Soil Sampling Methodology and Economics

Morton, T., Torbert, H.A.*, and Prior, S.A.
USDA-ARS National Soil Dynamics Laboratory, Auburn AL, USA

Soil sampling for soil fertility has been extensive conducted for many years in precision farming operations to develop soil management zones. But measuring the soil fertility levels does not address the level of soil quality or the yield potential across a farming landscape. Recently, there has been tremendous interest in developing soil maps for farmers fields that include more extensive information about the soil than simple soil fertility measures. Developing improved methodologies for precision agriculture will depend on developing extensive knowledge of soil conditions within each field, which requires extensive soil sampling by farmers across these individual fields. Soil sampling must be done precisely so that high quality field maps can be developed to guide farmer decisions regarding changes in management practices that will be imposed as part of precision application inputs. One method of improving the effectiveness of management zone maps is to include measures of soil quality distribution across a field. For example, soil carbon (C) is often used as the first indicator of soil quality because it is a measure of the level of organic matter in soil, and changes in soil C distribution across a field can be used to help develop better precision management maps. However, very little information exists regarding the potential cost of taking soil samples for documenting soil C and other soil parameters. While laboratory measurement techniques for C concentration in each soil sample are available, methods needed to efficiently measure soil C content (mass basis) in a soil profile across field landscapes are very difficult. When extrapolating such methods of measuring soil C content or other measures across whole fields, this process becomes even more difficult. A fundamental question that must be address if improved maps are to be utilized by farms is the cost of collecting and processing soil samples. Therefore, the primary questions are: how should soil samples be taken for soil measurements, what is the correct methodology, and how much will the process cost? The following is a cost analysis of requirements needed for soil sampling on large scales for precision agriculture purposes. In addition, here are some important criteria and considerations for adequately measuring C in soil profiles.

1) The predominance of C in soil will be in the root zone where organic matter is produced, but there is a large change in soil C distribution by soil depth over very small depth increments. Taking soil samples by depth is essential to capture changes in C concentration in the soil profile. While mixing of soil from a soil sample is an essential part of the analysis to guarantee a representative, homogeneous sample, no level of mixing will be adequate if a large volume of soil contains a large change in C distribution. This all becomes more problematic if the “large volume” equates to “large fields” and the assessment is based on a low number of non-representative soil cores. In such a case, analysis would be based on a simple non-representative average (rather than the true soil C value of a large volume with changes in C distribution with depth) when converting C concentrations to C content.

2) While the predominance of C in soil is in the root zone, where organic matter is produced, the depths of the rooting zones can be very different between plant species and even between different cropping systems. Most of the plant roots will be near the soil surface along with

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all the aboveground litter. Both inputs contribute to soil organic matter build up. Although many plant species produce roots that go deeper into the soil profile, the actual concentration of C at deeper depths drops off rapidly due to lower rooting density. For this reason, C variability with deeper depths increases markedly, which makes it very difficult to get adequate assessment measurements based on traditional soil sampling techniques.

3) Soil bulk density is a critical measurement that must be included to calculate soil C mass. Soil bulk density can be impacted by not only soil and climate conditions, but also by management practices.

4) There are an untold number of factors that interact to change soil C content over a landscape. For example, the same factors that have led to different soil types over a landscape will likewise influence soil C present in these soil types. However, since soil C is primarily driven by biological factors, there are a multitude of additional factors that will result in spatial changes in soil C. To properly account for the actual changes in soil C content distribution across a fields, sufficient soil sampling must occur across a landscape to adequately capture these changes. Therefore, field sampling must be based on some type of grid increment across the landscape to adequately capture spatial field variability.

Soils are inherently variable and there is very little information as to the frequency of soil sampling required to address inherent and spatial variability that would be encountered when attempting to accurately determine soil C distribution across landscapes. To conduct this economic evaluation, a total number of soil samples that would be taken had to be established. Taking this into consideration and utilizing suggestions from other soil scientists that have struggled with these same issues, we have conducted this cost analysis based on the following criteria:

1) Grid sampling is required. A method for establishing the grid pattern and discerning where to take samples while in the field must be included.

2) A grid size small enough to capture the spatial variability must be used. We use a grid density of one soil sample per 3 acres in our analysis.

3) For the cost analysis, a soil depth of 30 cm was selected. This depth is believed to adequately capture the vast majority of C present in most agriculture production systems.

4) A soil increment of 10 cm (or 3 soil depths/soil sample) was selected as a reasonable compromise for the number required to capture soil C changes by depth.

5) A field size of 300 acres (100 cores) was selected as the base field size for this analysis.

6) The cost of laboratory analysis, for soil C concentration, was based on available commercial cost of soil testing facilities conducting soil C analysis. Costs for soil C analysis were averaged from soil testing facilities across the US.

Other Assumptions

To measure soil samples across a large landscape, a systematic approach to collecting soil samples is required to take the large number of samples. All equipment described and methods used were derived from methods we have utilized as soil scientists in conducting on-going research (e.g., Prior et al., 2004; Prior and Rogers, 1992, 1994). Although these systems have been advantageous in terms of reducing sampling time, subsequent processing steps are still time-consuming. The time required for taking and processing soil samples was derived from our >30 years of experience as soil scientists. Other methodologies could also be used, but we have provided all the information and associated costs that were part of this analysis so that others can judge how an alternative method may change the results. The following is a detailed list of all the components and explanations relevant to the analysis that was used. This study focused on soil C, but other measures of soil would require the same cost structure to collect the soil and prepare it for lab analysis. The change in cost of the lab analysis is separated from the cost of collection so it the analysis can be adjusted for different laboratory analysis cost for other components of interest.

Conclusion

The economic evaluation of soil sampling for soil C is based on the concept that a company will be established to take and process soil samples for precision agriculture purposes. The cost of equipment and labor for collecting and processing the samples for bulk density and preparing them for shipment to an analytical lab for analysis are considered. A detailed list of the equipment that was considered as part of this project and the justification for doing so is provided below. A Microsoft Excel spreadsheet with all associated sampling costs (and cost calculations) for this project is also available.

Summary of Expenses

The summary of these expenses is shown in Table 1. However, the cost of the actual analytical analysis is not included in this summary. Rather, a survey of commercial laboratories that perform soil C analysis was conducted and the average cost from across the US (separated by methods) is listed in Table 1. The assumption is that each lab would have considered its own cost in providing the services which is reflected in the price offered to customers. The most widely accepted analytical method for soil C sampling would be to use #1- Combustion Method – Organic C (with inorganic C separation).

The grand total for the cost of soil sampling a 300-acre field would be $13,264.26 US. A 300-acre field was chosen as the field size because it could be reasonably expected to be sampled by a crew in one day (assuming that travel time to the field was not a limitation). After including the cost of the laboratory analytical analysis of the samples (Combustion Method – Organic C with Inorganic C separation), the grand total would be $19,693.26 for a 300-acre field. This would calculate out to $65.64/acre. To reduce the cost of sampling, alternative sampling grid frequencies could be considered. However, the basic expenses considered in this evaluation would be consistent, resulting in a cost calculation on a per core sample basis equal to $196.93

per core sample. Therefore, the cost/acre could be calculated by dividing the $196.93 cost by the number of acres (3) that this one soil sample will represent to arrive at the cost/acre.

Table 1. Cost summary and Lab analysis summary

CORE SAMPLING COSTS (100 CORES OVER 300 ACRES)	
TOTAL START-UP INPUT COSTS	$10,243.26
TOTAL VARIABLE INPUT COSTS	$1,129.74
TOTAL LABOR COSTS	$990.00
TOTAL MACHINERY COSTS	$901.26
GRAND TOTAL	$13,264.26

LAB ANALYSIS COSTS (100 CORES OVER 300 ACRES)	
1.) Combustion Method - Organic C (with Inorganic C Separation)	$6,429.00
2.) Combustion Method - Total C	$6,732.00
3.) Loss on Ignition – Soil Organic Matter	$4,086.00
4.) Modified Walkley-Black – Soil Organic Matter	$2,550.00

START-UP INPUT COSTS FOR SOIL CORING OPERATION

Equipment

- ***2025 GMC Sierra 3500HD 4WD Crew Cab Pro (6.6L Duramax):*** *Used to pull a gooseneck trailer to and from locations. A heavy duty truck is imperative with loads being pulled.*
- ***Gooseneck Trailer w/ Brakes (GVW 14,000 lb – 8' x 20'):*** *Used for transportation of tractor, soil corer, UTV, and all equipment. This size is required to load all equipment onto 1 trailer.*
- ***Giddings #15-TS / Model GSRTS Soil Corer:*** *Used for the actual soil coring. This model is required since it uses a rotating head to collect samples from cores without causing compaction in the soil tube.*
- ***John Deere 5050E Utility Tractor (50HP):*** *Used to operate the soil corer. This tractor is needed for basic PTO horsepower requirements and clearance.*
- ***John Deere Gator Work Series Utility Vehicle 4WD:*** *Used for transportation of soil cores throughout the field back to the larger transport truck. Light enough for rough field conditions.*
- ***Garmin eTrex 10 Worldwide Handheld GPS Navigator:*** *Used to gather GPS coordinates for all cores throughout the field. The device identifies the correct position for every soil core taken.*
- ***HP 15.6" Laptop AMD Ryzen 5 - 8GB Memory 512GB SSD:*** *Computer used to plot all soil core positions (with GPS coordinates), run ArcGIS software, and to tabulate all data.*
- ***Ohaus SP2001 Scout Pro Portable Scale (2000g):*** *Used for weighing all subsamples from soil cores before and after oven drying. 2000g capacity required for accurate soil wet weights.*
- ***Thermo Scientific Lindberg Blue M Box Furnace:*** *Used for the drying of all samples before weighing and laboratory analysis.*
- ***Frigidaire 24.8 cu ft Chest Freezer:*** *Used for storing soil core samples (>32°F) before collecting data.*

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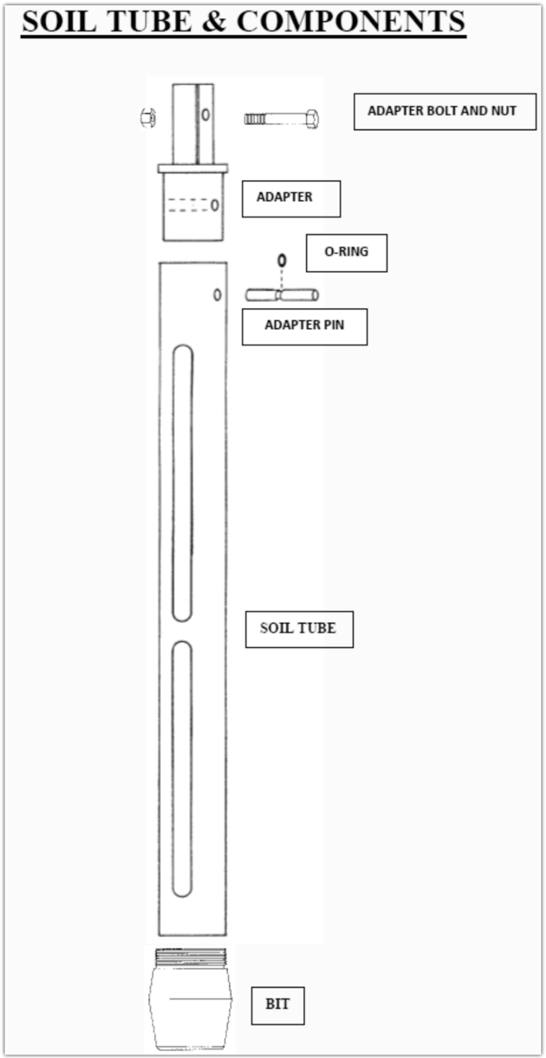
Giddings Tooling



- ***Adapter Bolt Assembly 1 1-4" Kelly Bar:*** *Attaches the adapter to the soil corer's Kelly bar.*
- ***Standard Soil Tube Adapter 1 1-4" Kelly Bar (2"):*** *Connects the soil corer's Kelly bar to the soil tube.*
- ***O-Ring for Pin:*** *Used to help the adapter pin hold the adapter to the soil tube.*
- ***Adapter Pin (2"):*** *Connects the adapter to the soil tube - 2".*
- ***Steel Tube for 48" Liner (2" x 50 1-2"):*** *Holds the plastic liner that contains the soil core samples that inserts into the soil tube.*
- ***Heavy Quick Relief Sawtooth Bit (2"):*** *Rotating head with saw teeth for boring into heavy soils.*

- ***Soil Tube Cleaning Brush (2"):*** *Wire brush used for cleaning soil residue from the soil tube after a core is taken. 2" diameter tube*
- ***Soil Tube Cleaning Brush Handle (4'):*** *Handle for the wire brush head. 4' long soil tube.*
- ***Heavy Quick Relief Sawtooth Bit (2") *1 Extra:*** *Extra bit to replace a worn-out bit in the field.*
- ***Replacement O-Ring for Pin (5-Pack): *Extra:*** *O-Rings are rubber and tend to wear out. Extras needed.*
- ***Steel Tube for 48" Liner (2" x 50-1/2") *1 Extra:*** *Replacement in case the tube gets bent or dented.*

Miscellaneous

- ***1-1/4" x 48" Hardwood Round Dowel**: Used to push out soil cores before cutting 10cm subsamples.*
- ***3M 1.88" x 50 yards Duct Tape**: Used to tape the black and red endcaps onto the plastic soil tubes for transportation.*
- ***ArcGIS Pro (Creator) – Yearly License:** Needed for basic soil mapping of core collection points.*
- ***Empire 48" Aluminum Straight Edge Ruler:** Used to measure the correct 10cm subsections of the soil core.*
- ***Gearwrench 7" Round File:** Used to file the teeth of the sawtooth bit after several cores have been taken.*
- ***Husky 10" Hacksaw:** Used to cut the 10cm subsections of the soil core.*
- ***Husky 18" Aluminum Pipe Wrench (2" Jaw):** Used to release the adapter from the soil tube.*
- ***Husky 4 lb. Engineer Hammer:** Used when the soil tube or adapter pin gets stuck.*
- ***Microsoft Office Home 2024 (1 Device) - Windows:** MS Excel is used for logging data and GPS coordinates.*
- ***Ratchet Chain Binders 5/16" x 3/8" (2-Pack):** Used to bind chains around the tractor and UTV during transportation. 4 total needed.*
- ***Scepter 5 gal. Smart Control Diesel Can:** Used to re-fuel the tractor in the field.*
- ***Scepter 5 gal. Smart Control Gas Can:** Used to re-fuel the UTV in the field.*
- ***Transport Chain 70 Grade Standard Link (5/16" x 16'):** Used to fasten the tractor and UTV to the trailer during transport. 4 total needed.*
- ***Dewalt 10" Bi-Metal Hacksaw Blades (3-Pack):** Replacement blades for hacksaw.*
- ***Sharpie Permanent Markers (2-Pack):** Used for marking reference information on each plastic soil liner (after soil sampling) and associated Ziplock bag subsamples after cutting core into subsections.*

PPE

- ***Ariat Pull-On Steel Toe Work Boots:** Protective safety-toe boots needed for all field work. 3 total pairs needed for workers.*
- ***Honeywell Laser Lite Corded Earplugs (100-Pack):** Earplugs are required because of the decibel level of the soil corer.*
- ***Honeywell Uvex SVP 200 Series Safety Glasses:** Safety glasses are required to protect eyes from debris.*
- ***MCR Safety Unlined Pigskin Leather Gloves (1 Pair):** Protective gloves needed for handling the steel soil tubes and soil corer equipment. 3 total pairs needed for workers.*

VARIABLE INPUT COSTS FOR SOIL CORING OPERATION

Giddings Tooling

- ***48" Long Plastic Liner (1-3/4" x 48"):*** *Used to hold the individual soil core. (100) needed for 300 acres.*
- ***Black Liner Cap - Bottom (1-3/4"):*** *Bottom endcap for the plastic soil liner. (100) needed for 300 acres.*
- ***Red Liner Cap - Top (1-3/4"):*** *Top endcap for the plastic soil liner. (100) needed for 300 acres.*

Miscellaneous

- ***Fisher Brand Aluminum 20 mL Weighing Dishes (100-Pack):*** *Small weighing dishes for obtaining subsample weights before and after oven drying. (3) total packs needed.*
- ***Foam Insulation Board (3/4" x 4' x 8'):*** *Shims are cut from the foam to fill in the empty space in the plastic liners behind each soil core. (2) total boards needed.*
- ***Shipping & Handling UPS Ground (140 lbs. Total Weight):*** *Cost for the total weight of shipping all samples to a soil lab for analysis. Used a location in Kansas just for reference.*
- ***Uline Cardboard Boxes (20" x 20" x 20"):*** *Boxes used to ship all samples for lab analysis. (4) total needed.*
- ***Ziploc Freezer Quart Bags (100-Count):*** *Used to contain each subsample from each soil core. (3) total boxes needed.*

*****The total start-up input costs for all activities associated with sampling 100 soil cores over 300 acres is $10,243.26 US.***

*****The total variable input costs for all activities associated with sampling 100 soil cores over 300 acres is $1,129.74 US.***

LABOR COSTS FOR SOIL CORING OPERATION

Preparation

- *The site is visually inspected to determine where the landmarks are in the field. Usually takes 1 person 1 hour to complete.*
- *The best sample location and GPS coordinates are determined, and ArcGIS software is used to plot out a soil map of where the samples will take place within a given area. Usually takes 1 person 3 hours to complete.*
- *All equipment and materials are determined and prepared to be loaded onto the truck and trailer for transportation to the sample site. Usually takes 1 person 3 hours to gather all supplies.*
- *All equipment is loaded onto the gooseneck trailer and all sampling materials are loaded onto the truck for transportation to the sample site. Usually takes 2 people 1 hour to complete.*

Sampling

- *The tractor/corer is driven to the preplanned GPS coordinates using a handheld Garmin navigator and cores are taken exactly where the map states in the field. Each soil core is taken to a 30cm depth to ensure that all existing C can be measured correctly in the sample. Cores are drilled, pulled, and pushed out of the steel soil tube with a wooden dowel. Then, each sample is capped on the top and bottom ends of the plastic soil tube liner. A pre-cut foam shim is placed into the blank space in the tube before the endcaps are duct tapped to ensure that each core is safe for transportation. The samples are then loaded onto the UTV in the field where they are driven back to the work truck for transportation back to the lab. This whole process takes 3 people 8 hours to complete 100 samples from a 300 acre site. Labor cost for each worker is calculated at a $15.00 per hour average.*

Post-Sampling

- *All the equipment and supplies are unloaded and put away upon returning from the sample site. Then, all collected soil tubes (100) are unloaded and stored in the cooler (>32°F) before weighing/drying/analyzing. This usually takes 2 people 2 hours to complete.*

Processing

- *Data sheets, sample identification keys, and sample Ziplock bags (300) are prepared. This usually takes 1 person 4 hours to complete for all 100 core samples.*
- *All drying tins are weighed and then all subsamples are placed into drying tins. This usually takes 1 person 2 hours to complete for all 100 samples.*
- *Each core (100) is cut into (3) 10cm sections with a hacksaw; wet weights of each section are recorded; and finally, all sections are loaded into the oven (Thermo Scientific Lindberg Blue M Box Furnace) to be dried. This takes 2 people 8 hours to complete all 100 samples.*
- *The dry weights of each 10cm section (300) from each core (100) are recorded. This takes 1 person 2 hours to complete all subsections of all soil cores.*
- *All recorded data is entered into Microsoft Excel. The % moisture and bulk densities are calculated for all subsamples (300) of all soil cores. This takes 1 person 4 hours to complete all soil cores.*
- *All samples are prepared and packed into cardboard boxes to be shipped to the lab for soil analysis and C measurement. This takes 1 person 1 hour to box up all subsamples.*

*****The total labor costs for all activities associated with sampling 100 soil cores over 300 acres is $990.00 US.***

MACHINERY COSTS FOR SOIL CORING OPERATION

Ownership (Fixed) Costs

- *Total Depreciation = (Purchase Price – Salvage Value at end of life)*
- *Capital Recovery = [(Total depreciation x Capital Recovery Factor) + (Interest Rate x Salvage Value)]*
- *Taxes, Insurance, and Housing = [((Purchase Price + Salvage Value) x 0.01) / 2]*

Operating (Direct) Costs

- *Average Repair Costs Per Hour = Total Accumulated Repairs / Total Accumulated Hours at End of Life*
- *Fuel Costs per Hour = [0.44 (diesel) or 0.06 (gas) x Engine or PTO Horsepower x Fuel Price] **Fuel prices were based on average prices for 2025 data*
- *Lubrication Costs Per Hour = (0.15 x Fuel Costs Per Hour)*
- *Labor Costs Per Hour = (1.1 x Wage Rate) **Wage Rate used is $15.00 per hour*

*****The machinery costs for all activities associated with sampling 100 soil cores over 300 acres are $901.26 US.***

For more information, refer to the "Fixed Costs Soil Carbon Testing Equipment" Microsoft Excel worksheet

LAB ANALYSIS COSTS FOR SOIL CORING OPERATION

High Temp Combustion Method w/ Inorganic C Separation: Average Cost:

- *$21.43 per sample (x 300 subsamples = $6,429.00 US)*

High Temp Combustion Method for Total C: Average Cost:

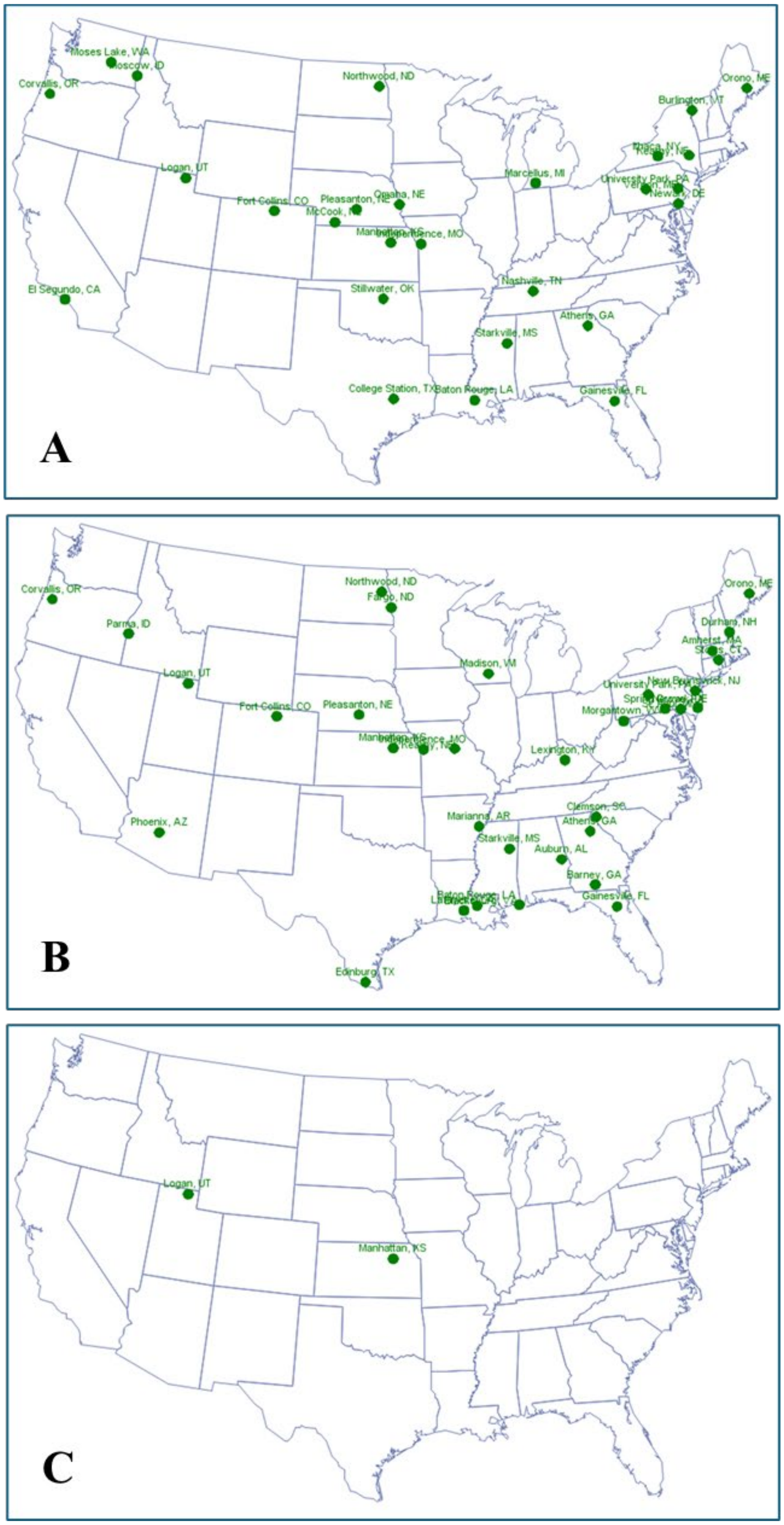
- *$22.44 per sample (x 300 subsamples = $6,732.00 US)*

Soil Organic Matter (SOM%) Loss on Ignition Method: Average Cost:

- *$13.62 per sample (x 300 subsamples = $4,086.00 US)*

Modified Walkley-Black Method: Average Cost:

- *$8.50 per sample (x 300 subsamples = $2,550.00 US)*



Locations of commercial laboratories that perform soil C analysis by the (A) Combustion Method, (B) Loss of Ignition Organic Matter Method, and (C) Modified Walkley-Black Method.

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