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Worms and water

By W. D. Kemper, T. J. Trout, Antone Segeren, and Murray Bullock

A raindrop's value to a farmer depends upon whether that raindrop is available or not available to the farmer's crop. Rates at which cloud bursts deliver water often exceed the rates at which water can move into the root zones of crops through the tiny pores between soil particles. Small puddles of water then develop on the surface. These puddles may grow until water flows over the lowest banks, joining overflow from millions of other puddles to flood nearby creeks. Meanwhile, much of the crop root zone remains dry.

In adjacent fields with macropores, puddles may also start to form, but the accumulating water drains into the soil through the macropores fast enough to prevent the puddle from overtopping its banks. Once the storm is over, the field with macropores will often have far more water in its root zone.

Macropores are bigger than the little pores that exist between closely packed soil particles. Large pores between clods, old root channels, and cracks due to drying and soil shrinkage are all macropores, but Bill Edwards at the Agricultural Research Service research station in Coshocton, Ohio, says that earthworm holes are the most effective macropores for draining puddles on the test watersheds at Coshocton. Edwards has a field that has been in untilled corn for 22 years. He has measured rainfall and runoff on this and nearby fields of tilled corn throughout this period. According to Edwards, rainfall has averaged 39.4 inches per year, while runoff averaged 4.9 inches on the tilled plots and 0.08 inch on the untilled plots.

Edwards and colleague L. D. Norton counted an average of about 6 large worm holes per square yard on the tilled plots and 155 holes per square yard on the untilled plots (5).

Farmers can't do much about the amount of rain they will get, but Edward's findings indicate that farmers can work with worms to capture precipitation in the root zones of their crops.

How many macropore-makers?

Soil scientists studying root systems in row-cropped fields in some southeastern states failed to find earthworms in those fields, but they were able to dig up enough worms in adjacent forested areas in a few minutes to go fishing!

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Forests, pastures, and lawns usually have healthy populations of earthworms. For instance, a housewife in Eden, Idaho, harvested and sold more than 440 pounds per year of night crawlers from her 10,765-square-foot lawn. Considering that she left all her grass clippings on the lawn and that the night crawlers probably ate most of them, she achieved production comparable to nearby irrigated pastures where grazing beef cattle gained about 132 pounds per quarter acre per year!

Studies by Eileen Kladivko at Purdue University indicate that the pasture was probably growing a good crop of worms, too. Kladivko has found from 240 worms to more than 15,550 worms per square yard in Indiana pastures; higher populations occurred where manure had been applied. In nearby corn and bean fields, populations were generally less than 60 worms per square yard, and they were subsurface feeders.

Where do they go?

The clearing of forests and plowing of native grasslands for row-crop production generally resulted in good crop harvests for a few years; then yields began to decline. These declines commonly were attributed to reduced nutrient levels in the soils. Crops used up the nutrients that had accumulated over centuries in the virgin land. Fertilizers restored yields to respectable levels on many soils and helped identify nutrient depletion as a primary cause of the lower yields that occurred as the land remained subjected to the plow.

But farmers were not just removing nutrients. They were removing or burying crop residue. This left soil surfaces neat and bare. Populations of surface-feeding earthworms declined in favor of earthworm populations better adapted to eating the buried, decaying residue.

Buried residue remained more moist than the leaves and grass that fell on the surface of unplowed land. Consequently, the buried plant residue decayed more rapidly, and there was less opportunity for earthworms to get their share of the calories contained in that organic matter before it was reduced to carbon dioxide and water by microorganisms. Farmers also treated their soils to kill cutworms and corn ear worms, not realizing that they were decimating the macropore-makers. As plows fractured and turned the soils, many earthworms were killed or weakened, and the flocks of seagulls and other birds that followed the plow contributed further to earthworm population declines.

The immediate and obvious effect of plowing is a rough, open, cloddy surface through which water passes like a sieve. But the beating action of one good rainstorm on an unprotected, cloddy surface can destroy those clods, eliminate macropores in the surface, and initiate runoff (8).

With no decaying residue on the surface, there is no incentive for surface-feeding earthworms to burrow their way to the surface, opening conduits from the surface to the interior of the soil. Consequently, when succeeding rains come, successively higher runoff commonly occurs. The result of this increased runoff is more erosion, which moves topsoil off sloping land onto lowland and into streams.

New methods of soil management

Topsoil erosion was so obviously destructive that farmers discussed it with their con-

Reprinted from the Journal of Soil and Water Conservation
November-December 1987, Volume 42, Number 6

servation district leaders and asked Soil Conservation Service technicians to help them find ways to hold that soil in place. SCS helped farmers terrace their land and apply known practices for reducing erosion. The agency also placed new and more effective erosion control methods at the top of its research needs list.

Scientists from the Agricultural Research Science and several land grant universities, working with SCS and farmers, found that the most effective management practices for holding soil in place involved as little tillage as possible and keeping crop residue on the soil surface. This practice doesn't look as neat as a clean-tilled field when the new crops are emerging through the residue. Some call it "trash farming." But it obviously helps hold the soil in place.

Early explanations of how crop residue on the soil surface helped to hold the soil in place were based on protecting the soil from the disintegrating effects of raindrop impact and slowing down the water as it ran across a field. There were many reports of reduced runoff from no-till systems, but there were a few reports of increased runoff as well.

Traffic during harvesting often compacts the soil, and farmers have relied on cultivation to help open the soil so it can absorb the rain. If cultivation stops and there are no earthworms to burrow holes into the surface, increased runoff may occur. Subsurface-feeding worms do not increase water intake rates appreciably.

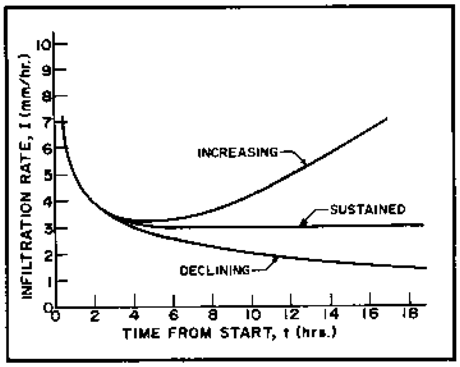
In field tests, we measured populations of subsurface feeders that ranged from 0 to 84 worms per square yard. We also determined infiltration rates using ring infiltrometers for two hours adjacent to each of 26 locations. The correlation between earthworm population and infiltration rate was practically negligible.

Not just any earthworm hole helps to drain rain puddles. Surface-feeding earthworms whose holes connect the interior of the soil to the surface are essential. This not only prevents erosion, but it prevents water from running off the land and stores more water for use by crops.

Increasing the water reservoir

Limited rooting depth often restricts the amount of water that crops can extract from a soil. When a plowpan or other hard layer keeps all plant roots in a shallow soil layer, plants run out of water sooner and may even suffer from drought and stop growing when moist soil is only a few inches away—on the other side of the hard layer.

Juang Wang at the University of Illinois and John Hesketh and Doyle Peters with ARS at the University of Illinois found that



Declining, sustained, and increasing infiltration rates.

worm burrows serve as channels for roots to grow deeper into soils. When soybean roots failed to find an earthworm burrow, soybean growth terminated in the top 12 to 16 inches of soil. However, when roots entered old earthworm burrows, they often grew 40 to 60 or more inches. These researchers believe that once such long earthworm burrows are in place, they may be used by several generations of roots, providing each new generation of plants with access to the enlarged reservoir of water that will keep them growing longer during dry spells.

Helping the irrigation farmer

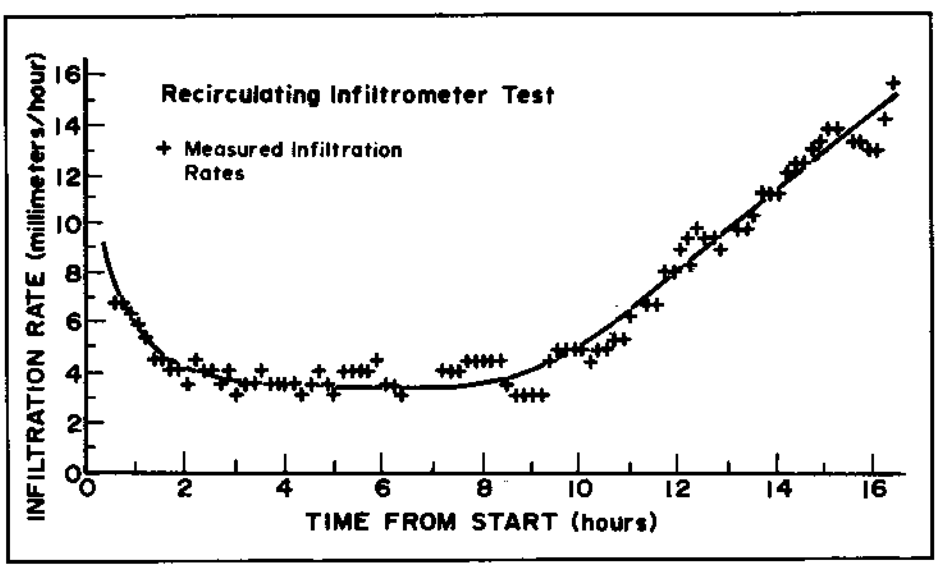
When most water used by crops comes from sprinkler irrigation, a farmer *can* design and operate his or her system so the rate of application is lower than the rate at which the soil will take in the water. In some popular irrigation systems, however, slow application has a significant cost. The outer end of a 130-acre center-pivot system moves about 100 feet in an hour. If the water sprays in a 100-foot-diameter pattern and 2 inches of water are applied, the rate of application averages 2 inches per hour. If a farmer wants to use low-pressure sprinklers that reduce the power required but only push the water out in a 50-foot-diameter pattern, the 2-inch application goes on in one-half of an hour.

Many fine- and medium-textured soils without macropores will not imbibe water that fast. Water runs off the high areas and accumulates in the lower areas of a field. The result is uneven irrigation. As the season advances, high areas in the fields become short of water, and nitrate is leached out of low areas by the excessive water. Large numbers of earthworm holes that drain surface water to the crop root zone allow the sprinkler irrigator to take advantage of the cost savings of low pressure systems without reducing the efficiency with which he or she uses water and nitrogen fertilizer.

Are worms ever a problem?

When furrows are used to distribute irrigation water across a field, their perimeters must be permeable enough to let adequate water into the root zone but sufficiently impermeable so that some water reaches the bottom end of the field. During irrigation, furrow intake rates change (see figure, above). Theory says that intake rates should level out or even decline as irrigation continues. Farmers in Idaho's Snake River Valley kept telling us that in many of their fields water would reach the bottom ends of the furrows one or two hours after they started irrigating, but several

Increasing infiltration rate measured on a furrow in a Portneuf of silt loam soil.



hours later would be running only part way down the furrow. This indicated increasing infiltration.

Careful measurements using recirculating infiltrometers confirmed the farmers' observations (see figure, below left) (9). Infiltration rates increased even if physically based theory said they could not. But the reason was not physical; it was worms. Almost all worms in these row-cropped fields were subsurface feeders, so they did not normally have ready-built tunnels to the soil surface. But like all earthworms, they moved toward water (see figure, right).

In one field test, a single line of sprinklers was set up and operated to supply about 1.2 times as much water as needed by the crops at the line, about half as much water as the crop needed 40 feet from the line, and no water 100 feet from the line. Worms migrated from the drying region of the field to the moist region.

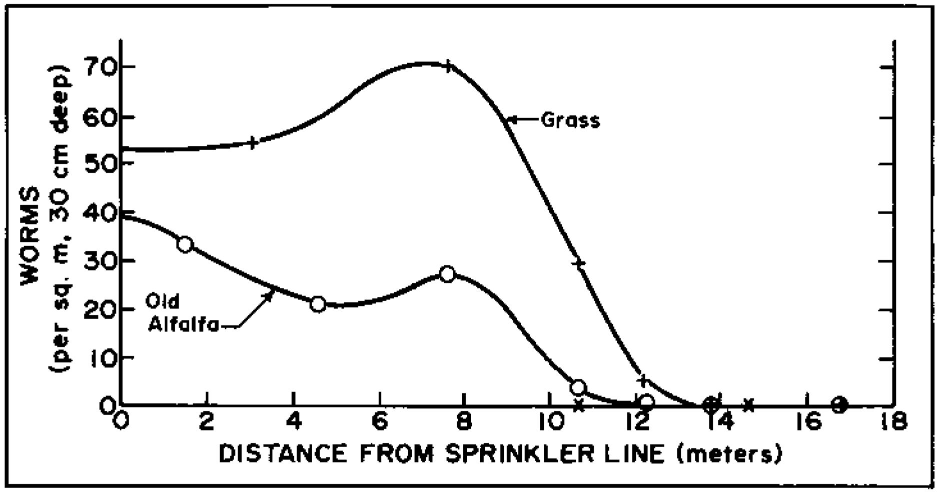
Their attraction to moist soil may be a survival instinct. Another possibility is that it is easier to burrow into moist soil, so they tend to burrow in the direction of soil that is more moist. Whatever the reason, a few hours after irrigation water began seeping out of furrows, many of these surface feeders reached the furrow and could be observed boring holes upward out of the soil into the water in the furrow.

M.L. Brown and colleagues (3) filmed one of these subsurface feeders emerging from the bottom of a furrow on a sunny day. It took only a few seconds for the worm to feel the ultraviolet light to which they are highly sensitive and pull back into the soil. During the night, or after crop canopy blocks out direct sunlight, worms often come completely out of their holes and float downstream. Some float down a furrow to drain ditches. Others find a place to burrow back down into the furrow. Whatever their fate, they affect the disposition of irrigation water, which flows down the holes in the furrow from which they emerged.

During these observations, the number of holes in the bottom of furrows often more than doubled during an irrigation, commonly reaching 10 to 50 holes per yard of furrow. When the number of holes increased, intake rates increased. When water consequently failed to reach the end of the furrows, the tail end of the field generally received less water than the plants needed, while the top end received too much.

To get a "worm's eye" view of the wetting pattern under these furrows, trenches were cut about five feet deep at right angles to the furrows. The rate water was absorbed into the soil from the furrows was monitored, and the extent and water content of the wetted zone was observed. The wetted zone consisted of the cylindrical zone common in soils without macropores. The radius of this cylindrical zone extended from about 8 inches to 16 inches during the observation. There were also long, slender fingers of wetted soil along worm holes, which extended as far as 48 inches from the furrow.

Assuming the cylinder was uniform along the furrow, about half the water applied to the furrow could be accounted for behind the cylindrical fronts. This indicated that about half the water that left the furrows traveled out further in the soil via worm holes. In the process, this water passed large volumes of soil in which the water content had not changed.



Worm populations as a function of distance from a sprinkler line.

Water loss from irrigation ditches

Ditch banks, moistened frequently, often grow lush vegetation above and below the soil surface, which eventually serves to nourish large earthworm populations. Evaluations of water loss from ditches in Pakistan's Punjab showed that the ditches were losing about 40 percent of the water delivered to the ditches before it reached farmers' fields (2). Water intake through the wetted perimeter of the sod-banked ditches ranged from 4 to 10 times greater than the intake into adjacent basin-irrigated fields. Worms don't deserve all the credit, or blame, for the high permeability of the ditch banks. Flow through large holes made by rodents and other animals was also observed. Even when these large holes were plugged, however, losses on old grass-banked ditches exceeded 35 percent of the supply (10).

The high permeabilities of these banks are further amplified when vegetation is allowed to grow in the ditch beds, which increases the roughness coefficient and raises the water level in the ditch. This extends the wetted perimeter to upper portions of the bank where surface-feeding earthworms have browsed and left their open holes when water was not that high.

Measurements of the effects of ditch-water elevation on water loss from ditches in Pakistan and in Colorado (see figure, next page) indicate that high permeabilities in the upper portions of grass-topped banks occur in both countries (1). These high permeabilities are a substantial cause of water loss if lack of cleaning causes ditch water levels to exceed design levels.

Are worms manageable?

If a water management goal is to reduce runoff and get more water into the crop root zone, a large population is needed of those big, surface-feeding night crawlers to open channels to the surface. Bill Edwards' data indicate that night crawlers will come and do this job if the soil is not tilled and crop residue remains on the surface for many years. Eileen Kladivkos found that her data generally support Edwards' conclusion. But her findings that worms are more abundant in soybean fields than in corn fields lead her to believe that further evaluation is needed to determine if pesticides and ammonia, which are often applied to corn fields, keep worm populations down.

If no-till cropping and the resulting increase in surface residue have not reduced runoff, compaction during the previous harvest may be the problem. However, Edwards' experience indicates that if those surface feeders are there, no-till cropping will increase their populations, and they will create the holes to let water in. One can check to see if night crawlers are present by digging a half dozen post-size holes. If this does not yield a few big night crawlers (4 to 8 inches long), one can try "planting a few worms." Fish bait stores buy worms for about $2.00 per pound, and most of their supply is night crawlers. Otherwise, night crawlers can be gathered from someone's lawn. A fish bait dealer can probably explain how to make the electric probes that will bring the surface feeders up for easy harvest.

If there are surface feeders in the area, they quickly concentrate under crop residue. An alfalfa field in Kimberly, Idaho, was divided into two plots. On one plot the alfalfa was killed, plowed under, and seeded to grain. On the other plot, the alfalfa was killed, but the plot was not tilled. Wheat was seeded in both plots. On June 1 the following year, a worm harvesting crew used a set of electric probes to harvest night crawlers from 645 square feet on either side of a section of the boundary between the two plots. Crew members collected 367 night crawlers from the no-till plot, which still had some alfalfa residue on the surface. Only 29 worms were collected from the side where alfalfa residue had been plowed under. Some worms on the plowed plot may have been killed by plowing, but the much higher population on the no-till side was probably due to the night crawlers scouting out the surface residue and taking up permanent residency near this food supply.

Much more must be learned about earthworms to manage them most efficiently. It is well known, however, that keeping crop residue on the soil surface and refraining from tillage increases the population of surface feeders and helps create the worm holes that conserve water.

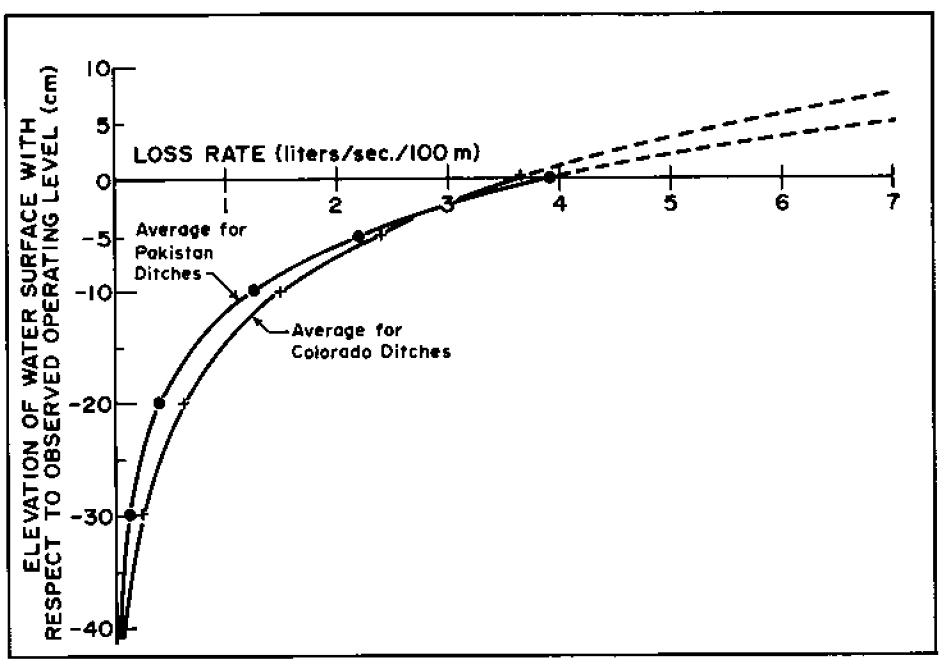
Keeping worms out of ditch banks and furrow bottoms is possible if sufficient compaction can be applied to the soil. Doral Kemper and associates (7) observed that night crawlers could exert forces between 45 and 90 pounds per square inch as they expand their hole in soils. When soils were compacted with about 90 pounds per square inch of pressure, the earthworms could not further compact the soil and were forced to ingest the whole volume of the holes that they began to burrow into this soil (their casts are less dense than this highly compacted soil). After penetrating about an inch of compacted soil, they backed out. Apparently, they have a survival instinct that tells them they will block the hole behind them and be trapped in an ever-shortening hole if they proceed into this highly compacted soil. If compaction pressures of 90 pounds per square inch or more can be applied practically to banks and furrows, worms apparently can be kept out of these critical areas.

T. J. Trout also observed that when he applied ammonium in furrow irrigation water there was no tendency for infiltration rates to increase, while in nearby furrows, where there was no ammonium in the water, appreciable increases of infiltration rates occurred (9). This observation fits with Kladivkos' observation that ammonium can damage earthworms, and its use should be avoided if possible. Concentrations of ammonium that Trout used would have been sufficient to provide corn with all the nitrogen it needed in four irrigations. Unfortunately, ammonium is not distributed evenly along the furrow (4). Urea is more uniformly distributed, and data from the Portneuf soil indicate that urea hydrolyzes to ammonium within an hour of when it enters the soil with irrigation water. That may be soon enough to head off earthworms and keep them from increasing infiltration rates.

Kemper and associates also found that earthworms could not penetrate six inches of subsoil with an organic carbon content of less than 0.2 percent and no fresh organic matter (7). Thus, if ditch banks were built of subsoil and vegetation kept out of them, worms probably would keep out, which would avoid the large water losses common to vegetation-covered ditch banks. Of course, drop structures may be required to keep slope and water velocity down in ditches that previously depended upon the root fabric of vegetation to keep soil in steep ditches from eroding.

Real potential exists for managing worms to improve water management. More must be learned about the burrowing pressures that different species can exert, how fast populations can regenerate under different climatic and plant residue conditions, what chemicals reduce worm populations, and so forth. Only now are researchers beginning to understand how badly worms have been treated and how much they can do for farmers and conservationists if treated right.

Effect of water levels on loss from ditches in Pakistan and Colorado.



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