EARTHWORMS CAUSE FURROW INFILTRATION INCREASE

Thomas J. Trout, W. D. Kemper, and G. S. Johnson[1]

ABSTRACT

Infiltration rates into furrows in Southern Idaho, after decreasing toward a base rate, often increase. The increase is caused by earthworms piercing the furrow wetted perimeter during the irrigation and water entering and infiltrating from their interconnected burrow systems.

INTRODUCTION

Furrow irrigators in South-Central Idaho commonly experience a problem which they call "backup". During an irrigation, the tailwater runoff reaches a maximum and then begins to decrease. Eventually runoff ceases and the water front in the furrow begins to recede up the furrow from the tail of the field. In order to maintain a uniform application to the field, the farmer must increase the furrow water supply rate to readvance the water through to the end of the furrow.

This unusual pattern is the result of furrow infiltration rates increasing during the irrigation. Physical factors normally considered do not predict infiltration rate increases. We believe the unusual infiltration phenomena is caused by earthworm activity. The objective of this paper is to describe the infiltration relationship and to present evidence that indicates that earthworm activity is the cause.

DESCRIPTION OF THE INFILTRATION RELATIONSHIP

Figure 1 shows two typical furrow infiltration rate curves for the Portneuf silt loam soil (coarse-silty, mixed, mesic Durixerollic Calciorthids) in South-Central Idaho. The rates are expressed in depth applied per unit time to the total soil surface from furrows spaced 1.1 m apart. Similar relationships have been measured with blocked furrow (stagnant and recirculating) infiltrometers, individual furrow inflow-outflow measurements, and field inflow-outflow measurements. The high silt soil normally approaches a sustained or base infiltration rate within three to four hours of the start of irrigation. On row crops, the base rate varies from 2 to 5 mm/hr and generally is only 10 to 40% higher during the first irrigation after tillage.

Often, the increasing infiltration rate relationship shown in Figure 1 is measured. Four to eight hours after the start of irrigation, the infiltration rate begins to increase. In many cases, the increase is fairly linear and continues for at least 20 hours. The 20-hour rate will often be 1.5 to 3.0 times the lowest rate reached. It cannot be determined whether the normal base rate is ever reached. In one

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[1]Agricultural Engineer and Supervisory Soil Scientist, USDA-Agricultural Research Service, and Research Associate, University of Idaho. Snake River Conservation Research Center, Route 1, Box 186, Kimberly, Idaho 83341.

recirculating infiltrometer test, the rate increased to 6.5 times the lowest rate before becoming constant at about 40 hours.

This unusual infiltration relationship can be modeled by a two-term, 3-parameter time-based infiltration function of the form:

$$I = abt^{b-1} + 2ct \tag{1}$$

where I = infiltration rate
t = infiltration opportunity time
a, b, and c = empirical curve fitting coefficients.

The cumulative infiltration, z, relationship would be:

$$z = at^{b} + ct^{2} \tag{2}$$

This is similar to the extended Kostiakov-Lewis relationship except the time in the second term is squared.

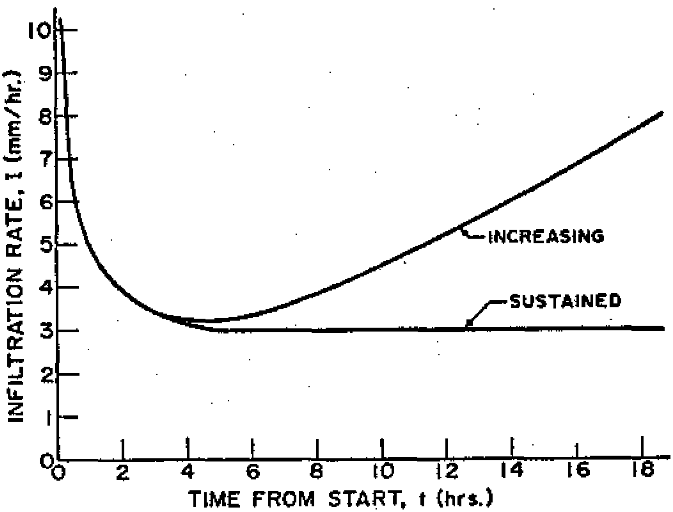

Figure 1. Typical sustained and increasing furrow infiltration rate curves for Portneuf silt loam

EXTENT OF INCREASING RATE PHENOMENA

Sixty furrow irrigations on 35 fields were monitored over two years by measuring total field inflows and outflows to determine the extent of the increasing infiltration rate phenomena. On one-third of the irrigations, the difference between the inflow rate and tailwater runoff rate decreased at least 17%, indicating at least a 20% increase in infiltration rate. The infiltration rate measured in this manner is limited by the inflow rate and the maximum measurable increase is equal to the maximum runoff rate. Higher infiltration results in tail-end recession or the total inflow infiltrating into a portion of the field area. On an additional one-third of the monitored irrigations, a lesser rate increase was measured. On the remaining third, the base rate was sustained to the end of the irrigation. All farmers interviewed in the area have experienced tail-end recession of their furrow flows. Some consider it a major factor in their irrigation management.

The measured irrigations were of three row crops (dry beans, field corn, and sugar beets) and one broadcast fodder crop (alfalfa). The rate increase was not correlated with any row crop. Alfalfa exhibited a 3 to 5 times higher base rate and essentially no rate increase. Monitored irrigations began both in the morning and evening and the infiltration rate increase was not related to time of day. During the first measurement season, the occurrence and amount of rate increase greatly increased through the season. During the second season, infiltration rate increases were noted during some early season irrigations also. These seasonal trends were also noted on research plot furrow-by-furrow measurements.

CAUSE

One consistent observation on furrows in which the surface water front was receding due to increasing infiltration was the presence of earthworm holes in the furrow wetted perimeter. In some cases, the small remaining flow at the receding front was observed to all drain into one earthworm hole. Live and dead earthworms were sometimes found in the tailwater. In the absence of other probable causes for a furrow infiltration rate increase, earthworm activity was studied as a possible cause.

Extensive recirculating and stagnant blocked furrow tests were carried out on one field to study the physical conditions that may relate to the infiltration increase in more detail. On 25 of 30 blocked furrow tests, infiltration rates increased over time to some extent. The time the rate increase began varied widely but was between 4 and 16 hours on two-thirds of the tests. The increase was not related to time of the day, and was not affected by furrow compaction with a tractor wheel, tillage of the surface 40 mm, or whether the water was stagnant or flowing.

On the 1 m long stagnant water blocked furrow sections and 6 m long flowing sections, the infiltration rate increase was highly variable, even in adjoining sections of the same furrow. The variability (as indicated by the coefficient of variation) of the rate increase at 12 hrs was two to three times the variability of the base or lowest rate reached. The high variability indicates the presence of a factor which strongly affects infiltration which can vary widely over short distances, or of an individual phenomena, such as one large macropore, which can have a significant effect. Earthworm holes could cause this response.

An average of 15 earthworm holes per meter appeared in the furrow wetted perimeter during the blocked furrow tests. Dye injection into stagnant ponded water showed that water was entering a portion of the visible holes. Plugging all visible holes during a test in which the infiltration rate had increased from 4 to 30 mm/hr after 16 hours reduced the rate to 3 mm/hr. After 10 additional hours, the rate again began to increase.

A 1.5 m deep pit was dug 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, and one was 1.3 m below the soil surface. The collectable seepage amounted to 10% of the water being infiltrated. Such seepage under positive pressure indicates direct hydraulic contact with the water on the surface, which could occur only with continuous macropores.

In a paired set of recirculating infiltrometer tests, half of 16 furrows were treated with Chlordane, which is reported to be lethal to earthworms. The 12-hour cumulative infiltration was reduced by 50% and only two of six treated furrows showed any increase as compared to four of six untreated furrows. Live earthworms were present below the treated furrows but their activity was retarded.

Aqueous ammonia (NH_4OH) was dribbled into furrow inflows to attempt to repel earthworms from the furrow. Approximately 10L of the solution was dribbled into each treated furrow over 3 to 7 hours, resulting in a concentration of less than 0.25% in the irrigation water. Figure 2 shows the average infiltration response of 5 treated furrows and 5 alternate untreated furrows. The treated furrow infiltration rate continually decreased to a base rate of 2 mm/hr, as shown in the figure. In the untreated furrows, the rate similarly decreased for 3 hours, reaching a minimum of about 3 mm/hr, and then began to increase to 5 mm/hr after 18 hours.

During a second test, aqueous ammonia was applied to half of the untreated furrows 10 hours after the beginning of the irrigation and after the rate had already increased 50% from the lowest rate achieved. The application stabilized the infiltration rate while the rate in the remaining untreated furrows continued to increase.

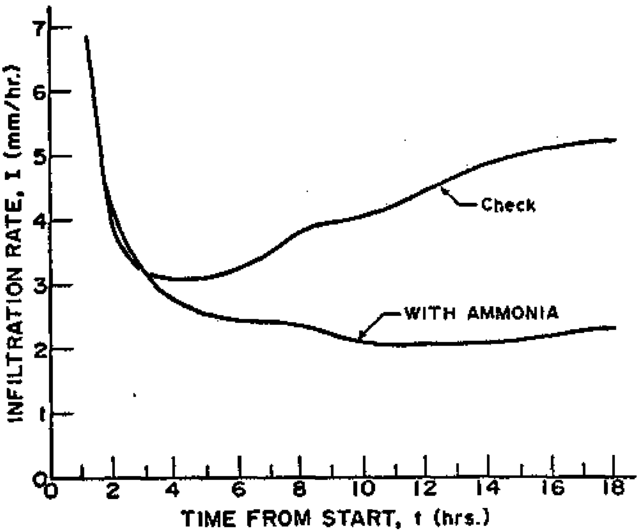

Figure 2. The effect of aqueous ammonia application on filtration rate

The application of aqueous ammonia in the water prevented the infiltration rate increase. Although the solution can disperse clays and reduce soil permeability, application at the same concentration on another field with the similar soil had no effect on infiltration rates. On the treated field, the effect was only on later rate changes.

DISCUSSION

The evidence overwhelmingly indicates that earthworm activity is the cause of the increasing furrow infiltration rates. Apparently, the earthworms are attracted either to the flowing water in the furrow or to the high moisture content near the furrow. Their apparent attraction to moisture is noted in the literature (Edwards and Lofty, 1977) but no reasons are given. When they pierce the low permeability layer that forms on the wetted perimeter, water flows into and infiltrates from their extensive burrow system.

The initial flush of sediment, especially bed load, that moves through a furrow with initial filling, tends to fill and plug the holes left after the previous irrigation. 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.

The observed trend toward increasing occurrence and magnitude of infiltration rate increase with the progression of the season is probably a result of the increasing extent of earthworm burrows in the cultivated layer. In alfalfa or permanent pastures, where the soil is undisturbed for extended periods and sediment movement is minimal, persistent high infiltration rates would be expected. (Abbott and Parker, 1981; Ehlers, 1975). In fact, base furrow infiltration rates in alfalfa fields in the area average 3 to 5 times rates in annual row crops. Sustained rates above 300 mm/hr were measured in border irrigated permanent pastures. These environments provide not only an undisturbed soil medium but also a plentiful food supply for a large earthworm population. An intermediate infiltration response would be expected under reduced tillage conditions due both to reduced disturbance of the soil and surface mulches.

The importance of earthworm burrows on infiltration under rainfall conditions has been documented by numerous studies (see references). However, observations of increasing infiltration rates with time attributable to earthworm activity is rare. Bezborodov and Khalbayena (1983) described an increasing furrow infiltration rate very similar to that discussed in this paper on medium and heavy loamy 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) also 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 wetted zone and increased saturated hydraulic conductivity 385%.

If earthworms cause increasing infiltration rates, why has the phenomena not been more widely reported? Either some aspect of the local soils or ecological conditions must be unusual; or the phenomena, when noted, being in disagreement with both theory and published measurements, is disregarded as an anomaly or attributed to measurement error. A localized soil or environmental condition that would foster unusually high earthworm populations or cause their activity to affect furrow infiltration in a unique manner has not been identified. Earthworm populations in cultivated fields generally vary from 50 to 200 per square meter of ground surface. Species have not been identified but the smaller, subsurface-feeding field worms are distinct from the large "nightcrawlers" which are found in permanent sod and pastures.

CONSEQUENCES

Even in furrows on which the supply rate is sufficient to advance the flow to the end if the infiltration rate increases sufficiently, the supply will be absorbed in less than the complete furrow length and the water front will recede up the furrow from the bottom. This results in deficient application at the tail of the field. The nonuniform water distribution is magnified because the final infiltration rate is high relative to the depth of water infiltrated. Farmers who try to irrigate uniformly are forced to monitor their fields during irrigation sets for this "backing up" of the water. When tail-end recession occurs, they must either stop the irrigation, or increase the furrow supply rate to match the increasing infiltration rate. Increasing the supply in order to minimize the uneven water distribution is difficult when the supply is fully utilized. Many farmers purposely set their supply rates high, anticipating that the infiltration rate may increase. This can result in excessive tailwater runoff and erosion.

Another alternative, illustrated in Figure 3, is to interrupt the flow temporarily (as in surge irrigation) until the furrow is dewatered. This tends to consolidate the perimeter soils and decrease the infiltration rate sufficiently to allow the reintroduced water to readvance completely. As the figure shows, the lowered infiltration increases similar to that in the constant flow furrow. Consequently, the recession problem is not eliminated but only delayed, hopefully long enough to complete the irrigation.

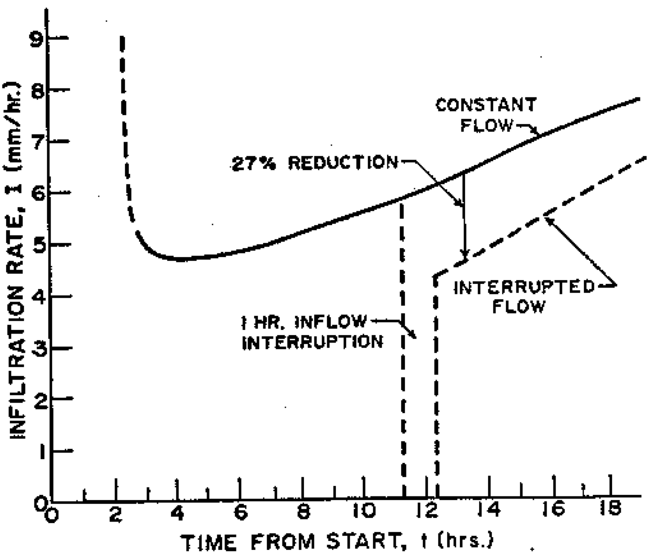

Figure 3. Effect of a one-hour flow interruption on infiltration rate

The more effective solution to the problem would be to eliminate the earthworms or to discourage their movement to the furrow during the irrigation. Several agricultural chemicals decrease earthworm populations, although the most effective (chlorinated hydrocarbons such as Chlordane) cannot be used in the USA, and are expensive to apply. Also, earthworm populations are beneficial for soil tilth and aeration and organic matter incorporation. On the Portneuf soil, the furrow perimeter soil cannot be compacted sufficiently to inhibit earthworm penetration. Ammonia does discourage earthworm movement to the furrow and may be a viable control alternative when the nitrogen is required by the crop. Additional control measures are being sought.

A possible consequence of the water absorption through earthworm burrows is that a portion of the applied irrigation water may bypass the plant root zone. Although worms found in the row-cropped fields generally burrow down to only about 0.5 m below the surface, water conducting macropores more than 1 m below the surface were observed. Also, water balance studies on alfalfa fields indicate that, even when water application is less than available storage in the surface 1.3 m, as much as 30% of the application may deep percolate beyond this depth. Deep percolation loss of water through earthworm burrows requires further study.

CONCLUSIONS

1. Furrow infiltration rate increases during an irrigation event occur during about 30% of the irrigations in Southern Idaho.

2. The increase is due to earthworms piercing the furrow perimeter which allows water to enter and infiltrate from their interconnected burrow system.

3. Increasing infiltration rates cause irrigation water to be non-uniformly distributed across a field.

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