Irrig. Sci. (1988) 9:79–87

Irrigation Science

Soil Management to Prevent Earthworms from Riddling Irrigation Ditch Banks

W. D. Kemper, Paula Jolley, and R. C. Rosenau

USDA Research Center, Kimberly, Idaho 83341, USA

Received August 24, 1987

Summary. Earthworm activities were observed under subdued light in lucite fronted soil filled boxes in which bean plants were growing. They formed their burrows by ingesting a relatively small core of soil about 2 mm in diameter and expanding these holes to a diameter of about 5 mm by flexing their muscles. The compacted zone extended about 4 mm from the radii of these burrows. As shallow bean roots of young plants extracted water from the upper portions of the soil, worms moved downward to moister soil. During furrow irrigation, worms moved toward the water source through existing burrows. A few of them burrowed new holes to the furrow and emerged and swam in the water for up to 20 min before burrowing back into the mud in the bottom of the furrow. In columns with sections packed with pressures of 50, 100, 200, 300 and 600 kPa, worm burrowing was reduced in sections packed at higher pressures and was practically negligible in the sections packed at 600 kPa. Visual comparison of porosity in the compacted soil surrounding earthworm burrows and the soil compacted at 300 and 600 kPa indicated that the worms are able to compact soil with a force between 300 and 600 kPa. Worms were not able to survive long enough to burrow through 15 cm of a subsoil with organic carbon content less than 0.2% that lay between them and topsoil. Both compaction and use of subsoil for the banks show promise for reducing earthworm burrowing and water loss from ditches.

Banks of old irrigation ditches observed in Pakistan, Colorado, and Idaho, which are used intermittently, commonly have infiltration rates which are 4 to 10 times those in adjacent cultivated fields (e.g., Akram et al. 1981). As the findings of MacKay and Kladivko (1985) and Kladivko et al. (1986) would predict, these old, sod-covered, frequently wetted banks often develop large earthworm populations and become riddled with worm holes (e.g., Fig. 1). Many insects, such as ants, also make holes in the soil, but under moist irrigated conditions, earthworms are usually the primary hole makers. Water flows out of the ditches through holes when the

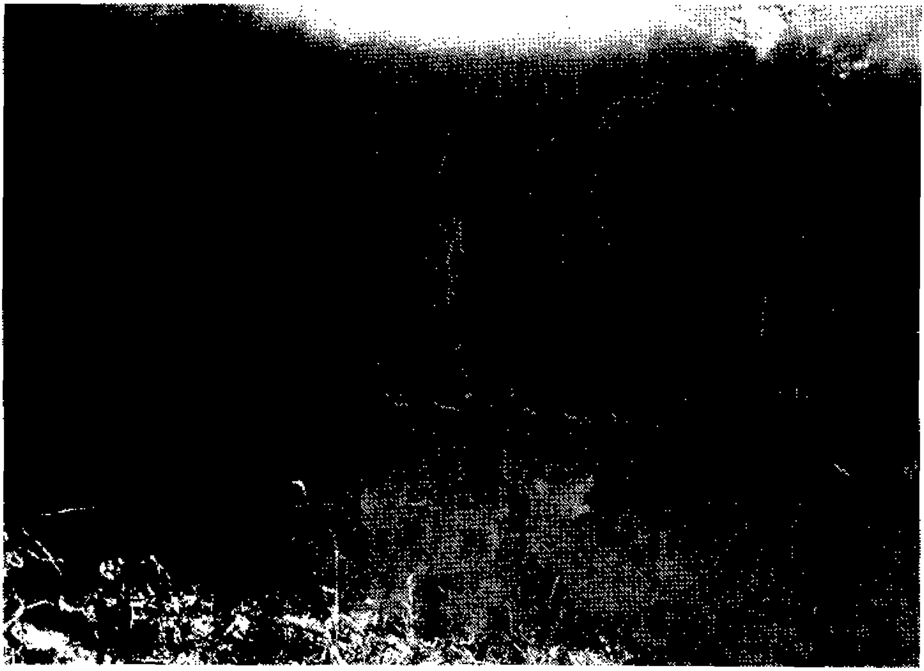

Fig. 1. Earthworm holes in ditch bank

water level on the inner sides of ditch banks rises above their openings. As much as 50% of the irrigation water delivered from canal system laterals to farmers' ditches can be lost before it reaches the farmers' fields (Clyma et al. 1981). Studies by Kemper et al. (1981) and subsequent unpublished counts of hole openings in ditch banks and measurement of flow in a few of these holes convinced them that these holes were a primary route by which water was lost from many ditches.

Trout et al. (1987) found that worms were attracted to water in irrigation furrows. Worms often burrowed so many holes up through the bottom of the furrows during irrigations that infiltration rates into soil around the furrows increased 50 to 600%. Farmers often adjusted flow rates to get water to the end of their furrows without excessive runoff. When their infiltration rates increased, all of the water was absorbed in the upper reaches, leaving the bottom reaches without water. Consequently, while earthworms often help improve several aspects of soil structure, intake rates, and yields, they can also cost irrigation farmers significant amounts of water and labor.

Compaction of ditch banks and furrows is possible and could conceivably prevent earthworms from burrowing in them. Making ditch banks of subsoil to reduce the organic matter content is another option that could make them less attractive to worms. The following studies were set up to observe burrowing activities of worms and evaluate effects of subsoil and of compaction on earthworm burrowing activity.

Materials and Methods

Soil

Portneuf silt loam soil (20% sand, 60% silt, and 20% clay) was used in all these studies. The topsoil had an organic carbon content of 0.5% organic carbon. The subsoil had an organic carbon content of about 0.1%.

Simulated Field Conditions

Observation boxes 5 cm thick by 60 cm wide by 60 cm high were constructed with transparent lucite fronts. The bottom 30 cm of the boxes were filled with soil in 5 cm increments, packing each with a pressure of 200 kPa. The top 25 cm was filled in the same manner and packed with a pressure of 75 kPa. Topsoil was used in both layers. The differences in compaction were designed to give densities of about 1.25 in the top 24 cm and 1.4 in the bottom 35 cm which were near those observed in the field. Soil was excavated to simulate half of a V-shaped furrow 10 cm deep and 30 cm wide in the top right hand corner of each of these boxes. A bean was planted in the center of each box and was grown to maturity. Irrigation water was applied via the furrow when needed. Four healthy subsurface feeding type earthworms were placed on the surface of the soil in each box. They generally worked their way into the soil within a few hours. Their burrowing activity was observed occasionally under dim light during evening hours through the transparent fronts of the boxes. The extent of observable holes and their associated compaction zones were charted about twice a week. The front was covered during the rest of the time to keep soil next to the lucite dark.

Density Studies

The effect of soil density on earthworm burrowing activity was studied using lucite cylinders 10 cm in diameter and 40 cm long filled with topsoil in the manner shown in Fig. 2. A screen on the bottom of the cylinder was covered with filter paper to retain the soil and give access to air. The lucite lid on top was drilled with 25 holes 1 mm in diameter which were the primary source of oxygen and CO_2 exchange. The bottom 7 cm of each of these cylinders was filled with soil (at 0.22 g H_2O/g soil) in three increments, compacting each increment to a dry density of about 1.6 g/cm^3 which required pressures of 600 kPa. The next 7 cm was compacted to a density of about 1.5 g/cm^3 using 300 kPa of pressure. The third, fourth, and fifth sections were compacted at densities of about 1.4, 1.3, and 1.2 g/cm^3 using pressures of 200, 100, 50 kPa, respectively. Four nightcrawlers (Lumbricus Terrestris) were placed on the moistened surface of the soil in each of four of these cylinders and the cylinders were placed in a dark cabinet where temperatures ranged from 20 to 24 °C. When all of these worms had worked their way into the soil, two of the cylinders were laid on their sides while two remained vertical to check on whether gravity and cylinder orientation would influence burrowing activity. A fifth check cylinder was compacted in the same way but worms were not introduced. This cylinder was used later to measure amounts of large size pore space at these compaction levels. After 45 days, the lucite cylinder and enclosed soil were cut into sections 7 cm long corresponding to the five density zones. Filter paper, screen, and lucite bases were fitted on the bottom of each section. These sections, including those from the check cylinder, were then placed in desiccators, evacuated, and wetted to as near saturation as could be achieved. They were then allowed to drain through a tube attached to an outlet in the bottom of the cylinder which dripped into a graduated cylinder at atmospheric pressure 1 cm below the bottom of the soil. This subjected the soil in the column to a water tension which ranged from 1 cm at the bottom of the column to 8 cm at the top. The volume of water removed from each section was measured. The volume of worm holes in each section was estimated by subtracting the volume of water removed from the respective density segments of the check cylinder (no worm holes) from volumes of water removed from the segments which had been exposed to worms.

Burrowing in Topsoil vs. Subsoil

In a study to determine worms preference for topsoil vs. subsoil, Portneuf silty loam was taken from a field which had been fallowed during the previous crop growing season so that it

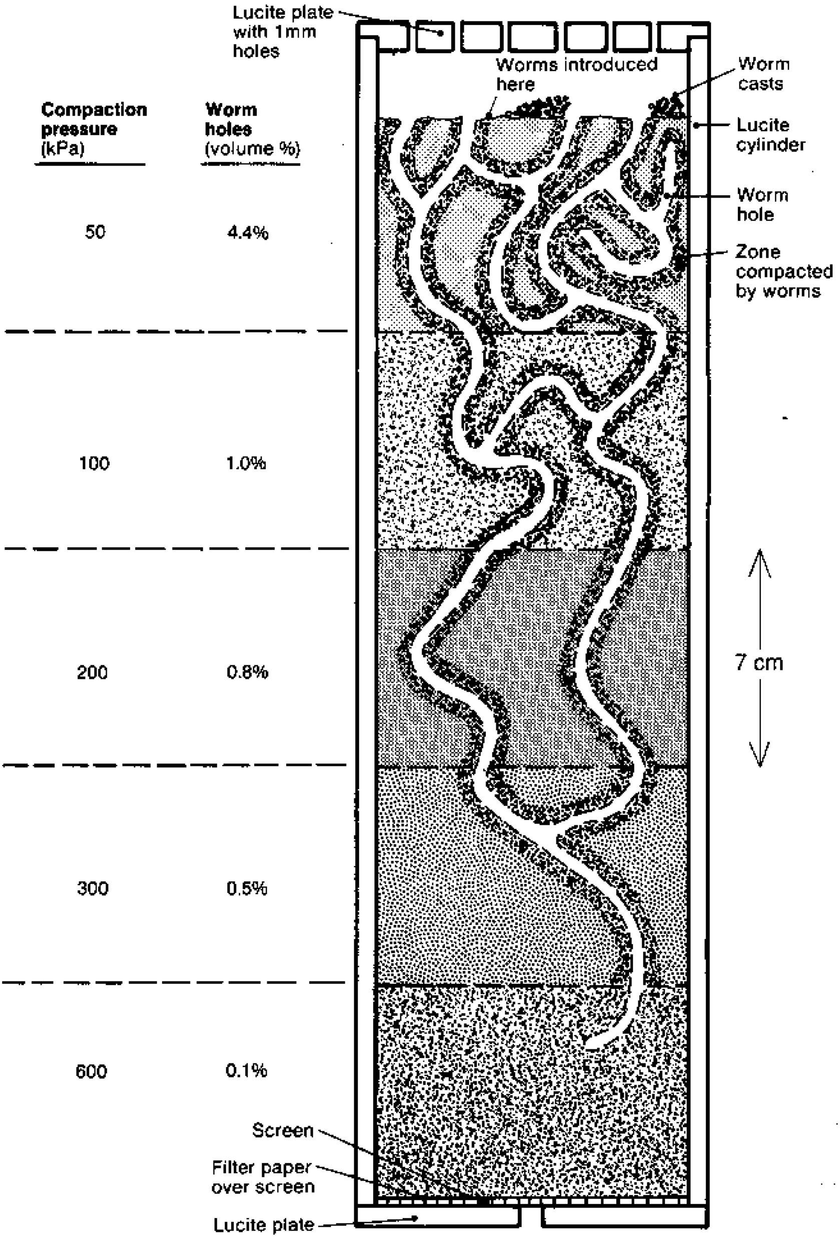

Fig. 2. Cylinders of soil to evaluate soil density effects on earthworms

contained no "fresh" organic matter. Topsoil was taken from the plow layer and subsoil was taken from the zone from 25 to 50 cm below the plow layer. These soil samples, at field water content (about 0.15 g H_2O/g soil), were passed through a sieve with 5 mm diameter holes. They were brought to 0.22 g H_2O/g soil by spraying and mixing on a plastic sheet and were then packed into lucite cylinders with pressures of about 100 kPa to a density of about

1.3 g/cm³. In one cylinder, the bottom half was packed with subsoil and the top half with topsoil. The four worms (night crawlers) could be introduced only on top of the soil and we did not want to bias worm activity with proximity of soil type to point of introduction. Consequently, in the other cylinder, topsoil was packed in the bottom and subsoil in the top.

Observations and Results

Simulated Field Conditions

There were few casts on the surface in the observation boxes which had soil densities of 1.25 and 1.40 in the top and bottom sections, respectively. Casts in the visible portions of the worm holes (next to the lucite plate) made up less than 20% of the hole volumes. This indicates that less than 20% of the hole volume resulted from soil ingestion by the worms and over 80% of the hole volume resulted from compaction of surrounding soil. The earthworms drew their front ends to thin extended points with which they probed the soil in front of them. After excavating a small diameter hole a few millimeters into the soil by ingestion, they drew their tail ends forward and successive waves of muscle flex against the sides of the hole expanded the hole to a final diameter of about 5 mm. The visibly compacted zone commonly extended 3 to 5 mm from the hole, and examination with a magnifying lens (×10) indicated that pores larger than 0.2 mm in diameter had been eliminated from the compacted zone.

After bean roots had penetrated 30 cm or more into the soil, worms often dug their tunnels alongside an older root. They cleaned the soil from about 180° of the root perimeter, probably ingesting decaying root hairs, associated microorganisms, and other organic matter sloughed from, or exuded by, the root. The fact that root tips to which photosynthate was being provided by these cleaned roots appeared to be growing just as well as root tips served by "uncleaned" roots indicated that this "cleaning" did no damage. Some of these burrows followed along older roots for 100 to 200 mm.

Prior to the first irrigation, when the bean roots were in the upper 25 cm of soil, water content of that layer was reduced to near the wilting point, and the worms migrated down and worked in the lower sections which were still relatively moist. The worms generally migrated toward the water source when the irrigation water was added. A few of them emerged from the soil in submerged portions of the furrows, swam around for up to 20 min, and then burrowed back into the submerged mud in the bottoms of the furrows.

Density Studies

In the compaction cells, set up as indicated in Fig. 2, distributions of worm holes were practically the same in the columns which were standing upright as in those that were laying on their side. The average coefficient of variation of the hole volume means in the top four sections of the columns shown in Fig. 2 was 7%. There were sufficient casts on the surface to account for about one-third of the earthworm hole volume in the 50 kPa compacted section. Proximity to the surface and the opportunity to unload there may have been a factor in the worms' excavating holes in 0.044 cm^3/cm^3 of the soil in that top section. However, low density appears to be the major factor.

In general, the fraction of the volume tunneled by the worms reduced as density increased. Only two of the cylinders had penetration by the worms in the highly compacted (600 kPa) bottom section. These holes were "clean" with no casts and extended only about 30 mm into the dense soil. There was no apparent additional compaction around their perimeter. This indicated that the holes resulted completely from ingestion and that the worms had backed out rather than burrowing through far enough to turn and emerge head first.

Visual comparison of pore space size in the compacted zone around earthworm burrows in the sections originally compacted at 100, 200, and 300 kPa indicated that density of the worm compacted zones was about the same. A hand lens was used to compare pore sizes of sections in the cylinder compacted mechanically without worms to pore sizes in soil in the worm compacted zones. Worm compacted soil appeared to have slightly larger pores than soil compacted at 600 kPa and smaller pores than soil compacted at 300 kPa. Consequently, we estimate that the worms have an ability to exert a pressure of between 300 and 600 kPa to compact the soil around them.

Where worms enter soils that have been compacted at pressures higher than they can exert, such as the sections compacted at 600 kPa, they have to ingest practically all of the soil that constitutes their holes. Since their casts have densities (1.2 to 1.4 g/cm^3) lower than that of the highly compacted soil (1.6 g/cm^3), they would more than fill the holes behind them which would force them into a continually reducing hole length. Moreover, since they ingest from only one end, they could not reverse direction and would be trapped. Apparently evolution and selection have developed an instinct in the survivors which senses this danger and warns them to back out of holes in dense soil. Thus, if soil is compacted to densities as high as or higher than those to which worms can compact it, they will not penetrate the soil.

Burrowing in Topsoil vs Subsoil

Volume percentages of the topsoil and subsoil occupied by the worm holes 30 days after introducing them to these cylinders are shown in Fig. 3. Four active worms were placed in the top compartment of each cylinder, and within 2 h all of those in the cylinder with topsoil on top had eaten and worked their way into that soil. Two days later, the worms in the cylinder with subsoil on top were still probing over the surface but had not made holes more than 2 or 3 mm deep in the subsoil. They seemed willing to starve rather than ingest this low calorie fare! To provide them with access to the underlying topsoil, we drilled a 6 mm diameter hole through the subsoil. Under the laboratory lighting, which made the worms placed on the topsoil start burrowing for cover, the worms placed directly on the subsoil with the drilled hole did not make use of the hole for several hours. One eventually found the hole, stretched out its front end and probed the entrance, touching the perimeter of the hole at several points with its pointed front end and then withdrew. Concerned that they would starve before using the hole, we filled the hole with loose moist topsoil. Within a few minutes one of the worms touched the topsoil in this hole with its

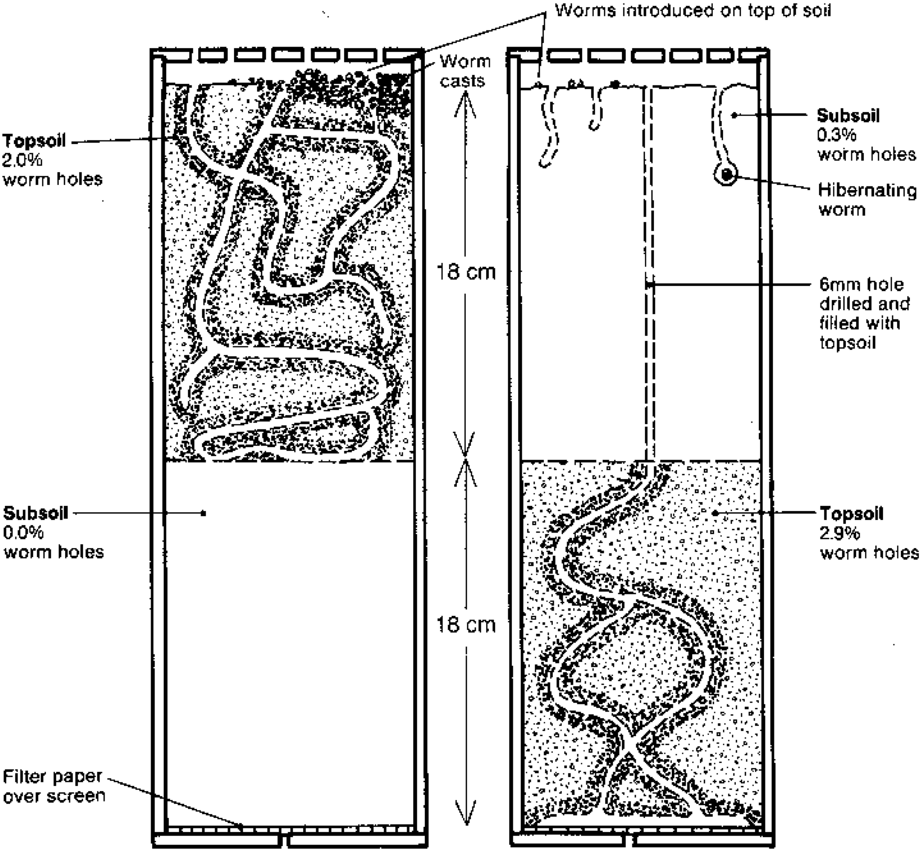

Fig. 3. Setup to determine relative burrowing activity in topsoil and subsoil

probing front end. Apparently this was what it had been looking for. Within 10 min it had eaten its way down through the soil in the hole and its tail end was disappearing into the hole. As the topsoil entered its intestine, the small amount of subsoil that it had previously ingested was displaced. That subsoil was cast at the hole opening and covered the top of the hole.

The other three worms continued to probe the surface for 3 more days before they began to burrow into the subsoil. They penetrated about 50 mm. Two of them died before the conclusion of the study and the third was found balled up in hibernating position in an emaciated state.

However, the worm that went through the topsoil filled hole in the subsoil and reached the topsoil was especially active, forming holes in 2.9% of the topsoil. Inspection of this soil at the conclusion of the study showed that over half of these holes were adjacent to the filter paper on the bottom of the cylinder. Apparently the worm was obtaining nourishment from decomposition products of the filter paper. This extra energy supply was probably a major reason why this single worm formed more burrow volume than 4 worms in the topsoil of the other cylinder. Those worms did not penetrate the subsoil and thus did not reach the filter paper.

On the surface of the topsoil, in the cylinder where topsoil was on the top, there were 34 g of casts. Compaction around the burrows and their total volume of 23 cm^3 indicated that only about 10 g of the soil in these casts could have come from the burrows. Close observation of the surface showed that the night crawlers had ingested large sections of the surface soil to depths as great as 5 mm. This soil ingested from the surface apparently constituted at least 70% of the casts on the surface. Apparently night crawlers will graze on the surface when that surface is moist and dark. This topsoil had not been cropped for a year so it contained little fresh organic matter. Moreover, it contained only about 0.5% total organic matter. Consequently, it is probable that the worms were not getting enough nutrient out of this soil to be fully activated!

Conclusions and Applications

Most worm burrows in normal density topsoils were created by the worms ingesting cores of soil about 2 mm in diameter then flexing their muscles, pressing against the walls until the holes were enlarged to about 5 mm in diameter. Some earthworms bored holes alongside older roots and apparently ate exudates decomposing root hairs and other sloughed organic matter from the roots. This "cleaning" of these old roots did not appear to damage them.

The night crawlers avoided subsoils with low amounts of organic matter in them. Their extendable front ends were highly sensitive to the presence and absence of food sources and they declined for several days to ingest the soil necessary for them to enter the subsoil. When they did burrow into the subsoil, they died before they worked their way through the 15 cm of subsoil that separated them from the topsoil.

Compaction of soil to bulk densities higher than the earthworms can compact it resulted in no appreciable penetration of the compacted soil by the worms. In this soil that critical compaction pressure appeared to be between 300 and 600 kPa.

Worms had to ingest all of the soil from the holes in the few cases where they attempted to burrow into soils compacted with forces greater than those which the worms could exert. While they were able to ingest all the soil in this matter for about 30 mm, excretion of this much soil behind them would more than fill the burrow and trap them in ever shortening confines. Apparently they have a survival instinct that senses this danger and they backed out of the holes begun in such compacted soils. Consequently, compaction of ditch banks and furrows to more than 600 kPa should reduce earthworm burrowing in and decrease seepage rates from them. Constructing ditch banks from low organic matter subsoil, rather than high organic matter topsoil, should also decrease worm activity and seepage loss because worms strongly prefer soils with organic nutriment.

However, if the ditch banks are rapidly revegetated, the roots of the vegetation, as they die, provide a food supply that attracts the worms back into the banks. There is a strong tendency for farmers to encourage ditch bank vegetation to provide root fabric in the banks to prevent erosion of steep ditches. Less seepage loss will occur if drop structures are provided so the ditch sections are not steep and vegetation on the ditch banks can be eliminated with herbicides.

References

Akram M, Kemper WD, Sabey J (1981) Water levels and losses and cleaning in watercourses. Trans ASAE 24: 643

Clyma W, Kemper WD, Ashraf MM (1981) Reducing farm delivery losses in pakistan. Trans ASAE 24: 367

Kemper WD, Trout TJ, Segeren A, Bullock MH (1987) Hydrology and worms. Soil Water Conserv (In press)

Kladivko EJ, MacKay AD, Bradford JM (1986) Earthworms as a factor in the reduction of soil crusting. Soil Sci Soc Amer J 50: 191

MacKay AD, Kladivko EJ (1985) Earthworms and breakdown of soybean and maize residues in soil. Soil Biol Biochem 16/17: 851

Trout TJ, Johnson G, Segeren A (1987) Erath worms and furrow infiltration. ASAE Trans (In press)