane was applied with irrigation water to half of twelve 6-m furrow sections. Although the earthworm kill was not complete and some activity was observed in the Chlordane-treated furrows, infiltration increased during the following irrigation in only two of the six treated furrows compared to four of six untreated furrows. The 12-h cumulative infiltration into the treated furrows averaged 50% that into the checks.

In a field-scale experiment, aqua ammonia (NH_4OH) was added to furrow inflows to attempt to repel earthworms from the furrows and thus eliminate the infiltration rate increase. Zero, 2, 4, or 6 L of aqua ammonia (20% nitrogen solution) were slowly added to the inflows of the 160-m long furrows during the irrigation. These volumes resulted in nitrogen concentrations of approximately 0, 0.02, 0.05, and 0.07 g/L, respectively, in the flowing water. Infiltration was determined from the difference between the constant inflow rate and the runoff rate measured with recording flumes at the tail of each furrow. Each of the treatments was replicated twice and the experiment was repeated during two irrigations in two plot areas.

Figure 6 shows the effect of the ammonia on infiltration during one of the tests. The other tests produced similar results. As the figure shows, the infiltration rate in the check plots nearly doubled and both furrows eventually backed up. Ammonia in concentrations as low as 0.05 g of nitrogen/liter (4 L aqua ammonia/furrow or 40 kg nitrogen/Ha) was effective in essentially eliminating any infiltration rate increase. The small increase at 1200 min occurred on a furrow on which the 4 L of solution had all been added by 600 min. Note that even a .02 g/L concentration significantly delayed and reduced the magnitude of the increase. The ammonia applications greatly reduced or eliminated the visual evidence of earthworm activity at the surface.

Additional field tests with ammonia showed that the infiltration rate may begin to increase several hours after ammonia application has ceased. Also, ammonia applied later in an irrigation after the infiltration has

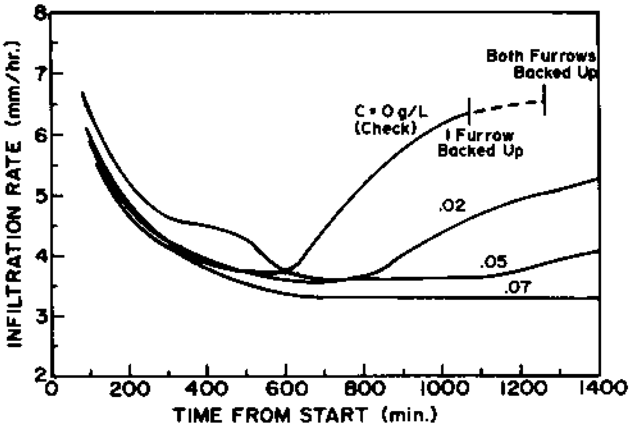

Fig. 6—Furrow infiltration rate with varying concentrations, C, of ammonia nitrogen added to the water. (Each line represents an average of two replications.)

begun to increase will stop the increase. The effects of the ammonia do not appear to carry over to later irrigations. This is expected since the dilute solutions applied from the surface should not kill the worms and after the ammonia ions are absorbed onto soil particles, they should no longer affect worm activity.

ANALYSIS AND DISCUSSION

The evidence indicates that earthworm activity is the cause of the increasing furrow infiltration rates which commonly occur in southcentral Idaho during furrow irrigation. Apparently, the normal subsurface-feeding worms are attracted either to the flowing water in the furrow or to the high moisture content near the furrow. The attraction of earthworms to moisture is noted in the literature (Edwards and Lofty, 1977) but reasons have not been documented. When they pierce the low permeability seal that forms on the furrow wetted perimeter, water flows into and infiltrates from their extensive burrow system.

The initial flush of sediment that moves through a furrow with initial filling tends to fill and plug any worm holes remaining open from the previous irrigation and any holes that may be made early in the irrigation event. As the irrigation proceeds, the furrow perimeter stabilizes and sediment load decreases allowing newly-formed holes to remain open to conduct water. As the infiltration rate increases, furrow flow rates in the tail portions of the furrow decrease so sediment transport further decreases, further facilitating the process. Thus, with each irrigation, the infiltration rate tends to return to the normal rate without the macropores until the earthworms again begin piercing the perimeter and the sediment movement is low enough that the newly formed holes remain open. Sediment concentration measurements indicate that this normally takes at least four hours.

Sediment movement in furrows in alfalfa tends to be much lower than in row crops due to less tillage and higher vegetation-caused roughness of the furrows. With less sediment to plug earthworm holes, the holes tend to remain open from irrigation-to-irrigation. Thus, infiltration rates do not increase during alfalfa irrigations but remain higher in alfalfa than in row crops.

The somewhat erratic occurrence of the infiltration increase phenomena from field-to-field and over the season is apparently due to the varying population and activity levels of the earthworms and subsurface moisture distribution. Attempts to correlate increasing infiltration with earthworm populations were not successful. The tendency for greater occurrence late in the season could be caused by earthworms further extending their burrows through the plowed layer, decreasing sediment loads as the furrows stabilize and vegetative growth increases roughness, and earthworms remaining nearer the surface as subsoils become drier.

Although the positive effects of earthworms on rainfall infiltration have been widely reported, little attention has been given to their effects on infiltration under irrigated conditions. Only two reports were found which describe increasing infiltration rates during irrigated events attributed to earthworm activity. Bezborodov and Khalbayeva (1983) describe an increasing furrow infiltration rate very similar to that described in this report on medium and heavy loam dark sierozems of the keless massif, Kazakh, USSR. They noted earthworm holes in the furrows and attribute the phenomena to earthworm activity. Clothier et al. (1983) noted that the ponded area around a trickle source on a Manawater fine sandy loam (Australia) decreased with time. They found that 30 worms had vented their burrows within the ponded zone and increased saturated hydraulic conductivity 385%.

If earthworms, which inhabit nearly all soils, can cause increasing infiltration rates to the extent that was measured in southcentral Idaho, why hasn't the phenomena been more widely reported? Is there some unique local soil or ecological condition or set of conditions which fosters the phenomena? As noted, earthworm populations in the studied area are higher than in many other cultivated areas, especially low organic matter arid soils. Alfalfa, which fosters high earthworm populations, is commonly included in the local crop rotations. Corn is not a major crop in the area so chemicals commonly used with corn which may decrease populations, such as anhydrous ammonia and insecticides designed for root pests, are seldom used. The local silt loam soil has very low aggregate stability and is very erosive. The tendency of furrows to seal up and quickly approach a surface seal-controlled steady-state infiltration rate makes the effects of earthworm activity on infiltration changes much more evident.

A possible reason increasing infiltration rates have not been more widely reported could be that, when an increasing rate is measured, being in disagreement with both theory and published measurements, it is disregarded as an anomaly or attributed to measurement error. Although farmers in the study area had been aware of the back-up problem for several years, scientists first documented the phenomena only recently.

IMPLICATIONS FOR IRRIGATION MANAGEMENT

The silt loam soils in southern Idaho normally reach a steady infiltration rate quickly. Consequently, irrigators can set furrow inflows at rates which will complete advance quickly without causing high runoff rates. Due to the erosiveness of the soil, minimizing runoff rates and thus inflow is important. However, if the infiltration rate increases during an irrigation, a furrow with an initiallly low runoff rate will soon yield no runoff and the furrow stream will recede up the furrow from the tail. This results in poor irrigation water distribution. Consequently, to insure reasonable water distribution, farmers must either set their flows higher than otherwise necessary, which results in higher runoff and erosion, and/or they must monitor the field during the irrigation to check for back up. If back up does occur, they must somehow boost the supply rate to readvance the furrow flows, which is difficult if the supply is being fully utilized, or stop the irrigation earlier than planned.

A more permanent solution to the problem would be to eliminate the earthworms. Chemicals are available which will decrease earthworm populations, although both the economic and environmental cost of eradication can be high. However, earthworms are widely recognized to be beneficial for soil tilth, aeration and organic matter incorporation. Therefore, eliminating earthworms is generally not desirable.

Ammonia applied in the irrigation water discourages earthworm movement to the furrow and may be an available control alternative when the nitrogen is required by the crop. Unfortunately, furrow irrigation-applied ammonia is not distributed evenly along the furrow (Denmeade et al., 1982). On the Portneuf soil, the furrow perimeter soil cannot practically be compacted sufficiently to inhibit earthworm penetration (Kemper et al., 1988). Additional control measures and management techniques are needed.

One obvious option to avoid the management problems associated with increasing infiltration is to switch from surface to sprinkler irrigation. High infiltration rates are beneficial for economical sprinkler irrigation. Another possible option might be to convert to minimum-till. Stabilized surface soils with roughness-enhancing residue in the furrows dramatically decrease sediment movement in furrows (Carter et al., 1989). Thus, earthworm holes would tend to stay open as occurs with alfalfa, leaving high infiltration rates but eliminating or at least reducing the difficult-to-manage infiltration increase.

A possible consequence of the water absorption through earthworm burrows is that a portion of the applied irrigation water and any chemicals in the water, may bypass the plant root zone. Although the subsurface-feeding worms excavated in the cultivated fields usually burrow down to no more than 0.5 m below the surface, water conducting macropores more than 1 m below the surface were observed and burrows more than 1.5 m deep have been reported (Ehlers, 1975; Bouma et al., 1982). Deep percolation loss of water and chemicals through earthworm burrows requires further study.

CONCLUSIONS

1. Furrow infiltration rate increases during irrigation events on about 30% of the irrigations in southcentral Idaho.
2. The infiltration increase is due to earthworms piercing the furrow perimeter during the irrigation which allows water to enter and infiltrate from their burrow systems.
3. Increasing infiltration rates often result in non-uniform water distribution across a field and cause irrigation water to be more difficult to manage.
4. Low concentrations of aqua ammonia in the irrigation water prevent the infiltration increase, apparently by repelling the earthworms from the furrows.

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