Soil Sampling Plan

The ESMC Protocol calls for inclusion of a soil sampling plan and attainment of baseline soil sampling results for soil organic carbon (SOC), bulk density and pH within 6 months of a producer's enrollment in the program for projects that generate greenhouse gas (GHG) credits or assets and Scope 1 Water Quality Credits. Sampling and measurement for SOC, bulk density and pH will be repeated at the 5-year and 10-year marks.

The soil sampling plan must include:

- Contact information for the entity conducting soil sampling, for all contractors involved in sampling, the soil sampling SOP, the laboratory used for analysis, and confirmation of laboratory accreditation. Errors in estimating changes in SOC over time are minimized by using the same sampling procedure, laboratory, and processing procedures across all three sampling times during the enrollment period (baseline, 5-year, 10- year).
- Statement, description and justification of method used to generate sampling density, strata and locations. Please see Appendix III for suggested stratification methods, which will continue to be refined through pilot research in 2020.
- The final set of sampling locations identified on a map and georeferenced with latitude/longitude coordinates and the type of device used to collect the site location data.
- A clear record showing that soil samples are collected at the same time of year each time sampling is repeated. Samples should be collected within the same seasonal timeframe every year (preferably using phenological indicators) to provide consistency in capturing timing of carbon cycling. Ideally, samples should be collected within 60 days of the day of year of the first sample timing.
- Documentation of chain of custody and a unique sample ID with each sample. Soil samples should be shipped to the lab within a week of being pulled from the ground and not stored at extreme temperatures.
- Quality assurance activities, including error and uncertainty calculations. Additional guidance is included in Appendix III.

Soil Sampling SOP Requirements and Guidance:

- Methods for conducting stratification and for determining sampling density and locations will continue to be developed through ESRMC Working Group research projects and pilots. Initially, for pilot projects we recommend that:
  - A minimum of 27 samples per field unless the field is less than 50 acres which reduces the recommended number of samples to 17 per field.
  - Refer to Appendix III for guidance on stratification methods
  - Initial sampling locations should be generated with three to four extra locations then on-site reconnaissance will be used to determine accessibility of each sampling location.
  - Where samples cannot be collected in places such as tractor tracks, fence rows, edges, headlands of row crops, cow paths, and watering areas, workers can

move to within 10 meters or can remove these sites from the sampling ledger and make a final count to ensure the requisite number of sites are mapped and sampled per strata.

- Soil should be sampled, and assets calculated, at a depth of 30 cm or to the limitation of sampling capability (whichever is shallowest); in some locations, rockiness or presence of a lithic or paralithic contact (rock) will prevent sampling to 30 cm The soil sampling depth must be recorded and used in the bulk density and carbon stock calculation.
- Optional deeper soil samples (up to 60 cm) may be taken and used for asset quantification if desired.
- Optional additional 0-15 cm and 15-30 cm samples should also be collected if possible and analyzed for use in improving model initialization and calibration.
- Timing of soil samples should take into account site history, fertilizer and manure application and other features that might influence soil C, pH or phosphorous measurements.
- Samples should be collected within the same seasonal timeframe every year (preferably using phenological indicators) to provide consistency in capturing timing of carbon cycling. Ideally, subsequent year samples should be collected within 60 days of the day of year of the first sample timing.
- Soil samples should be shipped to the lab within a week of being pulled from the ground and not stored at extreme temperatures.
- All samples should be analyzed for SOC and bulk density and 1 in every 5 for pH.
- If possible, an optional one sample per strata should be sent to the lab for a hydrometer measurement of soil texture. Another option is to send all samples to the lab and use VisNIR or MIR spectroscopy to provide a modeled estimate of texture and color.

- Laboratory analysis methods should follow FAO guidelines, specifically:
    - Dry combustion for SOC, with removal of soil inorganic carbon by direct determination (small-scale acidification technique using HCl) or by the difference between total soil C and soil inorganic carbon.
    - Soil bulk density should be determined in the same core in which SOC concentration is measured using a direct measurement method, i.e., the undisturbed (intact) core method and the excavation method.
    - See Appendix III for more specific detail on laboratory methods
- Where available emerging measurement tools including handheld spectrometers (e.g., QuickCarbon), may be used to generate a second set of SOC estimates. If these tools are deployed, a minimum of ten percent (10%) of locations sampled with those tools shall be paired with standard laboratory SOC measures. Those minimum ten percent of sites must use a random selection of sites and be documented in the sampling plan. ESMRC is currently developing more specific recommendations for employing these technologies to more cost effectively monitor SOC increase at ESMC enrolled sites.

The ESMC Protocol also requires reporting of soil phosphorus testing results which are used each year for quantifying water quality outcomes. Prior testing done by producers as part of nutrient management planning can be used for reporting. Soil phosphorus testing (0-10cm) should be conducted at least every 5 years or annually if prior soil phosphorus test values have been above state University Extension recommended thresholds.

Appendix III. Soil Sampling Plan Information

Appendix III-A - Recommended Laboratory Methods

A. **Total soil carbon (C).** Total soil (C) concentration should be measured using the dry combustion method (Nelson and Summers 1996). This method is recommended by the NRCS as well is the standard method for measuring total soil C in soil.
B. **Soil organic carbon (SOC)**. Sometimes soil contains inorganic sources of carbon (IC) such as calcite and/or dolomite ($CaCO_3$ and $MgCO_3$), respectively. Total carbon (TC) is measured by dry combustion (above) and the soil organic carbon (OC) if found by subtraction of IC from TC; e.g. OC = TC-IC. Soil Health Institute recommends the USDA NRCS methods of determine if carbonates are in soil. The USDA NRCS soil survey lab method is called the fizz test. This test uses a dropper to dispense 10% HCL on the soil and if the soil "fizzes" it has IC in it. If a soil fizzes, measure IC.
C. **Soil inorganic carbon.** The cheapest measurement of soil IC directly is the modified pressure calcimeter method (Sherrod et al., 2002).
NOTE: many labs like to use soil pH to decide whether to measure IC. This test will create false positives and more IC measurements will be made than necessary. Also, labs like to treat a soil with acid to remove the IC then run dry combustion to measure TC with IC removed.
D. **Spectroscopy-based soil C measurement.** Where available, QuickCarbon or other recently developed measurement tools could be used to estimate soil organic Carbon at sampling locations for all GHG assets. Ten percent of these locations shall have paired laboratory analyses for SOC using stratified random selection of sites (stratify by sampling strata) which must be documented in the sampling plan.
E. **Bulk density.** Using the core method (Grossman Reinsch, 2002 p 207) and a 2-inch diameter soil core (5.08 cm dia.), the volume of the soil is calculated by the inner diameter (d) of the bit used for coring and using the equation for a cylinder. Bulk density is measured by dividing the oven-dry weight of soil by the volume of that soil (Grossman and Reinsch 2002).
F. **Bulk density with coarse fragments** (> 2mm diameter). Many row-crop ag soils of the Midwest are derived from loess and have no coarse fragments. If coarse fragments exist, their volume needs to be determined and subtracted from the soil volume.
G. **pH.** A 1:1 water:soil paste is measured for pH.

H. **Phosphorus.** The Bray-P1 test is reliable on neutral or acid soils but may underestimate available P on calcareous soils. The Olsen test is more reliable for calcareous soils. Many laboratories use both methods. The Mehlich-3 method has been proposed as a universal alternative for routine soil testing. (Mallarino, 1995).

References:

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Appendix III-B - Stratification Methods

<u>Step 1 - Consideration of Scope 3 versus Scope 1</u>

If the program participant is confident that only Scope 3 assets will be generated, the scaled back Scope 3 method can be used. If in doubt, it is recommended that the Scope 1 method be conducted.

a. Scope 1 Soil C measurement will require a third-party validation. A third-party validation has sampling implications. In a third-party validation, the soil C sampling at 0 yr (the starting time of the soil measurements) will be random within a given area or stratified area of a field. The 5-yr measurement will also need to be random. Hence an analysis of how many samples to collect has assumption of comparing the means two normally distributed measurements of soil C.
b. Scope 3 measurement has less rigor. It is acceptable for the farmer to be aware of where the soil will be sampled at the second sampling time. Hence for the analyses to estimate how many samples will be needed is much less because we are comparing the mean of paired measurements.

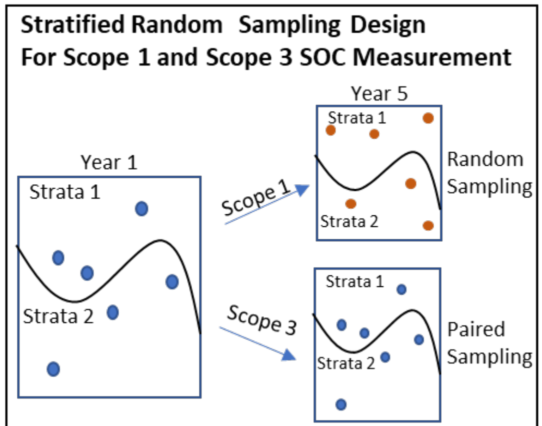

Fig. 1. An illustration of Scope 1 and Scope 3 sampling design for soil organic C. Scope 3 sampling is paired in placement and Scope 1 remains random for the 1st to 2nd sampling event.

Step 2 - Spatially stratify the extent of fields that are to be sampled

The method of stratification to be used for ESMC is not currently defined. Methods for conducting stratification and for determining sampling density and locations will continue to be developed through ESRMC Working Group research projects and pilots.

The current list of possible stratification methods is listed in order of simplicity.

1. Use 1 covariate (elevation for the Midwest). Stratify the field based on a "natural neighbors" delineation and guess 3 zones using any GIS product. The natural neighbors delineation in most GIS platforms uses some sort of a k-mean algorithm.
2. Multiple covariates.
   a. Use the commercially available Stratifi
   b. Use a conditioned Latin hypercube sampling code in R. (cLHS) (Minasny and McBratney 2007; clhs package in R). Note that this may be intimidating at first glance but cLHS is well document in R code and straight forward to use.
   c. Use Optis (deGruijter, Wheeler, Malone 2019). Optis was created for the Australian Soil Organic C sampling protocol. The nice thing about Optis is that it optimizes 1) sample placement (Location) 2) sample number based on prior soil maps and their variability, 3) the worth of the carbon credit, 4) the cost of soil sampling, and 5) 60% uncertainty.

Step 3 - Select number of soil locations to sample within each strata.

Once the field is stratified, number of sampling locations within each strata need to be selected. Once sampling locations are selected, then they should be randomly place within each strata. A algorithm should be used because no human can place sampling sites randomly.

For an estimated uncertainty of 60%, 20 samples per strata are required for Scope 1 and 12 for Scope 3, but this needs to be balanced with cost considerations. Table 1 provides sampling numbers for each strata for decision making based on uncertainty estimates. The table reports estimated sampling numbers assuming a paired (Scope 3) and two random (Scope 1) sampling design. The sampling number were obtained using the pwr package in R, pwr.t.test function, with a type I error of 0.05, a type II error from 0.1 to 0.6 (power = 1-type II error), assumed a coefficient of variance for soil C to range from 35 to 55 % (Wilding, Smeck, and Hall, 1983) and a minimum detection level of 0.5 % carbon concentration. Wilding et al., 1983 report that an average soil pedon will have a coefficient of variation of more than 35% for soil organic carbon. Table 1 starts with a minimum CV of 35% and increases to provide a reference of the impact of good stratification.

ESMC has not landed on a required uncertainty level, only that the uncertainty be reported. Tables 1 and 2 provide some guidance for selecting sampling numbers given expected variability in soil organic carbon. A power of 0.6 is an uncertainty level of 60%. In other words, there a 60% probability of finding a difference in SOC from year 1 to year 5 if it exists and is at least a 5 % difference in concentration (assuming a bulk density of 1.2 g cm^{-3}).

Table 1. Sampling number per strata, calculated using a minimum detection limit of 0.5 % soil organic C concentration and a range in power and variability in soil organic C.

		Scope 3				Scope 1			
		Power				**Power**			
SOC CV*	Effect Size	**0.8**	**0.7**	**0.6**	**0.5**	**0.8**	**0.7**	**0.6**	**0.5**
% 100^{-1}		number of soil coring locations							
0.35	0.714	17	14	**12**	10	32	25	**22**	16
0.40	0.625	22	18	15	12	41	33	26	21
0.45	0.556	27	22	18	14	52	41	33	26
0.50	0.500	33	26	22	17	64	50	40	32
0.55	0.455	40	32	26	21	77	61	48	39

* CV is coefficient of variation; SOC is soil organic carbon.

Table 2. Sampling number per strata, calculated using a minimum detection limit of 0.7 % soil organic C concentration and a range in power and variability in soil organic C. Only for Scope 3.

		Power			
SOC CV*	Effect Size	**0.8**	**0.7**	**0.6**	**0.5**
% 100^{-1}		number of coring locations			
0.35	0.857	13	10	9	7
0.40	0.750	12	13	11	9
0.45	0.667	15	16	13	11
0.50	0.600	18	19	16	13
0.55	0.545	28	23	19	15

* CV is coefficient of variation; SOC is soil organic carbon.

Notes on minimum detection levels and uncertainties

1. Successful stratification will create lower SOC CV values and hence increase effect size. This is desirable.
2. In the second round of sampling (year 5), previous SOC samples will provide the SOC CV for each strata. Then a more informed sampling size number can be calculated.
3. There are SOC CV numbers available in the POLARIS product—the numbers are probably not wonderful but provide starting point**.**
4. Any prior SOC sampling the field may inform the CV value.
5. **Cropland vs grazing lands.** In a study performed on whole fields and 100 samples per field, paired minimum detection limits were calculated to be 0.043 to 0.077 % for 0 to 30 cm depth in row crops and 0.19 to 0.225 % C for 0 to 10 cm in grazing lands (Sehrumpf et al 2011). This study essentially points out that grazing lands have more variability in SOC. The Soil Health institute converted these numbers from stock to %C for ease of interpretation.
6. **Bulk Density.** In non-stony soils, the greatest source of variance in a soil organic carbon stock measurement is in estimating the carbon concentration. Variance in soil organic stock estimates from bulk density sampling was low 28 % of the variance and the variance from coarse fragments (> mm diameter) was low 15 to 30 % in soils less than 20% coarse fragments (Sehrumpf et al 2011).
7. **Soils with Coarse Fragments.** When coarse fragments (> 2mm diameter) were over 20% by volume, most of the variance in soil carbon stock estimates was from estimating the stoniness (Sehrumpf et al 2011). Practically, this means that SOC CV will be much greater than 0.35 in Table 2. When looking at USDA soil map once can know if a soil to be samples has over 15 % coarse fragments. Soils that are over 15% coarse fragments have a coarse fragment modifier in their texture, e.g. grcl; gravely clay loam or Cocl; cobbly clay loam are both between 15 and 35% coarse fragments.