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Full-Scale Rainfall Simulator Instructor Guide

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Acknowledgments

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Full-Scale Rainfall Simulator Instructor Guide

Introduction

In the suite of demonstration technologies, the full-scale rainfall simulator can be one of the most effective tools for introducing people to the principles of soil health and encouraging the adoption of soil health improving practices. Results from a 2015 survey of individuals who watched a rainfall simulator demonstration found that the demonstration was effective in providing education on the impact of the water cycle as well as prompting the adoption of conservation practices and monitoring techniques (Smart et al., 2017).

The conversation that accompanies the rainfall simulator demonstration can enhance or hinder the effectiveness of the demonstration to help people understand how management affects soil function. Those leading the demonstration need to have a solid understanding of the reasons for the observed differences in runoff and infiltration. They need to explain how management contributes to those differences. These two factors are critical for helping land managers make the connection between their management and how well their soils capture and store water. Many individuals watching the demonstration will not properly interpret and apply what they see to their own farming situation without expert guidance in making these connections. Because of this, the presenter must effectively convey the reasons for what the audience is seeing during the demonstration and the implications for both productivity and environmental concerns. The presenter needs to clearly relate how management of agricultural lands affects water infiltration and runoff, soil erosion, crop productivity and potential nutrient and pesticide movement from fields. This demonstration will be most effective if participants are guided to understand these interactions and can visually see the results.

The Soil Health Division created this instructor guide to provide guidance on: 1) getting prepared for the slake and rainfall simulator demonstrations, 2) important talking points for the slake and rainfall simulator demonstrations and, 3) a few commonly asked questions with answers. *Not every talking point needs to be used for an effective demonstration*. The presenter should use those points that are easy to internalize and appropriate for the audience.

Note: *For an abbreviated list of the main discussion points, a two-page quick guide is found at the end of this document. The quick guide can be printed on two sides of one sheet of paper and laminated for easy reference in the field.*

Getting Prepared: Extracting Sample Trays

The foundation for an effective rainfall simulator demonstration begins with properly collecting and preparing the trays. Below are some key points on how to collect a good sample and video links that show different ways of doing it.

- Collecting a sample is easiest with at least two people and can take 10 to 30 minutes per tray.
- Collect samples for the simulator that have the same surface texture. This helps reduce any variability based on soil textural differences between the various samples.
- Collect fully intact samples representative of the conditions needed for the demonstration. For example, if one of the trays needs to be from a no-till field with a certain amount of residue, collect a sample that has the desired quantity of residue already present rather than collecting a no-till soil that has insufficient residue and then adding residue on top of the tray.
- For the conventionally tilled and the no-till only (no cover crop) samples:
    - Collect soils one to two weeks before the demonstration so the soils can be dried.

  - Depending on soil texture and/or moisture, collection of intact samples may not always be possible. In such situations, use a shovel to scoop up the soil to place in buckets.
  - To adequately fill a tray with loose, dry soil, a five-gallon bucket will need to be filled so it is approximately two-thirds full.
  - Fill a five-gallon bucket at least two-thirds full with soil from the field that is only no-till (no cover crops). Fill another five-gallon bucket at least two-thirds full from a conventionally tilled field.
  - Dump the buckets onto a tarp and break up the chunks of soil with your hands so that the soil resembles soil in the field at planting time.
  - Spread the broken-up soil on the tarp so it can dry out.
  - After the soil has dried out, place the soil in the trays and any extra soil in buckets for storage. Label the buckets to prevent confusion in identifying the samples.
  - To show the impact of adding surface cover to conventionally tilled cropland, fill up a third tray and cover one with the mulch from crop residues while leaving the other uncovered.
  - If a conventionally tilled soil is cut from the field, be careful not to fracture it as it will likely have preferential flow that will be confusing to the infiltration discussion.
- Invite the landowner/partner to assist with the extraction of each sample. This has several benefits which include:
  - Provides an excellent opportunity for the landowner/partner to learn more about the importance of soil structure, rooting depth and evidence of soil life.
  - Enlightens the landowner/partner to the difficulty of the extraction process.
  - Landowner/partner can help determine areas to avoid such as compacted or typically wet areas.
- Links to videos showing sample tray extraction in different field conditions.
  - Conventional tillage (1:57): Click here
  - No-till with cereal rye residue (4:47): Click here
  - Living cereal rye cover crop (4:56): Click here
  - Hayland (5:36): Click here
- If possible, weigh each tray and record the weight immediately after extraction (a scale may be available in the landowner's shop).
  - Be ready to share the respective weights during the demonstration when talking about bulk density, pore space and water-holding capacity.
  - Healthy soils of the same volume weigh less than unhealthy soils. For example, a tray containing a healthy, diverse pasture under proper grazing management can weigh 29 pounds while an overgrazed pasture sample can weigh 37 pounds. No-till, multi-species cover crop samples will often be somewhere in between these extremes.

Getting Prepared: Rainfall Simulator Setup

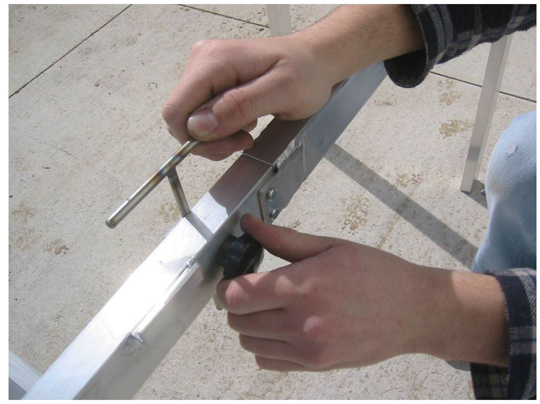


Figure 1: Adjusting metal T for changing slope.

- When setting up on uneven surfaces, use a hand level and blocks to ensure the simulator is level side-to-side. This is important so that the water that infiltrates flows into the infiltration jug properly.
- Set the slope to the typical soil in the region the group is from by represent adjusting each metal T up or down on the back of the simulator frame (see figure 1). If the group comes from rolling topography, then they will relate to erosion. However, if the group is from areas with little to no slope, then the focus should be on infiltration and ponding.
- Mount the oscillating nozzle so that it is six feet above the tray surface. This ensures that the nozzle changes direction beyond the very outer trays on both ends and that the droplet size and speed more closely approximate actual rain. If the nozzle changes direction over the outer trays, those trays will get significantly more water than any of the interior trays.
- Turn on the simulator before the trays are mounted to ensure proper spray pattern and pressure while bleeding out as much air as possible. Pressure needs to be high enough to get full coverage, but not too high that water is shooting out at high velocity. Generally, a pressure of 10 psi is a good place to start and adjust as necessary to get a realistic water velocity. If pressure is too low from the water source, remove pressure regulator valve. If trays are already mounted on the simulator before bleeding out the air, hold a bucket underneath the nozzle until only water is coming out.

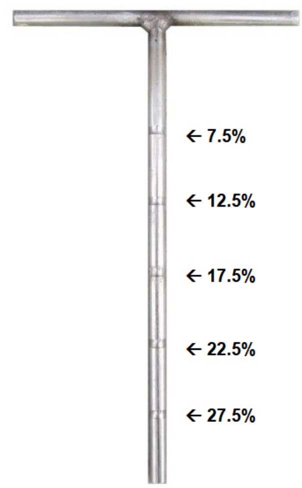


Figure 2: Metal T slope percentages

- Make sure tray edges are well-packed so there is no preferential flow between the sample and the tray it sits in. If the tray is transported to the demonstration site, run your fingers around the pan edge to remove preferential flow that may have developed during movement of the sample.
- Trays can be positioned in different ways depending on the samples being demonstrated.
- When two or more samples from two different land uses are on the rainfall simulator at the same time, place the samples from the same land use together (i.e., cropland next to cropland and grassland next to grassland).
- When three or more trays from the same land use are on the rainfall simulator at the same time, arrange the trays in sequence based on the amount of anticipated runoff so that runoff volume progressively increases or decreases when going in one direction within the same land use. Arranging trays this way makes it easier to show that adding soil improving practices can result in progressively reduced runoff and better infiltration.
- If one of the trays represents a conventionally tilled field with little to no residue, the tray can be positioned in the center, directly underneath the nozzle or on one of the ends furthest away from the nozzle. Traditionally the tray is positioned in the center. However, positioning the conventionally tilled tray on one of the ends can:

- Eliminate splashing soil from the conventionally tilled tray onto an adjoining tray, causing more soil to end up in an adjoining tray runoff jug, potentially skewing the results.
- Eliminate concerns that the conventionally tilled tray is being subjected to more water and higher impact forces than the other trays.
- When all trays are from the same land use, the tray with the least expected runoff is positioned on one end and the tray(s) with the most expected runoff are positioned on the other end. All other trays are arranged sequentially according to expected runoff.
- Make sure trays are centered over their respective catch pans so that all water that infiltrates is captured and directed to the infiltration jug.
- Place rain gauges in the center and outermost samples to show that all samples are receiving a similar amount of water.
- In windy conditions, place heavy-duty washers in the bottom of each of the jugs to keep them from swinging. A little breeze can wreak havoc with empty jugs, preventing water from going into them.
- Print off labels for each of the trays on letter-sized paper that can be placed in a cover slip or laminated. Clip these to the backsplash using a large binder clip. On the label describe the current management practice(s) in place for each tray such as conventional tillage, no-till, cover crops, continuous grazing, rotational grazing, etc. Optionally, other items could be added such as crop rotation (if there is one) and/or tray weight. Alternatively, if using the smooth side of the backsplash board, dry erase markers can be used to write the management above each tray. Afterwards the backsplash board can be cleaned using an eraser and dry erase cleaner.
- Optionally, place a dime on the highly disturbed tray so that the top surface of the dime is flush with the soil surface. After the simulation, the dime will either pedestal or be buried by soil that eroded from upslope. Either way, the dime provides an easy way to illustrate the relative amount of soil loss in a rain event. Additionally, it creates a memorable experience of the potential economic value of lost nutrients and water-holding capacity.
- If the simulator is set up on a tarp, place the lids of the water collection jugs underneath the legs of the simulator to prevent creating any holes in the tarp.
- After the simulator run, use 4 ft. by 6 ft. filter fabric or plastic tarp to dump soil from the highly disturbed tray to show audience the lack of soil moisture penetration in high-disturbance systems.
- Print and laminate photos of raindrop impact and dump truck (see last pages of this document) as well as any other relevant photos to enhance the simulation. Photos have been oriented in this document in landscape layout so they can be printed on 11 in. x 17 in. or larger paper.

Discussion for Slake Demonstration

- Who has heard of or read the phrase soil health before? What does the phrase soil health mean?
- Soil health is defined as the continued capacity of a soil to function as a vital, living ecosystem that sustains plants, animals, and humans.
- We learn from this definition that soil is not just some lifeless substance. Rather, it is a living ecosystem comprised of virtually innumerable organisms ranging from earthworms to fungi and bacteria. These organisms directly affect how the soil functions.
- What are some key soil functions? Answers can include: 1) grow a crop, feed, or fiber, 2) infiltrate and hold water, 3) maintain physical structure in the presence of water, 4) purify water, 5) provide a home for soil life and 6) good gas exchange – allowing oxygen in and carbon dioxide out.

- One of the most important soil functions is the ability to take in water (infiltrate) while maintaining its structure.
- To see this function in action, this first demonstration known as the slake/aggregate stability demo, can show how two soils of similar texture under different types of management behave when completely submerged in water.
- With a clod in each hand, walk around showing the audience the clods and asking them to point out any differences they see such as presence or lack of pores, roots and color.
- Explain the management of each soil.
- We now want to see what kind of relationship these soils have with water. We want soils that have a good relationship with water.
- Place each clod in the wire baskets so they are completely submerged in water (see figure 4).
- When the clods are submerged, water is rushing into the pores and pushing out air (as seen from the bubbling).

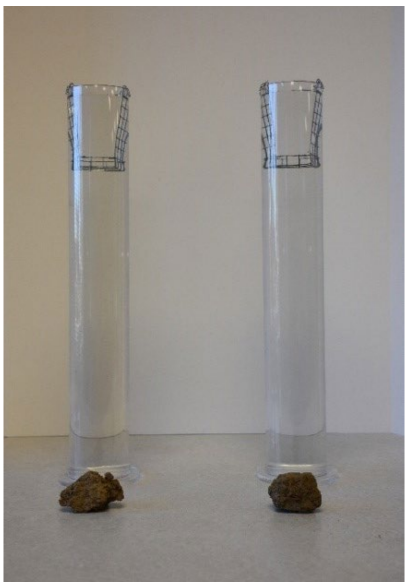


Figure 3: Two clear cylinders are filled with water to demonstrate how each clod will behave when completely submerged in water.

Figure 4: Two clods are gently submerged in water.

Figure 5: The clod on the left shows poor aggregate stability as the lack of biological glues allows the silt and clay particles to easily disperse into the water causing the water to be cloudy. The clod on the right shows good aggregate stability as there are plenty of biological glues that keep the individual soil particles together.

- As water rushes into the pores an internal pressure is created.
- Notice that the two clods are behaving quite differently. One is holding together (maybe a few large chunks come off) whereas the other is coming apart to the point that the water is clouding up.
- What do you think is suspended in the cloudy water? The smallest soil particles – clays and silts
- When soil is held together with roots and biological glues that come from plant roots, bacteria, and fungi, the internal pressure from the water does not cause the smallest soil particles (clays and silts) to slake.

- Even a healthy soil may slake a small amount, but the water remains clear. The aggregates that do slake still maintain their integrity. We would describe these aggregates as stable.
- Soil not held together by roots and biological glues begin to slake at the smallest soil particle level where the individual clays and silts go into suspension making the water cloudy. The aggregates that make up this soil are unstable in the presence of water.
- What would the water look like from a field where the aggregates are unstable? Or, how would that field behave in a rain event?
    - Let's see the importance of aggregate stability demonstrated further using the full-scale rainfall simulator.
    - Briefly explain the simulator and how it functions including how the sample tray and catch pan work to allow water to go into either an infiltration or runoff jug.
    - Explain the management for each sample tray.
    - Turn on oscillating nozzle before the water to avoid overapplying water to only one tray and skewing the results.

Slake Demonstration Guidance

- Always begin with the slake/aggregate stability demonstration. This helps the audience understand what aggregate stability is and its importance to soil function. Without this demonstration, one may erroneously conclude that the amount of soil cover alone is the sole determining factor on whether a sample infiltrates water or allows it to run off.
- Use soil clods that are completely air dried from the same or similar soil type. Comparisons can be made between cropland fields which are: 1) no-tilled versus tilled, 2) planted in cover crops versus fallowed, 3) cropland versus fence line and 4) pastures under rotational grazing versus continuous grazing or dedicated hayland.
- Practice with the clods before demonstrating so you know how they will behave when submerged in water.
- If the clod from the conventionally tilled soil does not slake significantly after a few minutes, tap on the cylinder for both clods at the same time or walk around holding a cylinder in each hand.
- Often tapping the cylinder or walking with the cylinders in your hands creates enough vibration to get the highly disturbed clod to begin slaking.
- If the clod from the conventionally tilled soil still does not slake significantly, remove both clods from water by lifting the wire baskets and dumping them on a table.
- Cut both clods in half using a knife to show how far water penetrated.
- The less disturbed clod should be moist all the way through and the highly disturbed clod should have a dry center.
- Less disturbed soils have good porosity allowing water to be rapidly absorbed. Highly disturbed soils have poor porosity preventing water from rapidly entering the soil. High bulk density clay soils are commonly the worst.
- Clods that should slake are best collected following a crop harvest and a rainfall event or early spring right before planting and after a rainfall event. Collecting clods where there is no growing crop ensures there is no root activity. And, collecting after a rainfall event ensures the biology remain alive so the clod does not seal over and prevent water from infiltrating.

Discussion During Rainfall Simulation

- The rainfall simulator mimics an extreme rainfall event by applying around 1-inch of water.
- We want to see which samples have soil that is continuing to function despite the intensity of water being applied.
- High-functioning soils can absorb the stresses from extreme weather events while maintaining key functions such as the ability to infiltrate and hold water for crop growth.
- Low-functioning soils cannot absorb the stresses of extreme weather events that high-functioning soils can.
- Rain drop velocity during an intense thunderstorm is around 20 mph.
- The steps of erosion are detachment, transport and deposition. How far do you think soil particles can move as a result of raindrop impact? Two feet vertically and five feet horizontally (show photo of raindrop splash on next to last page).
- The first raindrops detach silt and clay sized soil particles from surface aggregates, but where do they land? They land back on the tray filling up surface pores creating a surface crust, preventing additional water from infiltrating.
- More importantly, surface aggregates that did not detach from raindrop impact, can dissolve into smaller particles in the presence of water.
- These particles can move straight down into the pore space from one-quarter to three-quarters of an inch creating a surface crust within just a few minutes.
- The crust reduces air exchange by preventing oxygen from getting into the soil while allowing carbon dioxide from leaving the soil. Infiltration is reduced, runoff and erosion are increased. A crust negatively impacts the water and nutrient cycles.
- The crust causes the soil to become anaerobic leading to denitrification. Many of the disease-causing organisms thrive in anaerobic conditions.
- Can you see any differences between how water is interacting with these samples? What is happening?
- Look at the backsplash behind the highly disturbed tray. What is on the backsplash?
- Since many plant diseases come from pathogenic organisms on the soil surface, detached soil particles from the splash effect can transport disease to the plant as soil is splashed onto leaf surfaces.
    - Draw the audience's attention to the runoff jugs of the highly disturbed trays. Point out not only the volume, but also the cloudiness of the water.
- Does this remind you of the slake demonstration we did earlier?
    - After applying around 1-inch of water, turn off the water, then turn off the oscillating nozzle.
    - Be sure to shut off the water first then the oscillator so water is not sprayed onto the center tray under full pressure. Otherwise water can make it to the bottom of a highly disturbed tray and negatively impact the visual of flipping the tray to reveal dry soil.

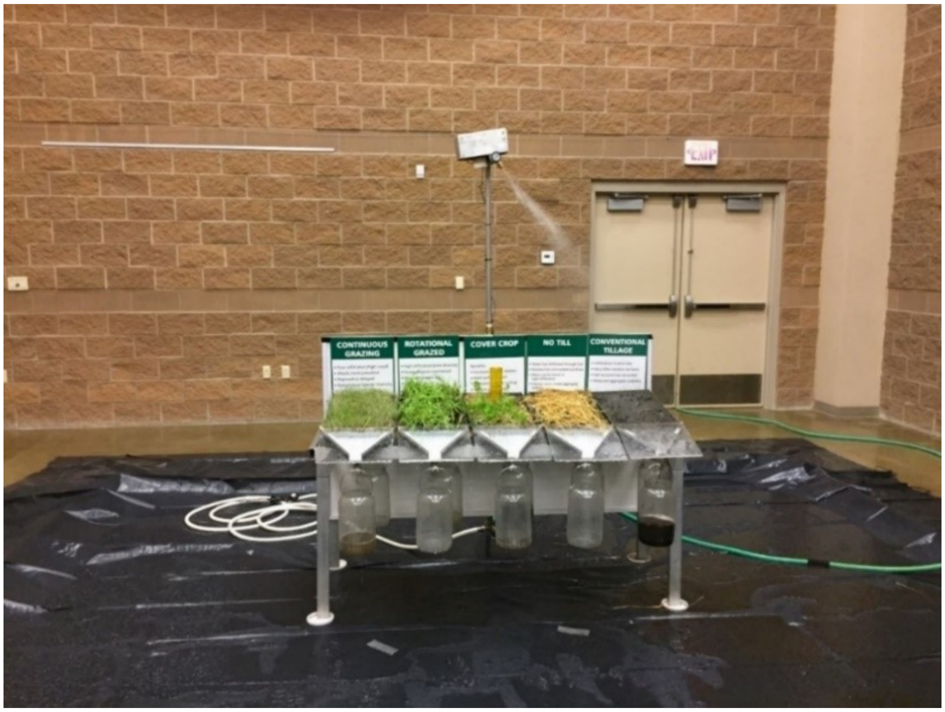


Figure 6: Rainfall simulator being operated on a tarp in an enclosed setting. To prevent holes being created in the tarp, the white plastic jug lids that came with the simulator were flipped upside down and placed in between the legs of the simulator frame and the tarp. The tarp was elevated around the perimeter to contain any water and soil that splashed off the simulator.

Figure 7: Key points being shared during a rainfall simulator demonstration. Notice the brown tarp directly in front of the audience that will be used later for showing how far water infiltrated into two of the trays.

Discussion After Rainfall Simulation

Allow the simulator to finish dripping for a minute or two. Pull the infiltration jugs out one at a time and discuss what happened with each jug. Place them in front of the respective runoff jugs so the audience can more easily compare what ran off versus what infiltrated for each tray.

- How much soil loss occurred around the dime on the conventionally tilled sample?
- Look at how much soil was lost relative to the thickness of a dime?
- There are no well-formed aggregates on the surface of the conventionally tilled sample.
    - Once the audience sees how much soil eroded, remove the dime and flip the tray onto a tarp to reveal the dry soil in the lower portions of the tray (see photo below).
    - Put some energy into flipping and dropping the tray to maximize the dust.
    - Dig into the dry soil and pick it up so that it falls through our fingers to maximize the impact of how little the water infiltrated (see figure 10).
    - Now, flip one of the high infiltration trays.
- See how aggregates are still visible and the entire sample is wet.
- Look at the slake demonstration and the aggregate that is still stable. That aggregate is stable because of the biotic glues holding the soil particles together despite how quickly water is rushing into the pore spaces and pushing out air.
- The same principles are at work in the clod and the pan.
- For the conventionally tilled sample, the main reason soil went into the runoff jug is because the aggregates on the surface were unstable, not because of the lack of cover.
- The unstable aggregates lacked the biotic glues to maintain structural integrity in the presence of water just like the highly disturbed aggregate in the slake demonstration.

Figure 8: The conventionally tilled tray is removed from the rainfall simulator just after turning off the water. The tray is placed on a tarp so the contents can be dumped to show how far water infiltrated into the sample.

Figure 9: As the tray falls on the tarp with great force and is lifted quickly, a lot of dust is created.

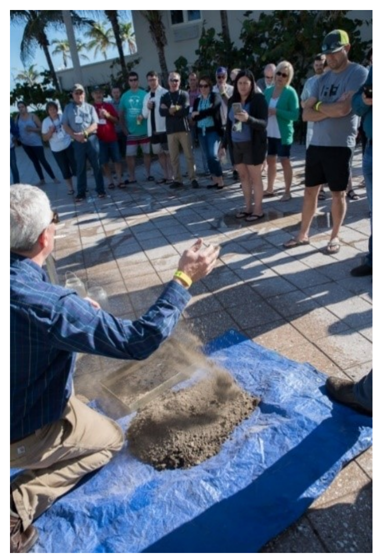


Figure 10: The sample is dug into with bare hands and filtered through the fingers to emphasize the dry soil.

Figure 11: Two trays are flipped upside down to show how deeply water infiltrated. The flipped tray on the left is from a field under conventional tillage while the tray on the right is from a field under no-till only. The runoff jugs are placed closest to the audience and the infiltration jugs are placed closest to the presenter. Notice the light brown color on the top of the tray from the conventionally tilled field.

- An optional step that can be impactful is to use nitrate and phosphate strips to check the runoff water from the erosion samples.
  - Depending on the sample, large amounts of N or P may have moved off the soil in the runoff.
  - This can lead to a discussion about nutrient dollars lost and environmental impact on surface waters.
  - Check this before the audience demo to be sure results are observable.
  - Soils that are not well aggregated will generally have more soluble nitrate and phosphorus as shown by a higher test level when using the nitrate and phosphorus test strips.
- Which sample(s) are holding the most water?
  - Generally, the rotated and well-recovered pasture holds the most water as it is the lightest sample with the most pore space.
  - Share the weights of each tray and relate that to pore space that can store water and allow the soil to breathe (inhale oxygen, exhale carbon dioxide).
- What are some things that influence how water is interacting with each sample?
  - Amount of past soil disturbance
  - Amount and type of surface cover
  - Amount of plant and animal diversity
  - Amounts of roots and root channels

- What influences all four of these characteristics? Management
- To improve soil function which includes improving the water cycle, we need to know and implement the four key principles of soil health:
  - Minimize soil disturbance
  - Maximize soil cover
  - Maximize biodiversity (including plants and livestock integration where possible)
  - Maximize presence of living roots
- Let’s see how our samples compared against these principles

Figure 12: Full-scale rainfall simulator with two grassland and three cropland samples. The cover crop tray in the middle is also a no-till field.

Principle 1: Minimize Soil Disturbance

Continuous Grazed or Dedicated Hayland.—No management as livestock are on this pasture for most of the year compacting the soil.

Rotational Grazed.—Managed disturbance as livestock are on this pasture for a few days then moved to other pastures in the rotation.

Cover Crop.—Low disturbance through continuous no-till.

No-Till.—Low disturbance through continuous no-till.

Conventional Tillage.—High disturbance from several tillage passes per year.

Principle 2: Maximize Soil Cover

Continuous Grazed or Dedicated Hayland.—Minimal cover from livestock grazing too much of the vegetation and insufficient plant recovery between grazing events.

Rotational Grazed.—Maximum cover as plants can recover before being re-grazed.

Cover Crop.—Maximum cover from a living canopy cover.

No-Till.—Maximum cover with lots of residue covering the soil.

Conventional Tillage.—Zero cover with no crop residue or living plant to cover the soil.

Principle 3: Maximize Biodiversity

Continuous Grazed or Dedicated Hayland.—No diversity with just one or two species of plants in pasture.

Rotational Grazed.—High diversity with several different plant species as well as livestock.

Cover Crop.—High diversity with multiple different cash crops from multiple functional groups plus a cover crop mix to make up for the missing functional groups in the rotation.

No-Till.—Minimum diversity with only two cash crops.

Conventional Tillage.—Same as no-till tray.

Principle 4: Maximize Presence of Living Roots

Continuous Grazed or Dedicated Hayland.—Minimal living roots with roots that are very short from being grazed severely with insufficient time for plant recovery.

Rotational Grazed.—Maximum living roots with fibrous and tap-rooted perennials in the soil year-round.

Cover Crop.—Maximum living roots with plants growing during non-cash crop growing periods that have diverse rooting types and depths.

No-Till.—Minimal living roots from monoculture cash crop that is growing for at most one-third of the year.

Conventional Tillage.—Same as no-till tray.

Table 1: Adherence to Soil Health Principle.

Type of Management	Minimize Soil Disturbance	Maximize Soil Cover	Maximize Biodiversity	Maximize Presence of Living Roots
Continuous grazed pasture or dedicated hayland				
Rotational grazed pasture	✓	✓	✓	✓
Cover crop	✓	✓	✓	✓
No-till	✓	✓		
Conventional tillage				

Optional Discussion on Soil Temperature

- While the rainfall simulator shows how different types of management affect the water cycle, management can greatly impact the temperature dynamics of a field.
- Where there is little to no soil cover, soil temperatures can often increase beyond the air temperature.
- As soil temperatures become excessive, plants and soils are negatively affected.
- What are some of those negative effects? On the plant or crop side:
  - Increased moisture loss within the plant (transpiration)
  - Plants stop taking in CO_2
  - Reduction in photosynthesis
  - Reduction in plant growth
  - Longer crop maturity times
  - Nitrates accumulate resulting in nitrate toxicity if plants are used as a feed source
- Negative effects on the soil:
  - Increased loss of moisture from soil surface (evaporation)
  - Reduced soil biological activity
  - Reduced mineralization/nutrient cycling
  - Fewer plant-available nutrients

Soil, Nutrients and Water-Holding Capacity Loss

- A dime, the thinnest of all U.S. coinage is about 1/20th of an inch (0.053 inches) thick.
- How much soil is lost when a dime's thickness erodes from a bare, tilled field? 6.6 to 9.6 tons per acre (clayey soils would be at the low end and sandy soils would be at the high end of the range)
- In most demonstrations, the thickness of one dime has eroded, sometimes two dimes. If the dime is buried by soil upslope, then compare the thickness of the soil over the dime to a dime's thickness.
- The quad-axle dump truck (four axles underneath the dump body) on the last page can haul 22.5 tons (45,000 pounds) of soil. With 6.6 to 9.6 tons per acre of soil coming off a freshly tilled, bare soil, a dump truck is filled every 2.3 to 3.4 acres or 29 to 43 dump trucks every 100 acres.
- Besides the loss of sand, silt and clay particles, what else is lost? Anything attached to soil such as nutrients, pesticides/herbicides, manure, slurry, etc.
- How much would it cost to purchase the lost nutrients if soil organic matter is 3 percent? Between $26 and $27 per acre
- How much available water-holding capacity was removed when a dime's thickness eroded away? Over 300 gallons per acre
- On a 100-acre field that would be over 30,000 gallons of water that could not be used for crop growth.

Conclusion

While the message of soil erosion and degradation of the water and nutrient cycles is not positive, we know how to reverse this process by following the principles of soil health. These principles work anywhere on the planet.

- Minimize soil disturbance
- Maximize soil cover
- Maximize biodiversity (including plants and livestock integration where possible)
- Maximize presence of living roots

Potential Questions

1. *I farm where depth to fractured bedrock is very close to the soil surface. Underneath the fractured bedrock is an aquifer that is contaminated with nutrients. If water infiltration is increased from using soil health improvement practices like no-till and cover crops, nutrients applied to the field will also infiltrate easier, passing through the fractured bedrock and cause greater contamination of the aquifer. Won't the improved infiltration be a detriment then?*

There are four important things to keep in mind in answering this question.

Let's first discuss the difference between infiltration in a healthy soil and preferential flow in an unhealthy soil. Unhealthy soils have poor soil aggregation meaning that they don't have that nice crumbly structure that is characteristic of healthy soils. Rather, the unhealthy soils usually are more cloddy where the soil comes out in large chunks, has less pore space and is subject to crusting, erosion and runoff. When these soils dry out, they shrink somewhat causing them to crack. These cracks are now channels for any liquid whether water or slurry to easily bypass the soil and reach the fractured bedrock. The unhealthy soil in this instance does not really absorb any of the liquid, but instead becomes a solid mass that repels any liquid from entering it except where the cracks were created from shrinking – this is preferential flow. As soil structure begins to improve with the formation of more water-stable aggregates, under non-saturated conditions where there is plenty of pore space, any liquid applied to the surface doesn't just go straight down. Rather, the liquid applied also moves horizontally through interconnected pores as it moves through the soil profile where it can be metabolized by more soil life. This phenomenon is observed simply by placing a drop of water on the soil surface and watching the saturated area spread out beyond the spot where the water made impact. That is why soil is typically pre-wetted prior to evaluating water infiltration.

Secondly, different cover crop species have different root types. Tap roots are larger diameter roots that grow vertically and are effective at penetrating plow pans. Fibrous roots are smaller diameter roots that grow laterally and vertically and are effective at improving soil structure. Integrating cover crop species with more fibrous rooting architectures like the grasses can greatly reduce off-season nutrient losses.

Thirdly, the concentration of soil life around a root hair is thousands of times greater than it is anywhere else in the soil. Thus, the more living roots there are in the soil going in all different directions, not just straight down, the more soil life can potentially metabolize (digest) the nutrients applied to the field as long as nutrients are not applied in excess of what the current population of soil organisms can metabolize. As the soil life digest the nutrients being applied, they immobilize (tie up) those nutrients in their bodies so they are not readily leachable. The fewer the soil organisms there are in the soil, the less liquid nutrients that can be metabolized without allowing unmetabolized nutrients to escape beyond where soil life is concentrated.

And fourthly, since the trays of the rainfall simulator are only 2-1/2 inches deep, there is a limited amount of pore space to absorb water and liquid nutrients. This means that some of the infiltration jugs may be quite full after running the simulation giving the perception that those soils will not absorb a significant amount of dissolved nutrients. However, healthier soils in a field setting that are deeper than the simulator trays will have that much more added pore space to absorb and prevent nutrients from leaching through the soil profile.

2. *If water infiltration is increased from using soil health improvement practices like no-till and cover crops, nutrients applied to the field will also infiltrate easier, passing through the soil and end up in the tile line. Won't the improved infiltration be a detriment then?*

Refer to explanation from question 1.

3. *I've heard that cover crop roots will plug up tile lines. Why would I want to plant them if that's true?*

This can happen when the weather conditions are favorable for cover crop growth such as a rainy period followed by a prolonged dry period and a mild winter. So, it is advisable to have an early termination strategy. Additionally, there are things that can be done if it is suspected that the roots are from a cover crop and not from the cash crop, trees or weeds:

- Alternating shallow-rooting covers with deep-rooting covers
- Terminating cover crop earlier in spring
- Alternating winter-kill covers with those that overwinter
- For new drainage system installations, avoid seeding the cover crop immediately over the new tile trench for the first year while the soil is quite loose

For more information, see the Purdue University Extension publication: Agricultural Tile Drains Clogged with Cover Crop Roots?

Calculations for Soil, Nutrients and Water-Holding Capacity Loss

Tons of soil per acre in a dime's thickness:

Dime thickness = 0.053 inches (0.053 in ÷ 12 in/ft) × 43,560 ft^2/ac = 192.39 ft^3/ac

Bulk density of soils: 1.1 g/cm^3 - clay, 1.33 g/cm^3 - silt loam, 1.6 g/cm^3 - sand

Multiplication factor to convert g/cm^3 to lbs/ft^3 = 62.427960841

1.1 g/cm^3 × 62.427960841 = 68.67 lbs/ft^3 1.33 g/cm^3 × 62.427960841 = 83.03 lbs/ft^3

1.6 g/cm^3 × 62.427960841 = 99.88 lbs/ft^3

68.67 lbs/ft^3 × 192.39 ft^3/ac = 13,211 lbs/ac 83.03 lbs/ft^3 × 192.39 ft^3/ac = 15,974 lbs/ac

99.88 lbs/ft^3 × 192.39 ft^3/ac = 19,217 lbs/ac

13,211 lbs/ac ÷ 2,000 lbs/ton = **6.6 tons/ac** 19,217 lbs/ac ÷ 2,000 lbs/ton = **9.6 tons/ac**

Converted to acres per dump truck load:

73,000 lbs (max truck wt) – 28,000 lbs (empty truck wt) = 45,000 lbs (available payload)

45,000 lbs ÷ 13,211 lbs/ac = **3.4 ac (sand)** 45,000 lbs ÷ 19,217 lbs/ac = **2.3 ac (clay)**

Converted to dump truck loads per 100 acres:

100 ac ÷ 3.4 ac/dump truck load = **29 (sand)** 100 ac ÷ 2.3 ac/dump truck load = **43 (clay)**

Note: Standard dump truck weights vary throughout the country. Use dump truck weights and photos for trucks that are common in your area.

<u>Soil Organic Matter</u>

Tons per acre of soil in a dime's thickness for a silt loam soil = 15,974 lbs/ac

Weight of 3 percent soil organic matter: 15,974 lbs/ac x 0.03 = 479 lbs/ac

Carbon

58% of soil organic matter is carbon

Weight of Carbon: 479 lbs/ac x 0.58 = 277.9 lbs/ac

Corn stalk round bales costs $30/bale 5 ft x 6 ft bale weighs 1,100 lbs

1,100 lbs/bale × 58% C = 638 lbs C/bale $30/bale ÷ 638 lbs C/bale = $0.047/lb of C

$0.047/lb of C × 277.9 lbs of C/ac = **$13.06/ac**

Nitrogen

5.8% of soil organic matter is nitrogen

Weight of Nitrogen: 479 lbs/ac x 0.058 = 27.8 lbs/ac

UAN 28% costs $214/ton* 2,000 lbs. of UAN × 28% N = 560 lbs N/ton of UAN

$214/ton ÷ 560 lbs N/ton of UAN = $0.38/lb. of N

$0.38/lb of N × 27.8 lbs of N/ac = **$10.56/ac**

Phosphorus

0.58% of soil organic matter is phosphorus

Weight of Phosphorus: 479 lbs/ac x 0.0058 = 2.8 lbs/ac

Diammonium Phosphate (DAP) costs $409/ton* 2,000 lbs of DAP × 46% P = 920 lbs P/ton of DAP

$409/ton ÷ 920 lbs P/ton of DAP = $0.44/lb of P $0.44/lb of P × 2.8 lbs P/ac = **$1.22/ac**

Potassium

Silt loam soil with a CEC of 20 cmol/kg 4% of CEC contains potassium (K)

$$\frac{20\ cmol \times 0.04\ cmol\ K \times 1\ kg\ soil \times 39\ g\ K \times 1\ lb\ K}{1\ kg\ soil \times 1\ cmol \times 2.2\ lbs\ soil \times 100\ cmol\ K \times 454\ g\ K} = 0.00031\ lbs\ K\ per\ 1\ lb\ of\ soil$$

Mineral fraction of soil (no soil organic matter): 15,974 lbs/ac x 0.97 =15,495 lbs/ac

Mass of Potassium: 15,495 lbs/ac x 0.00031 lbs K/1 lb of soil = 4.8 lbs/ac

Potash costs $329/ton* 2,000 lbs of Potash × 60% K = 1,200 lbs K/ton of Potash

$329/ton ÷ 1,200 lbs K/ton of Potash = $0.27/lb of K $0.27/lb of K × 4.8 lbs K/ac = **$1.30/ac**.

Sulfur

0.22% of soil organic matter is sulfur

Weight of Sulfur: 479 lbs/ac x 0.0022 = 1.1 lbs/ac

Elemental Sulfur (ES) costs $900/ton* 2,000 lbs of ES × 90% = 1,800 lbs S/ton of ES

$900/ton ÷ 1,800 lbs S/ton of ES = $0.50/lb of S $0.50/lb of S × 1.1 lbs S/ac = **$0.53/ac**

*Prices for semi-load quantities obtained from local supplier on February 2020. Contact local supplier for current prices.

Water

For a silt loam soil at 3 percent organic matter, field capacity is 0.33 cubic feet per 1 cubic feet of soil and the permanent wilting point is 0.12 cubic feet per 1-cubic foot of soil. The difference between these two numbers is the available water-holding capacity.

$$AWC = 0.33\ cu\ ft - 0.12\ cu\ ft = 0.21\ cu\ ft$$

$$\frac{0.21\ cu\ ft \times 43{,}560\ cu\ ft\ of\ soil \times 7.48\ gal}{1\ cu\ ft\ of\ soil \times 1\ ac \times 1\ cu\ ft} = 68{,}424\ gal/ac$$

$$\frac{68{,}424\ gal/ac}{12\ in} = \frac{x\ gal/ac}{0.053\ in}$$

$$\boldsymbol{x = 302\ gal/ac\ or\ 30{,}200\ gal/100\ ac}$$

Full-Scale Rainfall Simulator Instructor Quick Guide

Discussion Before Rainfall Simulation

- Soil health is the continued capacity of a soil **to function** as a vital, **living ecosystem** that sustains plants, animals and humans.
- Soil is a living ecosystem comprised of virtually innumerable organisms ranging from earthworms to fungi and bacteria that directly affect how the soil functions.
- What are some key soil functions? Answers can include growing a crop, feed, or fiber, infiltrating and holding water, etc.
- One of the most important soil functions is the ability to take in water (infiltrate).
- To see this function in action, the slake/aggregate stability demo shows how soils under opposing styles of management behave when completely submerged in water.
- Let's see aggregate stability demonstrated further using the rainfall simulator.
- Briefly explain the simulator and how it functions including how the sample tray and catch pan work to allow water to go into either an infiltration or runoff jug.
- Each tray will receive about 1-inch of water.
- Explain the management for each sample tray.
- Push a dime into the highly disturbed tray so that only the face of it is exposed.
- Turn on oscillating nozzle first, then the water.

Discussion During Rainfall Simulation

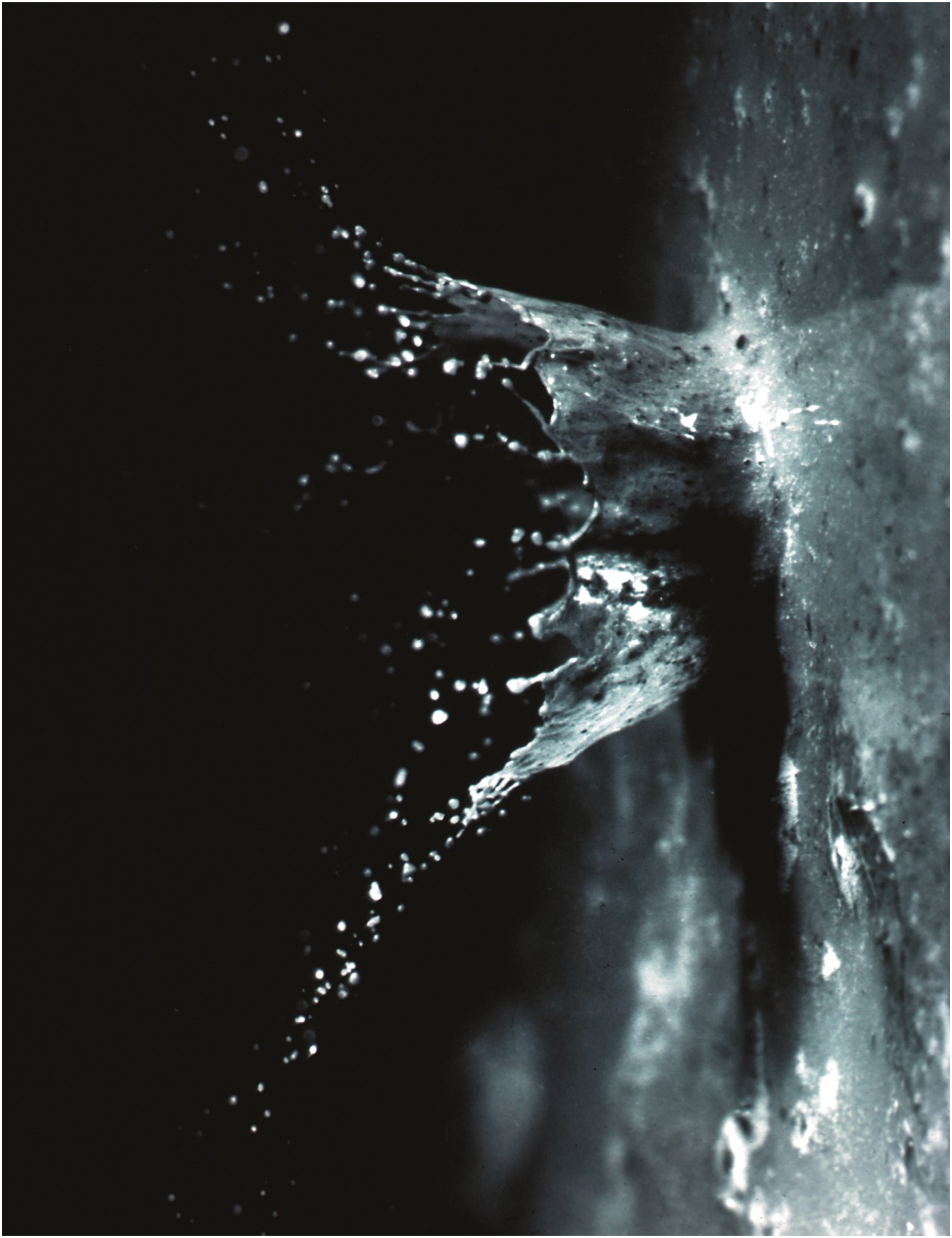
- Rain drop velocity during an intense thunderstorm is around 20 mph.
- The steps of erosion are detachment, transport then deposition. How far do you think soil particles can move? Two feet vertically and five feet horizontally (show photo of raindrop impact).
- More importantly, surface aggregates can dissolve into smaller soil particles that can move straight down in the pore space from 1/4 to 3/4 of an inch.
- Soil particles that detach and land back on the tray or dissolve and move down fill up the remaining surface pores, preventing additional water from infiltrating.
- A crust forms within just a few minutes that prevents water and air from getting into the soil AND carbon dioxide from getting out of the soil. The soil becomes anaerobic leading to denitrification.
- Are there any differences between how water is interacting with these samples and why?
- Look at the backsplash behind the highly disturbed tray. What is on the backsplash?
- As the runoff jugs are beginning to take water from the highly disturbed trays, draw attention to not only the volume, but also the cloudiness of the water.

Discussion After Rainfall Simulation

- Pull the infiltration jugs out one at a time and discuss what happened with each jug. Place them in front of the respective runoff jugs so the audience can more easily compare results.
- How much soil loss occurred around the dime of the most highly disturbed sample? Point out how the whole surface has eroded and lack of well-formed aggregates. Once people see how much

eroded, remove the dime and flip the tray onto a tarp to reveal the dry soil in the lower portions of the pan.

- Dig into the dry soil and pick it up so that it falls through your fingers to maximize the impact of how little the water infiltrated.
- One of the most important natural cycles on our planet is the water cycle.
- A resilient cropping system depends on soil with good infiltration and the ability to supply water throughout the season.
- Single most limiting factor to yield globally is lack of water. Photosynthesis requires water.
- One of the most important soil functions is the capacity of a soil to take in water (infiltrate) while keeping sand, silt and clay particles tied together or aggregated.
- Point to and discuss differences in runoff and infiltration between the various samples while relating the differences to the functionality of the water cycle.
- Which sample(s) are holding the most water? Generally, the rotated and well-recovered pasture holds the most water as it is the lightest sample with the most pore space.
- What are some things that influence how water is interacting with each sample? Amount and type of surface cover, amount of past soil disturbance, stability of surface aggregates and amount of roots/root channels.
- What influences all three of these characteristics? **Management**
- To improve soil function which includes the water cycle, we need to know and implement all four principles of soil health.
- Take each principle one-by-one and explain whether that principle was adhered to or not.
- A dime’s thickness of soil loss on 1-acre is **6.6 to 9.6 tons**, enough soil to fill up a quad-axle dump truck (22.5 tons) **every 2.3 to 3.4 acres**. (show photo of dump truck)
- What else went with the soil that eroded?
- Nutrients (OM, N, P, K, S) costing between **$26 and $27/acre**.
- Water storage capacity: **302 gal/ac or over 30,000 gal/100 ac**.
- Anything else attached to soil particles: pesticides/herbicides, manure, slurry
- While the message of soil erosion and degradation of the water and nutrient cycles is not positive, we know how to reverse this process by following the principles of soil health. These principles work anywhere on the planet.
- Reemphasize the soil health principles.




A dime’s thickness of soil loss fills this truck every 2.3 – 3.4 acres!
22.5 Ton Capacity
650049