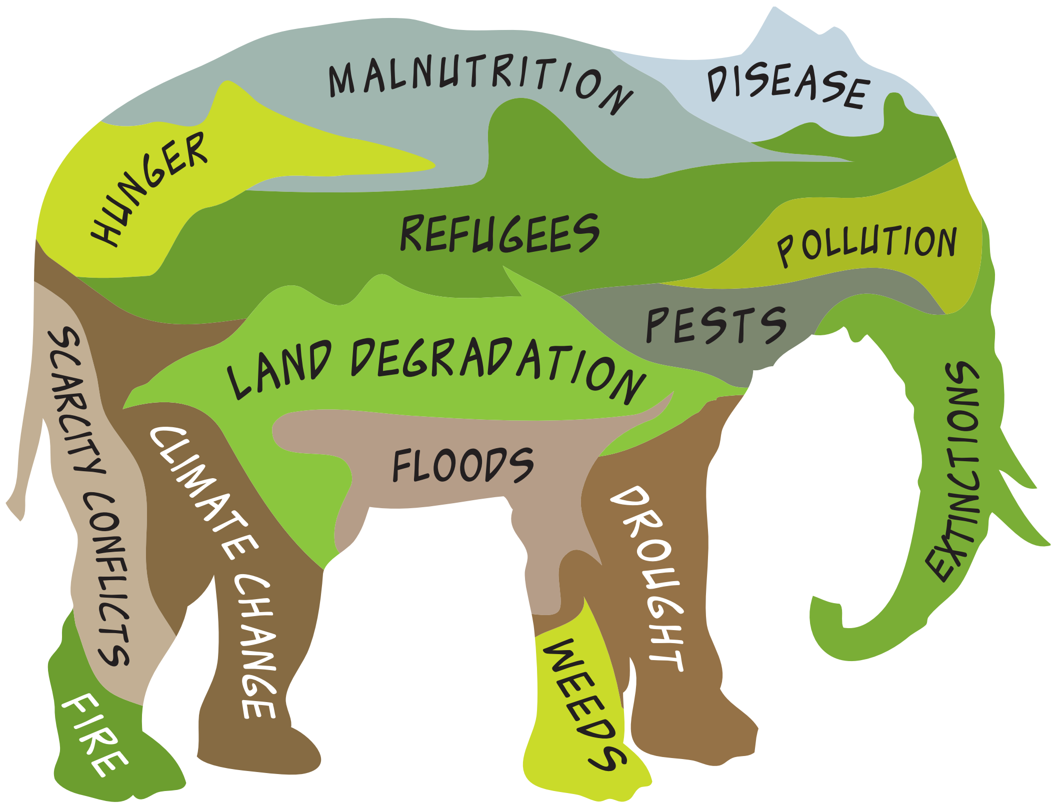
Some field methods for soil health and watershed function



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version: November 2016

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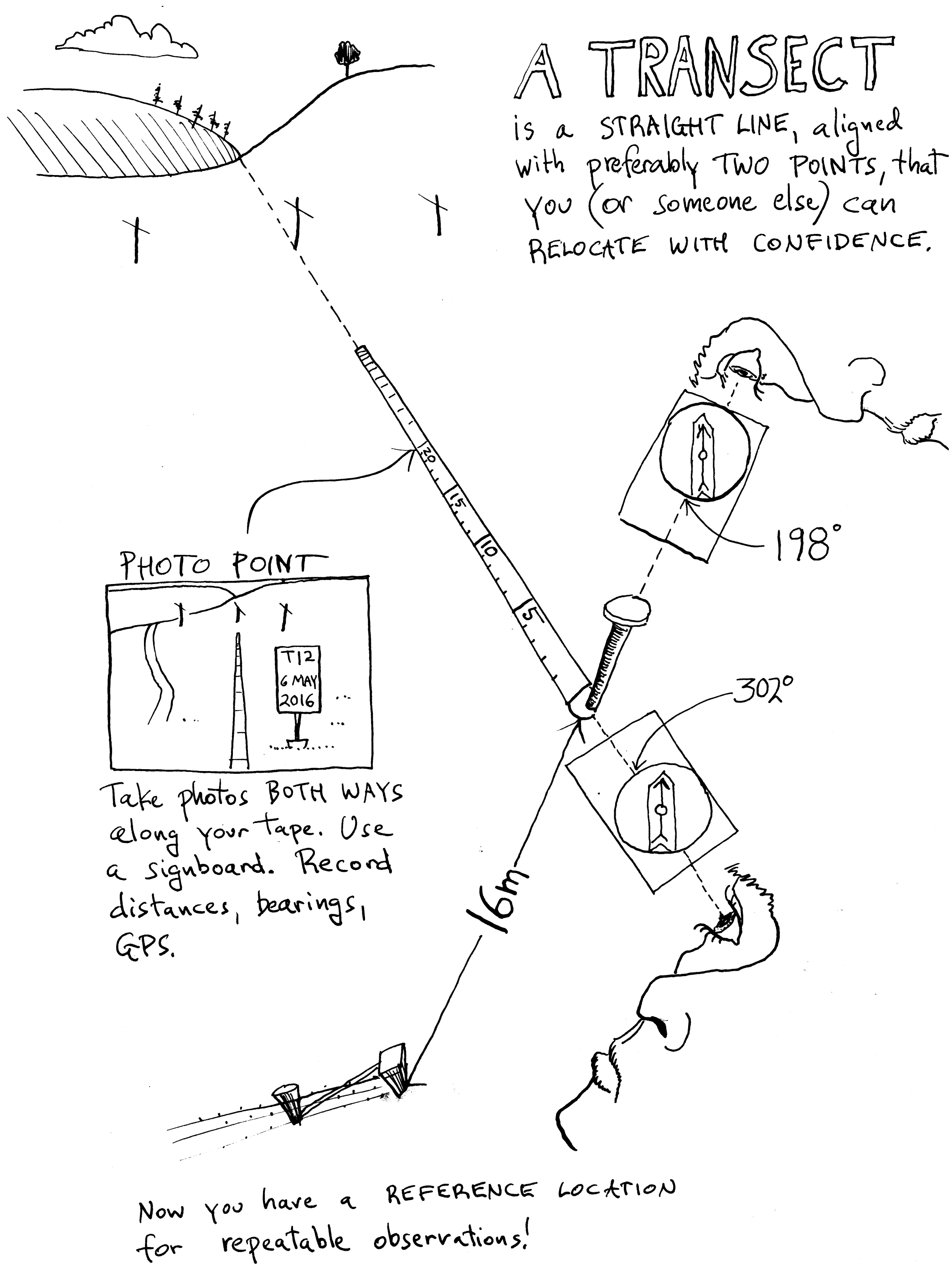

A TRANSECT
is a STRAIGHT LINE, aligned with preferably TWO POINTS, that you (or someone else) can RELOCATE WITH CONFIDENCE.
20
15
10
5
198°
302°
PHOTO POINT
T12
6 MAY
2016
Take photos BOTH WAYS along your tape. Use a signboard. Record distances, bearings, GPS.
16m
Now you have a REFERENCE LOCATION for repeatable observations!

> Are the observations you are making repeatable, with accuracy? Try to imagine repeating the observation you are making now, several years into the future, using the notes and data that you are recording.
>
> What are the sources of inaccuracy or error in your measurements and observations, and how can you address them? How confident are you that what you are recording can be re-observed with accuracy so as to detect change (or the absence of change)?

What we observe is not nature in itself, but nature exposed to our method of questioning.

Werner Heisenberg

Arthur Eddington, the British astronomer whose observations in 1919 during a solar eclipse gave confirmation to Einstein's general relativity theory, described a common scientific approach as casting a net into the ocean, and making an inventory of the catch. The scientist concludes that no sea-creature is less than two inches long, and that all sea-creatures have gills.

This guide is by no means exhaustive or definitive. There are many ways of tracking change over time on landscape function and biological work, with new understandings, new possibilities and techniques emerging all the time.

We can make observations on landscape function at **different scales**, ranging from a single point on a landscape, to a field, to a watershed, to an entire continent or planet. Observations at the point or small-area scale can add value and context to observations made at larger scales, and vice versa. The first few chapters in this section describe point or small-area field methods, and later chapters will describe larger-scale observations such as streamflow, remote sensing of photosynthesis and soil cover, and harvest.

Point observations can be highly particular, with all the advantages of detailed attention to observable features and changes. Point observations highlight the variability from place to place, reflecting more localized factors, and sometimes may be the only choice. However, limitations of time and resources usually guarantee a small sample size in relation to the overall land, and it is often difficult to make reliable conclusions about large areas from small sample sizes.

Observations over larger areas, such as the variability of streamflow with precipitation, are summations of many small-area processes. They may not reflect the variability of these smaller-scale processes. So where possible, it is best to do some small-scale and large-scale observations. They will complement each other.

The field procedures described here have all been tested, but revisions and improvements are ongoing. Check `http://soilcarboncoalition.org/guide` for the latest downloadable versions, as well as links to mobile apps for collecting data.

The following chapters outline some methods of observing and recording data on

atlasbiowork.com

`https://atlasbiowork.com` is a flexible and simple browser-based data-entry app that works on mobile devices such as smartphones and tablets, and laptop or desktop computers. When you upload your data, it becomes visible to others on a map.

It is usable in the field, and can be used without a network connection if you "Add to home screen" while on a network connection. When you again have network connectivity, you can upload your data to the atlasbiowork.com server, where it is viewable on a map. Development is ongoing, and as of this writing it is still a "web app" (browser-based), highly usable, and undergoing modifications and improvements.

The various forms available for data entry may be helpful as prompts or checklists as well.

landscape function and biological work. We start with establishing a reference location called a transect, and then describe some repeatable observations that depend on the transect for location, enabling the growth of a times series so as to learn what's possible and as feedback to management.

1

Site selection and location

Purpose

Accurately measuring change over time in a landscape (amidst variation in soils, management, vegetation, and weather) can be a challenging task. Good location is essential to repeatability of your measurements. An excellent and traditional way to designate and map fixed locations in a changing landscape is with a **transect**: a straight line across the surface of the earth, for example one determined by two points. This transect can be found again by using a sketch map, measuring tape, and compass, as long as you have chosen landmarks that are unlikely to change.

By itself, a transect may not be a useful observation, but it establishes a repeatable reference location or site for multiple types of observations over time—in particular, for soil sampling and analysis, and observations of soil cover in areas where perennial plants grow. It is also a good reference location for water infiltration measurements. If your observation plans include these, it is a good idea to start with a transect.

If your observations are going to be limited to earthworm counts, brix (sugar content), residue or soil cover in annual croplands, or if you are measuring change in a small space such as an urban backyard, a full transect may not be needed. For these, approximate location using a street address, description and/or hand drawn map, and latitude and longitude from common GPS receivers—such as those in many smartphones—may be good enough.

Selecting a location

The general location you select for a monitoring transect depends on your purpose. In measuring soil carbon change, for example, where the number of locations I am measuring is small (the usual situation) I try to locate a transect according to some or all of the following:

where a manager is interested in trying to enhance or grow soil carbon

where slope, aspect, and vegetation is representative of larger areas where soil series, or crop yield (some people have maps for both of these), is somewhat typical of larger areas

Unless you plan to have many sampling locations, you may wish to avoid areas that may receive atypical management or treatment, such as: edges of fields, where equipment turns around, fences, watering troughs, corrals, driveways, trails and heavily trafficked areas, pipeline corridors, or areas of rapid erosion or deposition of soil. You may also wish to avoid stream channels or gullies, ridgetops, or areas of uncharacteristic slope or aspect.

It is an excellent idea to do a short interview with the people who make management decisions on the land you are monitoring, and choose locations with them. With this interview, you can adapt your purpose, foresee and perhaps avoid practical difficulties, and gain insight into the history and context of the land and its management that you won't already have. While you're at it, note some of this down, and record some contact information for future use. Also check with the manager(s) to see if posting open data on your measurement results is OK with them.

How long is a transect? It depends on your purpose, the observations you intend to make, and the variability you encounter in the land. For a soil sampling plot only, a transect may need only be long enough to reach from a landmark or measuring point into an appropriate area for sampling. If you are establishing some repeatable soil cover observations in a perennial pasture with lots of variation, it may make sense to stretch your tape to its full length, or combine two or three tape lengths along the same line, to sample some of this variability. You can use one transect or line to cross field or pasture boundaries, and locate multiple observation sites along it.

Transect materials

- ☐ 200-foot (60-meter) open-reel fiberglass measuring tape (a shorter one may serve).
- ☐ Some means of pinning both ends of your tape to the ground. Foot-long (60p) nails will work, as will some tent pegs (with small hooks) or surveyor's chaining pins.
- ☐ Sighting compass. Compass apps in smartphones sometimes work well, but often get out of calibration. Be sure to set it to magnetic north. Try checking the accuracy of your smartphone compass with those of others!
- ☐ One handheld mobile device (smartphone) with a camera, and apps already downloaded for a GPS that shows latitude and longitude in decimal coordinates.
- ☐ Signboard for photos. Two 9 × 12-inch erasable whiteboards, hooked loosely together with wire ties through two holes on one edge, make an adaptable signboard that can be stood on the ground at a variety of angles, or hung over the D-handle of an upright shovel. A clipboard with paper and markers can be used in a pinch.

Warm-up exercise for learning groups

The best way to practice making sketch maps, and learn tape and compass skills, is to divide into small groups, go to different areas in a park or field (or even indoors) and practice drawing a map locating a specific point on the land, using a tape and compass.

One team then hands their map to another team and watches as they try to find the point. This will make it clear whether they have successfully defined landmarks, and mapped the transect (and the point along it) in a way that someone could find it in the future. For this exercise, it is helpful if there is some way of confirming the destination point in an open landscape, such as burying a small (natural or biodegradable, in case it's not found) object just below the surface. For example, a rock with an X written on it.

- ☐ Thick dark markers (erasable if using whiteboard, permanent if using paper) for marking signboard.
- ☐ (optional) Two or more 4-foot $\frac{3}{8}$-inch pointed fiberglass temporary electric fence posts are useful items when laying out a transect. I cut mine to 1 meter in length with a hacksaw, tape a brass cartridge over the end, and wrap the stick at intervals with black tape to make a handy, visible marker and **alignment stick** that can be pounded into hard ground with a hammer.
- ☐ "Rite in the Rain" all-weather notebook for drawing maps and recording data, and/or a notebook or paper on a clipboard

Landmarks, reference points, and markers

Each situation may suggest different ways of mapping and marking your transect. There are three basic strategies: 1) coordinates from GPS receiver and compass bearing, 2) lines of sight and landmarks, and 3) permanent markers. In order to find a transect several years after it has been recorded (perhaps by someone else), we recommend the first, plus the second or third. Using all three is best.

1. GPS coordinates and compass bearing

Use a GPS (global positioning system) receiver to record locations. Most smartphones and many tablet computers have these, some cameras do, and there are many types of handheld GPS receivers. For most smartphones and tablets, you will need some kind of app to get GPS coordinates. There are many of them, including our own `https://atlasbiowork.com` which will record location. Be sure to use latitude and longitude in

GPS. Most consumer-grade GPS receivers do not have accuracy better than about 20 feet or so. An interesting and revealing exercise for a group is for everyone to record coordinates at an easily identifiable point location such as a corner of a large building or a road intersection. Then enter these coordinates in an online mapping utility such as Google Earth, and see how far they differ. By yourself you can mark a spot in open land, record the location, go away several hundred yards, and try to find it again using only the GPS receiver.

It's a good idea to check your GPS record (and your hand-drawn map of a transect) against an online mapping utility such as Google Earth or Maps. Enter your recorded coordinates in the search box and see how it corresponds to your transect.

decimal degrees, which is the most popular and least ambiguous format for coordinates, and will give you a pair of numbers such as 41.39857, -82.23948 as your location, or the location of a landmark where you are standing.

2. Lines of sight and landmarks

Two points determine a line. An excellent way to fix and record the location of a transect line is to find a line of sight, a visual alignment, that connects two near-permanent landmarks or reference points. For example, can you find a line where a utility pole lines up with something more distant, such as a mountain peak, notch, steeple, or cell phone tower?

Good landmarks will be visible whether or not trees have leaves on them, when nearby trees have grown taller, or when a field may have 8-foot corn. Do not use trees (which grow, die, and fall over) or temporary buildings unless there are no alternatives. In some areas and seasons, low clouds and fog may often obscure distant features. These can make good landmarks:

- corners or peaks of permanent buildings, grain bins, or silos
- corners, centers, or edges of culverts, bridges, roads
- peaks, gaps, or saddles in ridgetops
- large boulders or rock formations with definable corners or points
- well-head covers, irrigation risers, water spigots
- utility poles
- cell phone towers, radio masts, permanent flagpoles
- treated fenceposts such as railroad ties, or steel posts in concrete

Large objects with defined edges from certain directions, such as the vertical side of a grain bin, rock formation, or road cut, or where one ridge disappears behind another, may be excellent landmarks and reference points but only when they are combined with another. The right-hand side of a silo, for example, depends on your angle of view.

A permanent rectangular building can sometimes supply two landmarks or reference points—two corners—if you line up with a side. Sometimes this alignment is easily visible, sometimes not. Check your alignment's sensitivity by stepping to one side and another.

3. Permanent markers

If there are no landmarks or lines of sight available, or if they are too far away to measure from with a tape, you should install your own in the form of permanent markers. Markers can also add good confidence to relocating the transect.

What markers you choose, and where you put them, will depend on the situation. You want something that:

- will remain in place, and can be found again
- is practical, durable, and easy to install
- does not pose a hazard to humans, animals or wildlife, or vehicle tires
- is compatible with management plans and tools, such as tillage, forage harvest, seeding, or even burning or wildfire

Check your choice of markers with the manager(s) of the land.

Markers are best placed at the ends of the transect, rather than at measurement locations or other midpoints, which can be relocated using the measuring tape. This is because markers, like landmarks, may influence soil changes locally. Livestock or game may use an upright post as a rub, concentrating hoof impact. Also, record the location of these markers with accuracy on your map, as they will be more difficult for future monitoring teams to find than visible landmarks.

In large pastures that aren't going to be drilled or tilled, heavy steel disk blades are very good, secured to the ground through the center hole with $\frac{3}{8}$-inch steel rebar, bent over so as not to be a hazard. A white plastic bucket lid, though it may not last more than a few years in full sun, is also a visible marker. It can be fastened to the ground with ring-shanked pole-barn nails, but won't last where wild pigs are common. In big open country, a bucket lid or disk blade can also be marked with a $\frac{3}{8}$-inch fiberglass post through the center, which might last years depending.

Lacking a disk, we recommend a 20–24-inch section of $\frac{3}{8}$-inch steel rebar with one end bent in a J or eye. This can be driven flush to the ground with a couple of feet of aluminum wire affixed at one end for easier relocation, or through a piece of an aluminum can. A heavy plastic stake driven almost flush to the ground is good where fire or mechanical disturbance won't occur. You may want to create signage that explains the reason for the marker—for example a piece of plastic saying "monitoring site landmark: do not remove" attached to the wire.

In cultivated fields a piece of steel such as rebar can be driven into the soil below the tillage layer, but this will then require a metal detector to relocate it. Steel that is at the surface can often be found, if your search area is small and vegetation is not high, by moving a magnetic compass over the area and watching for deflection.

Where a stake may be removed by agricultural machinery, it may also work to put a marker, or to improvise one, on a fenceline or tree row, and to extend the transect to it. Large stones or rock cairns are sometimes effective where machinery or animals won't scatter them.

Laying out your transect

1. Review your purpose. How does the general location you have selected meet that purpose?

2. What landmarks or reference points are available? Look for lines of sight that align near points with far ones, or a point in front of you with one behind.

3. Choose your zero point, a spot to start measuring from. If one landmark is within 150 feet of the plot (or within easy walking distance so that you can accurately stretch the tape out several times), then designate that landmark as your "0" (zero) point to start measuring from. Write it down, e.g.: "Point 0 = north side of well-head." (If neither landmark is near you, you will select a zero point from the choices in the "Lining up a transect" diagram.)

4. Secure the zero end of the tape to the ground with a stake or pin.

5. Walk out towards the second landmark, or compass direction, unrolling the tape, past the spot(s) where you may want to take measurements of soil, soil cover, or infiltration.

6. Stretch the tape between the two ends so that it is flat, and being sure that it is aligned exactly with your chosen landmarks. (Having two or three people working together on this to stand back and tell you when it is aligned is useful, but with alignment sticks you can also do this solo.)

7. Secure the far end of the tape into the ground by driving a tent peg through the handle, being sure it is stretched straight. In windy conditions, keeping the tape on the ground or touching plants can help keep your tape straight.

8. Decide where along the tape your photo point will be. Take a compass reading along the transect line, **away from the zero point**, and write it down.

9. Begin to draw your map, using a straightish line for the transect, with the zero point clearly indicated. It is conventional to orient your transect map so that north is at the top. If your compass bearing is 180 degrees, for example, your zero point will be at the top, and the transect line will run straight down the page. Add the photo point and its distance from zero, such as "30 meters."

Example line photo along a transect from a photo point. The axis of the center pivot sprinkler (center of photo) lines up with the tip of Mt. Shasta. If this volcano doesn't blow its top, this transect can be relocated within inches without GPS.

10. While standing at the photo point, take a GPS reading, using decimal degrees to five places, (e.g. 45.62020, -117.77186).

11. Choose a name for the transect. For example, the first transect at Hartford School could be named something like HART1.

12. Write a sign, using a thick marker that will show up in a photo. (An erasable white board is useful here so that you can add and change other labels for other photos and measurements). The sign should include today's date, and the transect name or identifier.

13. While straddling the tape at the photo point, take a photograph along the transect tape from the photo point toward the zero point—with someone holding the sign so that the tape, the sign and your line of sight is visible. (If you are alone you can prop the sign against a shovel or hang it from the shovel handle.) Shoot from eye

level. Get a little sky in the frame, but not too much. Shoot straight along the tape, which should divide your photo into two equal halves.

14. Take another photograph along the tape in the opposite direction, also showing your signboard

15. If your landmarks are distant and hard to see on a photo with a wide-angle view, zoom in and take another. You may also wish to take a photo along auxiliary lines of sight (with three- and four-point alignments, as in the "Lining up a transect" diagram.)

16. **Add some more detail to your map** showing:

    a) Which way North is on the map (most expect that North will be toward the top)

    b) The landmarks or permanent markers that you are sighting between. Be sure to describe what the marker is made of (such as metal rod, wooden railroad tie, large stone, cement well-head cover)

    c) The zero point

    d) Name and rough drawings of one or two other notable features nearby (Connecticut River, Route 5, blueberry shed, telephone pole etc.)

    e) The transect line, with compass bearing

    f) The photo point, and how many feet or meters it is from point zero

    g) The GPS location of the photo point

    h) Today's date

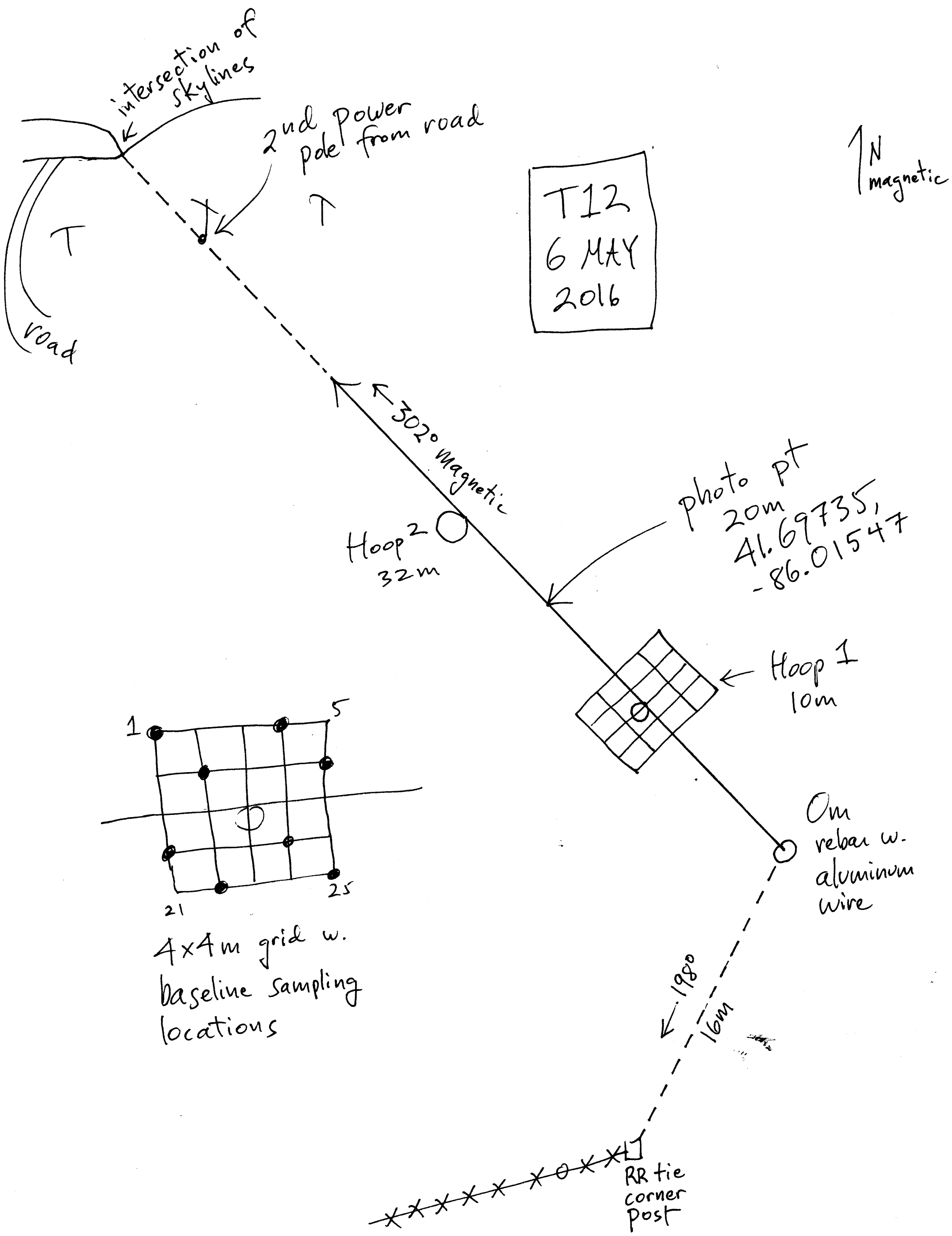
    i) The name and physical address of the general location (i.e. the name of the school, farm, etc.)

    j) A description of the area around the plot ("horse pasture" "baseball field," "school garden" "front lawn")

    k) The name you have chosen for the plot (e.g. "MASC1" or "HART3")

17. Record anything you know about the history of the land, how it has been managed in the past (with approximate dates) and how it is currently being managed. For example:

    > 1985–2012: maintained as school lawn, using commercial herbicides and fertilizers. Mowed once a week. 2012 turned into school garden and started planting diverse vegetable crops until present. 2012–2014: rototilled once a year, adding composted manure from Vaughn Farms each spring. No-till from May 2014 to present. Compost tea made according to Soil Food Web standards added May 2015. Currently no-till diverse vegetable garden using organic methods. See attached document for details of planting and management.



A sample sketchmap of a transect, with a soil sampling grid and soil cover hoops indicated.

18. Leave your stretched tape in place, and don't trip over it. It is now the reference location for subsequent observations.

19. Before you roll up your tape and leave the site, a) install any permanent markers you have decided on, and b) complete any auxiliary measurements and compass bearings to other landmarks or reference points, and add these to your map. Use the checklist below.

Checklist: recording your data

- ☐ Contact person with phone, physical address, and email
- ☐ Details of land management history and current practices
- ☐ Today's date
- ☐ Name or identifier of transect
- ☐ GPS coordinates
- ☐ Compass reading along transect
- ☐ Line photos of transect
- ☐ Hand-drawn map of alignments, distances, bearings, locations, and landmarks
- ☐ Complete any measurements such as soil sampling, soil cover, infiltration, and record locations on your sketchmap
- ☐ Install permanent markers if needed
- ☐ Finish and record distances and bearings to nearby landmarks

2

Using the observation hoop to track surface changes

Purpose

We use photographs and written notes about what we see within an "observation hoop" to track changes over time—in plant diversity, amount of bare ground, and other observations that can be seen without disturbing the soil—on a single spot on the land. This is an essential step in monitoring the health and function of grasslands and grassy areas such as lawns, hayfields, pastures, etc. (and can be useful even in regularly tilled ground).

When

If you are using a transect, this is typically the second step after setting up a transect. The first hoop observations are typically done at the side of the spot on the tape that will become the center of your 4×4-meter grid for soil sampling.

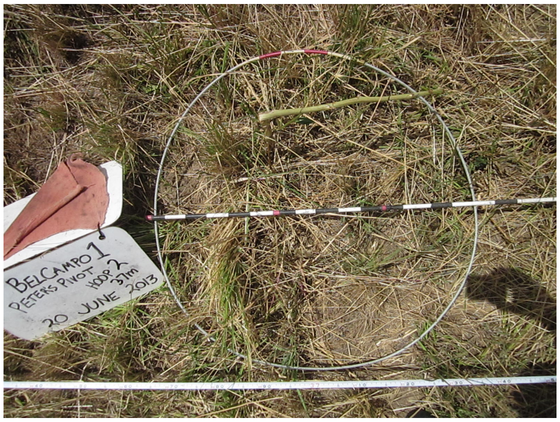
One or more sets of hoop observations can be done elsewhere along the transect tape—typically at spots that show something different than the first hoop, but which are still representative of the overall ground cover (such as above average, average, below average).

At the Soil Carbon Coalition, we've learned some of our methods from rangeland monitoring techniques such as Land EKG or the "Bullseye!" method.[1]

Materials

- ☐ 94" circumference hoop (a 94" section of plastic covered $\frac{3}{16}$-inch wire works best. If the ends are not secured, you can simply shape it into a circle).

[1] These methods were developed primarily for rangelands in the Intermountain West, but have some adaptability. For Land EKG, see `http://landekg.com`. For "Bullseye!", see `http://quiviracoalition.org/images/pdfs/1634-Monitoring_the_Resilient_Ranch_Presentation.pdf`



☐ Mobile device or smartphone with a digital camera and a GPS app already downloaded.

☐ Clipboard

☐ Pencil

☐ Notebook ("Rite-in-the-Rain" paper is great) and mobile data app: `https://atlasbiowork.com`

☐ Plastic bag to cover your phone and/or paper.

If you are using the hoop as part of a transect (which we recommend) please start with that section of this guide—being sure to draw a map, and record GPS readings and your location along the tape for the photo point of the transect.

Photographing the hoop and the sign

- Place the observation hoop on the ground (on the southern side of the tape if possible) so that one edge touches the tape. Make sure that the ends of the hoop (or wire) are touching to form a complete circle, and that the circle is round, not oval.

- Write a sign saying the date, the transect name ("CEDA-1") and the location in feet or meters away from the zero point on the tape. (Make sure you identify your units!) If it is the plot center, write "plot center," as well as the location in feet or meters.

- Place the sign on one side of it, and take two photographs of the hoop. a) One photograph, looking straight down at the hoop, that includes the sign. b) Step back a few paces and take a photograph of the hoop at an angle that includes the hoop, the sign, and the horizon. Get a little sky in the frame, but not too much.

Recording observations

1. Using your hand, calculate the percentage of bare soil that you can see within the hoop. (The following percentages correspond to an average adult hand. You can adjust accordingly if small children are doing the measuring.)

    a) Whole hand with fingers at maximum spread= 6%

    b) Whole hand with fingers not spread = 4%

    c) Bottom of fist = 1%

    d) Thumbprint = $\frac{1}{3}$%

    Add up the percentages of bare soil, and record the result. In perennial pastures, record percentages of other definable covers, using subtraction if convenient, such as litter, moss or algae, rock, or plant base.

2. How many centimeters of dead and decaying plant material ("litter") do you see on the soil surface?

3. Does the soil surface appear to be sealed off from rain, or can see you open pores?

4. How many different grass species? If you know names of species, write them down too. Otherwise just count the numbers of different types.

5. How many different broad-leafed plants ("forbs")?

6. How many shrubs or shrub-like plants?

7. How many different tree saplings?

8. Are there mounded clumps of grass that seem to be part alive and part dead?

9. Any of the following: moss, mold, lichen, mushrooms?

10. Do you see insects, spiders, worms, or signs of their activity?

11. What else do you notice about the soil surface?

Using a hoop without a transect

If you are just doing hoop observations, you will want to be sure to record a location in a way that you or someone else can reliably find this spot again, and record the following.

- ☐ Name of observer
- ☐ Today's date
- ☐ Name of plot

Extra activities

Move some of the plant litter aside and, using a 5x magnifying loupe, look at the soil surface. If you see any spider or insect activity, what work do they seem to be doing?

Using a 5–10x magnifying loupe, look carefully at a plant, flower, lichen, moss, or insect. Draw what you see. What else does it look like?

Why do you think it is shaped like that?

Using a field guide, see if you can identify the plants and insects you found in your observation hoop.

Do some research, and answer one or more of these questions:

- Do any of the plants you found have medicinal (or other special) uses?
- Are they edible? If so, what do they taste like?
- Are they wild plants or do you think someone planted them?
- What work do those plants do in this landscape?
- What does the presence of those plants tell you about the ecosystem you are observing? Where is it at in succession? What does it tell you about what is happening with the water cycle?
- What work do the insects you observed do in this landscape? What do they eat?
- Why do you think these things are living in this location? What might it tell you about the health of the soil and surrounding ecosystem?

If you have time, you can create a drawing of some or all of what you see. This might help you notice details.

☐ Contact person with phone, physical address, and email for plot

☐ GPS location of hoop, (with at least 5 numbers after the decimal, e.g. 45.62020, -117.77186 and accuracy "to 16 meters")

☐ Details of land management history and current practices.

3

Infiltration: How water moves into soil

Why

There are many ways and devices for measuring infiltration—the vertical movement of water into the soil's pores. What follows is one method, using simple equipment, that fosters **an increasing awareness of water cycle function for participants.** If you do this carefully and attentively, it can also furnish **a repeatable observation that might show change in soil structure and water cycle function.** Infiltration is not simulation of rainfall, which is varied, but when done consistently gives a good picture of **how soil accepts water,** reflecting the structure and stability of soil aggregates, and how well well larger pores stay open when water soaks the surface.

Infiltration often shows lots of variability: varying across short distances, with soil surface conditions, with soil moisture, and by season of the year and stages of plant growth, which influence pore and aggregate structure and activities of soil organisms. Measurements are probably best done when plants are well established and growing. If you make infiltration measurements at other times of year, it may be best to repeat them at approximately the same season—and this holds true for most indicators of landscape function and soil health, which can vary seasonally.

A good measurement may take an hour or two, but you will not be occupied the whole time, so it is easily combined with other observations at or near the same location.

For a short video on water infiltration, see `http://soilcarboncoalition.org/infiltration`

What you will need

- ☐ **infiltration rings:** 5 or more sections of metal pipe, mild steel is best, about 6 inches (15 cm) in diameter and about 6 inches long. These should be about $\frac{3}{32}$ inch (1.5 mm) in thickness, or about U.S. 12-gauge which is slightly more than a tenth of an inch in thickness. One edge should be beveled sharp at about 45 degrees with a grinder, and can be kept sharp with a file. You need a single reference point on the circumference of each ring for measuring drop in water level. A welded seam will serve, otherwise file a slight notch in the top edge.

For routinely soft soils, aluminum irrigation pipe works well, but steel is better for all-around use. In very soft soils a plastic 5-gallon bucket with the bottom cut off can substitute for several steel rings.

- ☐ **15 cm, 6-inch steel rule** with millimeter scale for measuring ring diameter, and depth to water surface

- ☐ **hammer or mallet** for driving rings into soil. A 4-pound deadblow hammer is best as these 6-inch rings can be hard to drive. A hand sledge also works well.

- ☐ **wood blocks** to place between hammer and rings for driving into soil, about $2 \times 6 \times 12$ inches is good. These may split or break so it's good to have replacements. Or, make a driver out of steel or very tough plastic.

- ☐ **water container** such as a 5-gallon collapsible jug for transporting water to the site. For five 6-inch rings, plan on having at least 3 gallons available.

- ☐ **mobile device** for recording data, getting location, and taking photos. You may use the infiltration form at `https://atlasbiowork.com` on a mobile device, which records timings as well as other data. If you are using a mobile device, it is also good to have backups: **auxiliary battery for mobile device, stopwatch, notebook, pencil.**

- ☐ **plastic bag or plastic wrap,** about 12 inches square, for protecting the soil surface from the pour of water from your measure

- ☐ **flat file** for sharpening beveled edge of infiltration rings

- ☐ **signboard** such as a pair of 9-inch by 12-inch whiteboards tied together at one edge, for labeling photos, along with dry-erase marker and a rag

- ☐ **some kind of measure** for 1 inch or 2.54 cm of water for your infiltration ring. A ring with an inside diameter of 6 inches will need about 15 ounces or 441 cubic centimeters (milliliters) of water. To calculate 1 inch or 2.54 cm of water for your ring, measure the inside diameter. Half the diameter is the radius r. The formula for the area of a circle is area = πr^2. The volume of water needed is the area multiplied by 1 inch or 2.54 cm.

  Metric example: a round section of pipe has an inside diameter of 14.8 centimeters. The radius is half that, 7.4 centimeters. Using the formula πr^2 we get $3.14159 \times 7.4 \times 7.4 \times 2.54 = 437$ cubic centimeters or milliliters. (1 fluid ounce = 29.6 milliliters.)

If you are measuring in inches, you will get cubic inches. For example, a pipe with a 6-inch inside diameter has a radius of 3 inches. $\pi r^2 = 28.3$ square inches, and the same in cubic inches when multiplied by our depth of 1 inch. Multiply cubic inches by .554 to get fluid ounces, thus our measure in this case should be 15.7 fluid ounces.

Using a measuring cup or graduated cylinder, pour that amount of water into a clear plastic bottle, set it on a flat surface, and mark the water level with an indelible marker, or cut the plastic bottle at the water surface. This will give you a measure of one inch of water for your ring. You may also use a can or other handy container with the correct volume.

☐ A serrated knife is always a good thing to have when working with soils that may be sodbound with abundant roots. In very heavy sod, it may be difficult to drive even a well-sharpened infiltration ring into the soil, which may just bounce with the blows. Cutting a slot in the sod, using the infiltration ring as a pattern and guide, may be needed.

How to do it

1. **Select a location.** This could be a fairly uniform area in terms of soil cover, vegetation, or management, or it might be a transition between these. It is best to place rings within a meter or two of each other to make it easier to watch them, and to record an observation for a small area.

2. **Place your rings on the ground, sharp edge down.** If rings are in an approximate line, such as along a transect tape, it is easier to keep track of the order and the timings. You may want to place rings on the variety of soil surfaces in the area that you have selected—such as bare soil, well-vegetated soil, average, and so on.

3. **Drive infiltration rings straight into soil** with your hammer and wooden block. In tougher soils and sods your rings must be sharp and you must swing that hammer in order to drive them in straight. Try to get them about halfway in (about 3 inches for a ring that is 6 inches in diameter and 6 inches long).

   You may firm the soil with your fingertips around the inside of the ring to take care of slight cracks from driving in the ring, but be careful not to disturb the rest of the soil surface, or the litter or mulch on it. In heavy vegetation it may be necessary to clip the vegetation in the ring area before driving in your rings.

4. **Place a plastic bag over the ring, push down the center enough to hold your inch of water, and pour in one measure (one inch) of water.** Slowly tug the plastic out from under the water and start your stopwatch. The purpose of the plastic is to

protect the soil surface from scouring by your pour, stirring up sediment which can then settle in and plug the soil pores.

5. **Time the disappearance of the first inch of water.** Record the amount of time (in minutes and seconds) it takes for the inch of water to infiltrate the soil. Stop timing when the surface is just glistening. If the soil surface is uneven or sloping inside the ring, stop timing when **half of the surface** is exposed and just glistening. When litter or heavy vegetation is present, use a pencil or similar object to push it aside so as to see whether there is standing water on the soil surface, or it is just glistening.

6. **Run an inch of water in the rest of your rings.** Unless the infiltration is very fast (under a minute or two), begin applying an inch of water to your other rings in order, using the `https://atlasbiowork.com` infiltration app to keep track of the timings. If using a stopwatch, start each ring at half- or one-minute intervals so you can use one stopwatch for all. For example ring 1 begins at 0:00, ring 2 begins at 1:00, ring 3 at 2:00, and so on. Just be sure you subtract the starting time from the finishing time for each ring in order to tally the elapsed time.

7. **Add subsequent inches of water.** After the first inch has finished using the half rule, add a second inch, recording the timing using the half rule, and a third and fourth inch similarly. The subsequent inches will generally take more time as more soil pores fill with water, and as pore space collapses. After several applications of an inch of water, most soils will tend to approach a fairly steady value, reflecting its ability to keep its pores open and take water in a saturated condition.

8. **Infiltration that doesn't slow down with subsequent inches.** If repeated applications of an inch of water do not result in slower timings, you may wish to "saturate" the soil in the ring with a generous dose of water, let it infiltrate, and try timing another inch or two.

9. **Recording the drop with the slow ones.** If the first or second inch is taking over 30 minutes, record the drop in water level in 30 minutes as follows: 1) Add another inch if needed, and measure and record the vertical distance in millimeters between the lip of the ring and the water surface, at the seam or notch in your ring. 2) Set a timer for 30 minutes. 3) After 30 minutes, remeasure this distance, and record the difference in millimeters.

Recording data

1. **Use the app.** Go to `https://atlasbiowork.com` which will enable you to enter data with a smartphone or computer, although we recommend having backup options in case your mobile device's battery dies. Data entered via the app will be public, open, and mapped.

Infiltration rings along a transect.

2. **Record the location** using GPS, and the approximate locations on a located transect if you are combining infiltration with other observations.

3. **Take a photo** that shows soil surface conditions and vegetation, using a signboard with site identifier and date.

4. **Describe the site:** its management, its vegetation and soil cover, its slope and aspect.

5. **Briefly describe the site of each ring** in terms of soil cover and vegetation, especially if they differ.

6. **Record timings** of each inch of water for each ring. If using paper, this is best done with a grid or table format, with a row for each ring, and a description of its soil surface, plus start/stop or elapsed timings for each inch of water in the columns across.

7. **Reflect and learn.** Do you see connections or correlations between the condition of the soil surface (crusting, litter cover, vegetation, arthropod activity, etc.), and the speed of infiltration? What might be the implications for runoff and surface water quality, groundwater or aquifer recharge, biodiversity both above and below

ground, or production of food and fiber? What about flooding and drought, or perceived drought? If this is a remeasurement, what is the trend, and how might that reflect management of this land?

Potential issues

If the **water goes down very quickly** (less than a minute) in one of your rings, and not nearly so fast in the others, it is likely that you have created a channel in the soil by rocking the ring back and forth as you pounded it into the ground. Or there may be a cavity such as a soil crack or animal hole under the ring. Note down the time, but also note that it seemed suspiciously fast. If you are only doing one or two rings, you might also want to redo that ring in another location.

In dry conditions, with shrink-swell or cracking clays, water may move in very fast through the cracks. If and when the cracks seal because the clay swells with water, the surface may become nearly impervious to water.

In very hard ground, such as dry, compacted hard clay, seriously rocky soils, or heavy sod, it may be difficult to drive rings halfway into the soil. In sod, cutting the sod with a serrated knife, using the infiltration ring as a guide, will help. Some soils may be difficult or impossible to test with these tools and methods. Do the best you can and note the fact that you haven't driven the rings very far in. Or come back when the soil is wetter and softer.

4

Sampling for soil carbon

Purpose

To extract relatively undisturbed samples of soil from distinct layers of the earth that can be tested for carbon (and other components, if desired). This should be done in a geo-located plot, so that results from that same area can be compared for gains or losses in carbon over time.

Related activities: Sampling for soil carbon should be done after setting up and mapping a transect, and photographing the observation hoop. Typically we also test water infiltration and bulk density at the same time.

Brief overview: After setting up a transect, lay out meter sticks to delineate a 4 × 4-meter grid. Lay out tarp nearby to create a workspace. Label your bags and soil containers. Take samples from predetermined spots on the grid, slicing each core into three or more samples (representing top, middle, and lower layers) and adding each sample into appropriate container, to mix with other samples from that layer. When you have finished collecting cores from 8 total sampling points then place contents of containers into a clearly labelled bag for transport. Dry samples and send to laboratory for analysis.

Materials

- ☐ Manual soil sampling probe. For ease of use and sturdy quality we recommend the Hoffer 36” soil sampler. (The open slot should be at least as long as the depth to which you will be sampling.) If you want to sample more deeply, other probes are available.

- ☐ Shovel. In case soil is so compact or rocky that you need to do a pit sampling technique.

- ☐ Soil probe with a slide hammer. (Optional but very useful in hard, compacted soils.) We recommend the 1” x 36” AMS brand soil probe with a replaceable tip (part number 425.52) along with a 12-lb. slide hammer (part number 400.99). Be sure to order at least one extra tip, as rocky soils will damage the tip easily (part number 425.74).

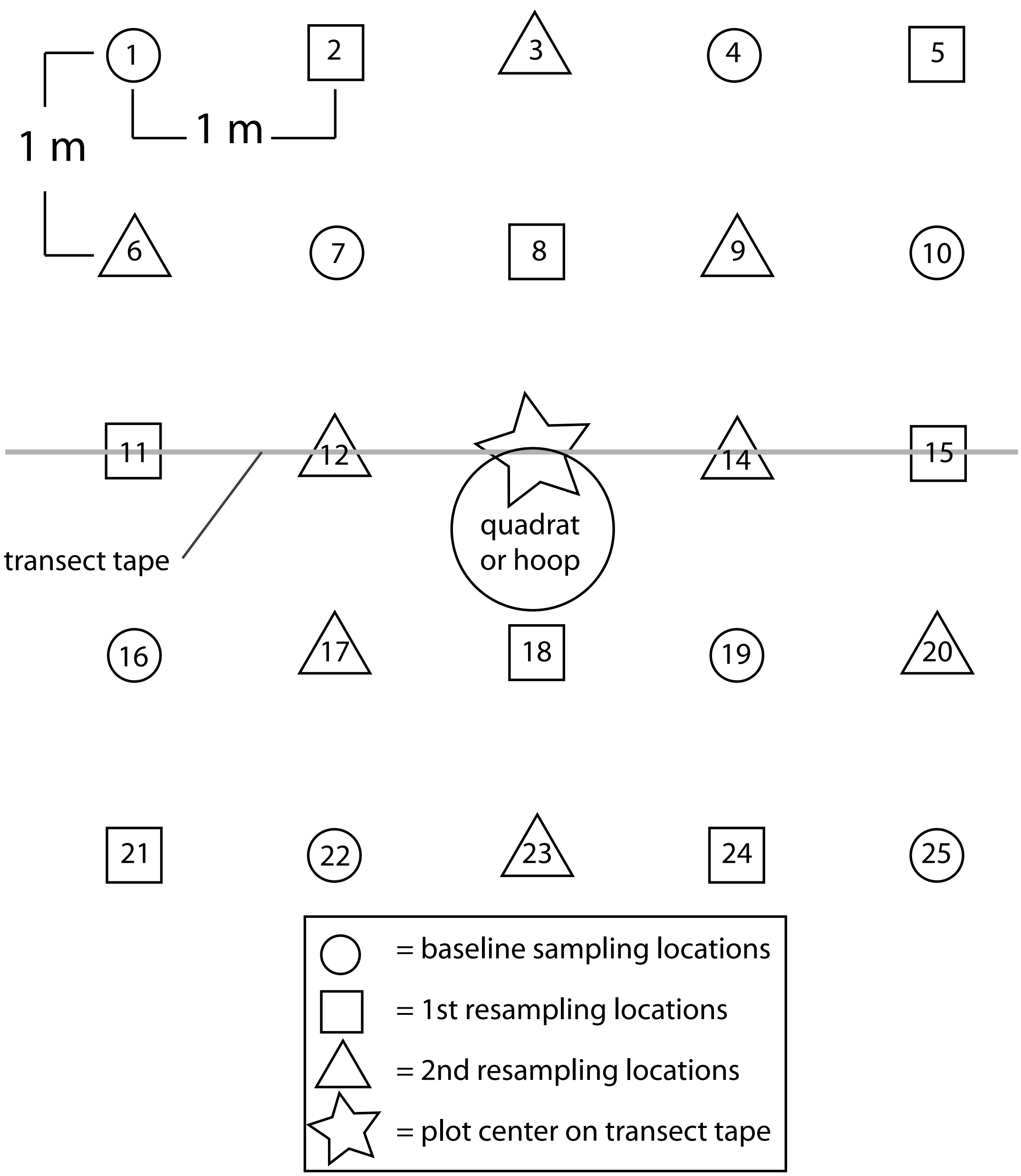
- ☐ Meter sticks to help lay out the grid (at least 2). These can be cheap wooden pre-made ones available in hardware stores, or you can make them yourself out of $\frac{3}{8}$-inch fiberglass electric fence posts or other rigid materials. They don't need to have markers on them, they just need to be one meter in length.
- ☐ A light-colored piece of cloth/tarp that you can put on the ground as a workspace (approximately 2 square meters is plenty). This can also double as a wrap for your long tools.
- ☐ Three sturdy plastic containers that won't tip over, to hold and mix the soil cores while you are extracting them. The kind that are sold for food leftovers—about 8 × 4 inches and 3 inches high—work fine.
- ☐ Quart or Gallon-sized re-sealable plastic bags, for transporting the soil samples when you are done. The heavier, freezer-style bags with a zipper closure are best. You will need 3 for each plot, but extras are always a good idea.
- ☐ Permanent marking pen for writing on bags
- ☐ Serrated knife, for slicing soil cores and extracting them from the sampler.
- ☐ A rigid flat metal metric measuring stick to lay out next to soil sampler when slicing core samples. (You could use meter sticks for this, if they are marked with centimeters.)
- ☐ Round metal file for sharpening inside of probe tips while in the field.
- ☐ A few ounces distilled vinegar: (optional) you can use this to test for inorganic carbon in soils.

Laying out the sampling grid

The sampling grid is an imaginary 4 × 4-meter grid, with 25 potential sampling points located at the corner points where the lines intersect (NOT in the center of each square meter; see illustration). The grid layout enables us to take multiple samples in a compact area, on repeated occasions over time, without resampling a previously disturbed hole.

If you have trouble visualizing this on the ground, you can lay out this whole grid with wire flags and meter sticks around your chosen center point of the transect. Groups may find this helpful the first time that they are doing a plot.

Once the grid is clear in your mind, in the future you can just refer to a picture of it to see the sampling points, and use several meter sticks that you move around as needed to be sure your measurements are accurate.



A grid plot layout provides 24 sampling locations, a meter apart, in a 4 × 4 meter square around the center point. At each sampling, up to 8 cores can be taken in previously unsampled points. If soil pits are needed, choose one of the outside locations. Use grid locations for bulk density sampling as well. After three samplings, the grid spacing can be expanded from 1 to 1.5 m to provide additional, previously unsampled points.

Deciding on sampling points

In an unplowed pasture, field, or yard, we recommend sampling 8 points on the grid, at three or more layers. In a tilled field, 4–6 sampling points on the grid should be adequate. In a forest, you will want to enlarge your grid substantially, in order to get soil samples that represent the larger scale of the variations in forest ecology (i.e. if you take samples under a single pine tree, it may be very different than what you would find under the various trees in the larger area.)

If you can afford it, you may want to have soil from individual sampling points analyzed, rather than mixing the samples together, especially the first year. The resulting data will establish the variability among samples in your plot, and can be used to gauge the sufficiency of your sampling design. (This may also be useful in the future if you choose to publish your data in a scientific journal.) In general, however, in testing for variability, we have found that 8 sampling points, combined into three total samples (one mixed sample for each layer) provides a sufficient number to overcome most variability concerns. That is the sampling design we have generally used for our own plots.

For your baseline plot (the first year that you sample), we recommend sampling at points marked with circles (see illustration). The next time you come back to sample, use points marked with squares, etc.

Decide on sampling depths

If you are resampling to measure change over time, you must use the same sampling depths and increments as were used in the baseline or prior sampling. For new sites, sampling depths depend on:

> **your purpose**: how relevant or important are deeper layers, and what is the capacity of management to influence them? (Even annual plant roots can reach down to 8 feet or more.)
>
> **your equipment**: how easy, practical, or accurate is it to sample to depth?
>
> **soil conditions** such as depth to impenetrable rock or subsoil.

Because we favor hand tools such as the Hoffer soil sampler for ease of use and sturdiness, our sampling depth has tended to go no deeper than 40 cm (and sometimes only to 30 cm.) We often divide our 40-cm core into three (yes, uneven) layers: 0–10, 10–25, and 25–40 cm.

Types of soil probes. The hammer probe listed above is bulky to transport, but can go to deeper depths and still provide an intact core with relatively little disturbance. Soil augers go even deeper, but they disturb the soil structure of the sample itself as they extract the core. You can use a pit method to go as deeply as you like and extract undisturbed samples by digging with a shovel, but that involves quite a bit more labor and creates more soil disturbance overall—not ideal for a plot to which one intends to return, but still the best choice for very rocky soils.

Optimally, you should sample up to the depth at which you think soil carbon is most likely to be changing, with at least 3 designated layers. These layers are measured not eyeballed. They will not necessarily correspond with visible soil horizons or color changes, because horizons will shift over time as soil health improves or deteriorates. Likewise, it is best if the division of sampling layers stays the same in future years, to track progress in that location (e.g. 10–25 cm).

If, over time, you are finding substantial gains in soil carbon at the 25-40 cm depth on a piece of land, it would be worthwhile to start measuring below that. Likewise, if substantial numbers of perennial plant roots are extending below 40 cm, you may want to consider doing deeper samples in at least a few of the sampling points.

If you are going to sample deeper than 40 cm. and you want to compare your data layers with ours, or if you decide to sample more deeply in future years, you can use the divisions we are using, and add an additional (4th) sampling layer at the bottom, rather than shifting your division of layers into three larger ones.

Labeling

Label the 3 containers, with the layers and the depths to which you will be sampling, such as: A layer: 0-10 cm; B layer: 10-25 cm; C layer: 25-40 cm. (These containers can be re-used, so don't put the plot name or date on them.)

Label each plastic bag with today's date, plot name (4-letters plus a number, e.g. CEDA-1 for the 1st plot at Cedar Circle Farm), and depth of the layer, e.g. 0–10 cm.

Extracting soil cores with a hand probe

1. Using the grid map, lay out the meter sticks to find your first sampling point.

2. Gently push aside litter (dried or decaying plants) from soil surface to create a spot for hand probe.

3. Push the hand probe straight down into the ground at your first sampling point. Try to go a few centimeters deeper than your deepest intended sampling depth. (You may need to give it a few extra shoves to get it down far enough. Do not screw it

into the ground or wiggle it back and forth, as that may disturb the sample and/or bend the probe.)

4. When you have reached the intended depth, give the probe a half turn, then pull upwards, tilting the probe slightly away from the open side as you come up, so as not to lose soil, especially if it is dry and crumbly.

5. Lay the probe on the workspace you created with your piece of cloth, with the handle on your left.

6. Lay the flat metal measuring stick along the probe. The 0 cm end of the measuring stick now represents the surface of the ground so it should be lined up with the top of the soil sample (on the left).

7. Using the serrated knife, slice the core sample into the desired layers. For example if you slice it at 10 cm, 25 cm., and 40 cm, this will give you three segments: 0–10, 10–25, and 25–40. Make sure the top of the soil (towards the handle) is your starting point for measuring.

8. While cupping your hand or placing the meter stick over the two other layers in the probe (so they don't spill out), tilt the probe so that the sample from the A layer goes into the plastic container labeled "A layer." Use the knife or your finger to help if necessary.

9. Repeat step 6 for the B and C layers, making sure they go into the appropriate containers.

10. Repeat steps 1–7 for each sampling point, adding all the A layer samples into the same A container, etc. (unless you are planning to test each sampling point separately, in which case they should be labelled accordingly and kept separate).

11. Pour the entire contents of the A layer container into the plastic bag, being sure that it is labelled correctly with plot name and layer (e.g. "CEDA-1A," for the combined A layer samples in the plot called CEDA-1). Make sure you also write down the top and bottom measurements of that layer, e.g. "0–10 cm."

12. At home, pour out the contents of each bag onto a plastic plate to dry. Attach the empty labeled bag to the plate with tape, clothespin, or use a stapler on the top edge of the bag, and place in an area where nothing will fall onto it. (The sample is considered "air dried" when a rebagged sample doesn't fog up when placed direct sunlight—usually about a week of drying, but it varies with temperature and humidity.)

13. Once the soil is air dried, you can send the labeled samples off to a laboratory. Check with local universities to find out what sort of sampling equipment they

have. At the Soil Carbon Coalition we use laboratories that can do elemental analysis for total carbon using dry combustion. Ward Labs in Kearney, Nebraska offers quick service and reasonable prices. `http://wardlab.com`

In rocky or gravelly soils, it may be most practical to gather two samples each from four small **soil pits**, taking care to note the size and location of the pits relative to the plot center, so that future sampling can use different locations, and to restore the pits upon completion as fully and carefully as possible. Dig a hole in the ground with at least one vertical side which can be made with a shovel. It should be at least 8 inches wide most of the way to the bottom. With a ruler, measure your depth increments from the surface and insert some kind of metal marker, such as a nail or small knife, into the side of the pit at your division points. Then you can get your samples from the sides of the pit using a spoon or ice cream scoop, again taking care to make each sample representative of the entire layer sampled. If there are rocks or gravel present, do your best to collect a representative sample of fine earth from the top to the bottom of the layer. Don't worry about collecting rocks, roots, or gravel as they will be sieved out during sample preparation.

If you wish to perform other soil analyses on your samples, you should have plenty of soil.

5

Soil density

Density is the oven-dry weight per unit volume of undisturbed soil. Density also reflects compaction, and decreases in density mean more aeration and pore spaces.

Measuring it requires taking a sample of known volume, drying it, and weighing it. The utility of this measurement depends on your purpose. If you are trying to measure tonnage of carbon in a given depth of soil, or change in that tonnage, then density is a needed factor. Density also reflects porosity and compaction.

Because of their lack of accuracy or consistency relative to carbon analysis using dry combustion, density measurements may merely introduce noise to a simple program of monitoring change in soil carbon due to management. Density also reflects porosity or compaction, and changes over time in density can reflect improvement or deterioration in soil structure.

Equipment

- ☐ A simple and practical bulk density **core sampler** can be made out of a section of sturdy steel pipe about 3 inches or so in diameter. Exhaust pipe works well. Cut a section about 4 or 5 inches long, making sure the cuts are true and square. With a file or grinder, bevel the edge on one end from the outside of the pipe toward the inside at about a 45-degree angle. The inside edge should be square and reasonably sharp.

- ☐ Hammer with wood block to drive sampler into soil

- ☐ 15cm steel rule graduated in millimeters, with a pocket clip that can be used as a slide, enabling you to use this as a depth gauge

- ☐ flat pointed trowel, sharpened

- ☐ sample bags and marker

Taking the sample

1. use a trowel or putty knife to prepare a flat plane surface of undisturbed soil near the midpoint of the layer you want to sample, at one of the grid locations. This can be a horizontal or vertical surface, but as you sample greater depths, we prefer horizontal surfaces.

2. With the block of wood and a hammer, tap the corer square into the flat surface of soil, at least 2 or 3 inches. If the soil surface inside the ring moves inward as you tap, you are deforming the soil and may need to use the clod method described below.

3. The depth of the ring determines the soil volume contained. With a short metric steel rule, take four measurements, evenly spaced around the ring, of the distance between the outer or blunt edge of the ring to the soil surface within. The best steel rule to use is one with a movable slide or shirt-pocket clip, as you are often working in the bottom of a dark pit and can't read it accurately. The clip can be moved with your thumb, allowing you to probe the depth from the rim of the sampler to the soil surface somewhat like a depth gauge, and then remove the rule to read the distance in millimeters.

4. The average of these four measurements in centimeters, subtracted from the length of your corer, gives you the length of your bulk sample. Multiply this by the cross-sectional area of your corer (πr^2, where r is the inside radius of your corer) to get your volume. Using centimeters, your result will be in cubic centimeters, which simplifies the bulk density calculation. For example, my corer, made from a section of 3-inch steel pipe, has a cross-sectional area of 41.51 cm and a length of 11.0 cm. After I tap it into a flat surface of soil, it protrudes 3.65 cm (average of four measurements around the circle). The length of my sample is 7.35 cm $\times$ 41.51 = 305.0985 which I round to 305.1 cubic centimeters.

   It is best to take these measurements **before** excavating your corer. In some situations you may want to seal the top of your corer with your sample bag and a rubber band so that no soil or other material leaves or enters the corer during excavation.

5. Write the volume in cubic centimeters, as well as the plot, grid position, and layer identifier, on your sample bag with a permanent marker.

6. With the trowel or sharpened putty knife, carefully excavate the buried sharp end of the corer, so as not to interfere with the soil within it, until you can cut off the sample, flat and flush along the sharp edge of the corer (a serrated knife works well for this). Now you have a known cylindrical volume of undisturbed, uncompacted soil. Push it out of the corer and into your labeled sample bag, taking care to collect the entire sample. This may take a bit of practice.

A bulk density sampler tapped into a flat surface beginning at 28 cm below the soil surface. The next steps are to measure the inset of the soil surface inside the sampler and calculate the volume, then label the sample bag and excavate the sampler. This photo shows my preferred method of first digging narrow but deep pit, and then doing density sampling adjacent to the pit as a series of steps, where the corer can then be excavated from beneath.

The clod method

If you cannot take a sample using the this method because of gravel and rocks, or because the soil fractures or crumbles easily when the corer is tapped in, you may need to use the clod method.[1]

At one of the grid sampling locations, prepare a level plane surface of undisturbed soil at the needed depth, about midway down in the layer you are sampling. With the trowel, dig a bowl-shaped hole about 3 inches deep and 5 inches in diameter. Avoid compacting the soil around the hole while digging. Place all of the soil and gravel removed from the hole in a plastic bag.

Put the soil in the plastic bag through a 2-mm sieve and into a clean bucket. Put the

[1] This clod method is taken from the USDA Soil quality test kit guide, prepared by John Doran.

sieved soil back into the plastic bag, and keep the gravel and rocks in the sieve. (If the soil is too wet to sieve, you'll need to save it for later, when you can air dry it, sieve it, and account for the volume of gravel by displacement in a graduated beaker or cylinder.)

Carefully line the hole with plastic wrap, leaving excess around the edge of the hole. Place the sieved rocks and gravel carefully in the center of the hole atop the plastic wrap, making sure they do not protrude above the level of the soil surface.

Using the 140-cc syringe to keep track of the volume, fill the hole with water up to the level of the soil surface. The volume of water required is the volume of the sample you have in the plastic bag. Write this volume in cubic centimeters on your sample bag.

Drying and weighing

Most soil labs will dry and weigh samples to calculate bulk density. You may also do this yourself, after the field sampling, if you have a gram scale accurate to .1 gram.

After the sample has been thoroughly air-dried, spread it on a microwaveable paper plate of known weight. (Large samples may require more than one paper plate.) Weigh the sample. Dry the sample thoroughly using a microwave at full power for 1–3 minutes depending on the size of the sample. If you smell smoke, you are overdoing it, combusting organic matter! Weigh the sample again, and record the weight. Microwave it again for 15 to 30 seconds. When it no longer loses weight after a short drying cycle in the microwave, it is dry. Record the weight of the dry sample in grams, less the weight of the paper plate of course. The bulk density D is

$$D = \frac{W}{V} \tag{5.1}$$

where W is the weight in grams and V is the volume in cubic centimeters (even including sieved-out rocks; see below).

You may also oven-dry your density samples in an oven at 250–300° F for several hours. If samples are moist to begin with, it will take longer to get them oven dry.

It is important that the bulk density sample be as similar as possible to the carbon samples. If there are rock fragments larger than 2 mm in your bulk density sample, sieve out the rocks over 2mm in diameter and note the volume of the rocks using displacement with a graduated cylinder or beaker. However, and this is important, **do not subtract the volume of the sieved rocks over 2mm in diameter from your sample volume, but do not include them when weighing your oven-dried sample.** In effect, this assumes that there is no carbon in these rocks, which may or may not be true, but unless you want to grind and analyze the rocks, you are better off just using the lower bulk density figure that results from not weighing the rocks in calculating the tons per hectare of carbon.