SOILS4 LIBERIA

Protocol for Nationwide Soil Inventory

Guidelines on Soil Sample Collection, Field Assessment &

Lab Analysis across Liberia

‘From productivity to product, linking peers to peers (P2P)’
‘Land knowledge improved’

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Acronyms

AU	African Union
CAA	Cultivated Aquatic Area
CARI	Central Agriculture Research Institute
CMTA	Cultivated and Managed Terrestrial Area
CS	Country Supervisor
CSV	Comma separate values
EU	European Union
EUDEL	European Union Delegation to Liberia
FAO	Food and Agriculture Organization
FNSSA	Food and Nutrition Security and Sustainable Agriculture
FYM	Farmyard manure
GPS	Global Positioning System
GPX	GPS eXchange format
GSP	Global Soil Partnership
IITA	International Institute of Tropical Agriculture
ISRIC	International Soil Reference and Information Centre
KML	Keyhole Markup Language
LCCS	Land Cover Classification System
LINSIC	Liberia National Soil Information Centre
LSIS	Land and Soil Information System
MoA	Ministry of Agriculture
ODK	Open Data Kit
PMU	Project Management Unit
PSL	Proposed Sampling Location
PSU	Primary Sampling Unit
P2P	From productivity to Product, linking Peers to Peers, EU programme
QR	Quick response
Soils4Africa	Soil Information System Resources (EU-funded project under the H2020 programme)
Soils4Liberia	Liberia Land and Soil Resources Knowledge Project
SIS	Soil Information System
SDMT	Survey Data Management Tool
SNV	Semi-Natural Vegetation
SOTER	Soil and Terrain databases

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SP	Service Provider
SP-ID	Sampling point identifier
SS-ID	Soil Sample Identification
SSU	Secondary Sampling Unit
SWC	Soil and Water Conservation
TCI SSFSs	Team Europe initiative "Safe and sustainable food systems"
UL	University of Liberia
TSU	Tertiary Sampling Unit
VQC	Visual Quality Control
WP	Work package

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Preface

The EU Action "From Productivity to Product, Linking Peers to Peers (P2P)" contributes to the Team Europe Initiative on Safe and Sustainable Food Systems (TEI SSFSs) for Liberia. Within this framework, Output 1.1 "Improved land and market knowledge for planning and decision making" provides the strategic foundation for the Soils4Liberia project, with a primary focus on strengthening land and soil knowledge systems.

This protocol operationalises the commitment to conduct a nationwide soil survey and mapping campaign, land suitability assessments for agriculture and aquaculture, agro-ecological and land-use zoning, and the optimisation of land information services for research, extension, and business development. It responds directly to long-recognised gaps in soil and land resource data in Liberia and establishes standardised procedures for field inventory, laboratory analysis, data management, and information product development.

The protocol supports the establishment of a Liberia National Soil Information Centre (LiNSIC) within the Ministry of Agriculture (MoA), which will host the Land and Soil Information System (LSIS) developed under this project. Through strong emphasis on national capacity development, institutional strengthening, and stakeholder engagement, this initiative ensures that Liberia will not only generate baseline soil data but will also develop sustainable mechanisms to manage, interpret, and apply soil and land information.

This document serves as the official instructional manual governing the nationwide soil and land resource inventory under Soils4Liberia. It provides the technical standards, operational procedures, and quality assurance framework required to generate reliable, interoperable, and policy-relevant soil data for Liberia.

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1 Introduction

Reliable, spatially explicit soil information is fundamental for sustainable land management, agricultural planning, and environmental stewardship. In Liberia, the limited availability of harmonised and up-to-date soil data has constrained evidence-based decision-making and effective resource management. A nationally coordinated soil survey is therefore essential to establish a standardised baseline dataset describing the physical and chemical characteristics of soils across the country. The Soils4Liberia project is designed to establish a fully functional Land and Soil Information System that contains reliable primary current data and that facilitates managing soil data and information and generating information products according to user requirements.

This protocol outlines the methodological framework for the design and implementation of the nationwide field campaign to systematically characterise Liberia's soils. The survey is structured to ensure representative spatial coverage across major agroecological zones, land-use systems, and landscape positions. Sampling locations are selected using a stratified and spatially balanced approach to capture variability in soil-forming factors, including climate, topography, parent material, vegetation, and land management. Standardised procedures guide field team deployment, site documentation, georeferencing, and data recording to ensure consistency and reproducibility across all regions.

At each selected location, soil profile description and sampling are conducted according to internationally recognised soil survey standards. Detailed morphological characterisation of soil horizons, including depth, colour, texture, structure, consistence, rooting patterns, and evidence of hydromorphism or compaction, provides essential information for soil classification and interpretation. Representative disturbed and, where necessary, undisturbed samples are collected from defined depth intervals and from identified genetic horizons to support laboratory analysis.

Laboratory analytical procedures are implemented using standardised methods to ensure accuracy, comparability, and quality control. Samples are prepared through air-drying, sieving, and homogenization prior to analysis. Core physical and chemical parameters, including particle size distribution, soil pH, soil organic carbon, total nitrogen, available phosphorus, exchangeable bases, and cation exchange capacity, are determined using validated analytical techniques. Quality assurance measures, including calibration, duplicate analysis, and reference materials, are applied throughout the analytical process to maintain data integrity.

Together, the integrated field and laboratory framework described in this protocol ensures the generation of reliable, high-quality soil data to support national-scale assessment, planning, and sustainable management of Liberia's land resources. This protocol is a revised version of the Soils4Africa field survey protocol developed by Huising and Mesele (2022), taking special consideration of the situation in Liberia.

The protocol is presented as outlined below:

- Preparations and materials for fieldwork

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- Safety and Security issues
- Navigating in the field
- Rejection of a secondary or tertiary sampling unit
- Layout and sampling procedure
- Soil sample collection
- Labelling and packaging
- Land and Soil surface characterisation
- Landform and terrain observations
- What to do in special situations
- Protocols for making observations on land use and land cover
- Protocols for the reference sites – Soil profile distribution and pesticide residue
- Guidelines for the laboratory soil analysis

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2 Preparations for fieldwork

Preparation is crucial for a successful field survey. The process begins with downloading and studying all relevant reference materials and protocols. Next, you'll need to identify the sampling locations to be surveyed, map your itinerary, and gather all necessary fieldwork materials. This preparation can take some time, so it's important to start as soon as you're assigned a job. Be sure to factor in the time needed for preparation when planning your field survey.

For instance, QR codes will be used for soil sample identification (SS-ID). These codes must be generated and printed in advance. Additionally, test all the tools you'll use in the field; practice with them to avoid wasting time figuring out how they work on-site. Ensure you have a waterproof bag to protect devices like smartphones, GPS, and any important documents in case of rain.

When planning your itinerary, consider using Google Maps or similar apps to estimate how long you'll spend in the field. It's advisable to print maps showing the sampling point locations for each primary sampling unit (PSU). This will serve as a handy reference for navigating to those points and can be useful for noting where you've parked or for tracking your field observations.

In principle, all data should be recorded electronically. Install ODK-collect on your smartphone, download the necessary forms, and make sure everything functions correctly before heading to the field. Charge your smartphone fully, and bring along a fully charged reserve battery, power bank, or a second phone as a backup if you'll be out for several days. Don't forget to carry extra batteries for your GPS. It's also wise to download and familiarize yourself with additional recommended apps so that you're prepared for any surprises in the field.

Ensure you have received the accreditation letter from your country supervisor. This letter is essential for justifying your mission to farmers, landowners, or local authorities as needed. Before you leave for the field, connect with the County Agricultural Officer, another representative, or your assigned Field Supervisor (FS) to review all your preparations and obtain approval to start the survey.

Lastly, be mindful of the weather conditions. Soil sample collection cannot take place in the rain, nor can any associated observations be recorded. Ultimately, it is up to the surveyor to decide whether to proceed with the fieldwork. In cases of isolated showers, field surveys can often continue. Just make sure to wear protective clothing.

Below is a list of the equipment and materials needed for the fieldwork, along with their specifications.

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2.1 Materials and equipment

Item	*Specifications/Quantity*	*Sample*	*Remarks*
Accreditation letter			To be provided by CARI or Ministry of Agriculture
Suitable vehicle(s) for transportation in the field.	4x4 car / saloon car, motorbike	 	A vehicle, or means of transport, is needed to reach the area (PMU) where the sampling points are located. Type of vehilce, 4wd or 2wd, depends on the condition of the roads. If motorable roads can't bring you close to the sampling locations, consider hiring a motobyke that is often avaialbe locally at little cost. (It will save a lot of time).
Smart phone	Android Version 9.0 or higher, 4GB RAM or more - with all required apps such as barcode scanner and MAPS.ME as indicated in this manual		The smartphone is used as a data recording device and is essential to have. Don't use cheap chinese brand phones, because features like 'location' may not work properly. At least ensure that all required services are workng properly (like 'location' and barcode scanning services). Preferably have a back up smartphone. It is essential you have 2 smartphones if you are going to use your phone as a means of navigation in lieu of a handheld GPS device. Make sure you can power your phone for a longer period of time (use backup battery, powerbank, or other)
ODK field forms loaded onto the smartphone and print out for back up			ODK-collect is the primary means of data recording in the field. Instructions on how to access the forms is given below. Having a printed version of the ODK form is

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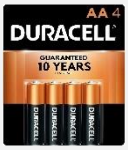
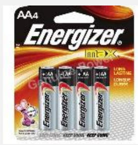
			useful for data recording if, for one reason or other, you cannot use your smartphone in the field. The data can be entered online at a later stage (contact your CS). You will be able to download the PDF version of the ODK from the SDMT
Permanent markers and pens plus writing pad			You need writing materials as back up if electronic recording device does not work. Markers are needed for writing the labels on the sample bags, to mark the soil augers at 20 and 50 cm.
Handheld GPS device			Handheld GPS device will be the recommended tool for navigation in the field (the last mile) to reach the designated sampling locations. Alternative solution is the use of MAPS.ME (see below)
Batteries for GPS	AA batteries	 	You need an AA size battery. This should be dry cell or alkaline battery. Ensure you load the batteries into the GPS device and also have at least 2 pairs as spare before going to the field
MAPS.ME App	[Android Apps on Google Play]()		MAPS.ME is an app for navigation like google maps. It allows to download maps on your phone so you have them as reference for navigtion in the field. Coordinates of the sampling locations are uplaoded and displayed on the map. The app will be used for this project as an alternative app for navigation in the field in the absence of a handheld GPS device.

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Power bank for Smartphone	10000MAh		The power bank provides additional power support for your smartphone. If you have a smartphone with a strong and fully charged battery, you may not need to carry a power bank along to the field but it is advisable to have one in case of any eventualities
Sturdy plastic **and** paper or cloth sample bags	About 30 cm by 26 cm, or 1-litre bag, both for the plastic as the cloth or paper bag; number of bags: 1 plastic bag and 1 other bag per soil sample; cloth bag should have cord to close the bag	 	Each sample is going to do double-bagged. The sample goes into the plastic bag and then the plastic bag is bagged with a cloth bag or papper bag to provide sturdiness. Pesticide residue samples should be placed directly into cloth bags.
Labels/barcode	QR codes printed on 300gsm A4 paper		There is a section in the ODK form where you will scan a QR code for the sample ID (SS-ID). After scanning place the QR code tag in between the bags. The QR codes are in duplicate, do not separate them. The barcodes will be provided centrally (either in electonic form or printed). If to be printed use quality paper 300gsm to make the labels more sturdy
Plastic pouches	Ziploc plastic pouches small; Size: 5 x 7 cm		The pouches are used to put the QR codes in (in duplicate). Ziplock plastic ouches are used to protect the labels getting moist or wet.
Stapler	Handheld stapler		Can be any type or brand, but if available a handheld stapler is preferred to be used in the field; it is used to seal the sampling bags. Make sure you have enough staples.

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Standard soil auger	Edelman type auger; combi type, 7cm ∅		The Edeleman type auger is the standard and preferred tool for soil sample collection for this project. It will be provided by IITA when required. The soil auger soil be marked at 50cm and 100cm with either permanent marker or tape.
Spade	standard size with the bottom flat rather than being pointed		The spade is used as alternative for, or as supplementary to the soil auger for sample collection (not for soil depth measurement). Sample collection for the 0-20 cm especially may be easier with spade in certain circumstances (very sandy or very clayey soils). The use of spade is recommended here for opening of the profile pit.
Hammer/mallet	A big size – Carpenter's hammer		Needed for the bulk density samples
Plastic buckets	Two 10-litre buckets, with different colours		You will need 2 plastic buckets of different colours for soil sample mixing in the field. Ensure you label the buckets: One as "TOPSOIL" and the other as "SUBSOIL". Sample for pesticide residue/plastic analysis should go directly into the cloth bag.
Jute bags	Size: 50kg bags; The number of bags is dependent on the number of samples to be carried (not more than 30-40 samples per bag).		You need the jute bags to carry the soil samples in the field and for transportation and later shipping to the lab. The number of bags depends the weigth you want tocarry per bag. (Thirty (30) soil samples may weigh already 20 kg). Use rice bags if more readily available.

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A box to store and transport the samples			Serves as possilbe alterantive to jute bags for carrying and shipping the soil samples (is not the preferred and recommended option)
Measuring tape	The tailor-type measuring tape (tape rule)		Any type or device that can be used to measure 20 cm, 50 cm, and 100 cm on the soil auger (and on pipe or spade when applicable) to mark these points, such that soil depth can be measured for soil sample collection and soil depth measurement.
Knife	One blade of about 20cm		A straight knife is needed to remove the soil samples from the auger or to slit the soil on the spade
Hand trowel	One (1)		Hand trowel is needed for mixing the soil samples in the buckets -making of composite soil sample
Appropriate wears			Safety shoes/boots, jungle boots, and raincoat, Appropriate clothing for the type of work and weather conditions are necessary.

2.2 Loading sampling location coordinates into handheld GPS device

If the surveyor will be using a GPS for navigation in the field, all the locations of the sampling points assigned to the surveyor needs to be uploaded to the GPS device. The list of points together with their coordinates will be provided by the CS and will be available through the SDMT. Depending on the GPS device, the coordinates need to be in a specified format (though very much standardized across the various brands) and may therefore require conversion. Instructions are provided below. Call in the help of the CS in case you need any help in this.

2.3 Downloading MAPS.ME app and uploading sampling locations' coordinates

1. First download and install MAPS.ME app on your phone (you need internet access). You will be able to do this using the Play Store on your phone (https://play.google.com/store/apps).

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2. Click to open MAPS.ME.
3. Click on the 3 horizontal bars
4. Click on ☰ and then select "Download Maps".
5. Click on the "Find map" bar and type in the name of your country, e.g., Ghana.
6. Click Download. In this way you have successfully downloaded your country map. You only need to do this once. Ensure your location is enabled on your device. You can do this on the settings of your phone.
7. Select ☰ and choose "Terrain" as map layer.
8. Also, download the file containing the coordinates of the sampling locations and save on your phone (you need internet access for this). You will receive the file as an email attachment from your Country Supervisor or their designates. The file will be in KML format. If the file is in csv format, convert to KML according to the instructions given in section 2.2 above.
9. Click to open the KML file containing the coordinates of the sampling locations which you have saved on your phone. Click on the file, some options to open the file will pop up (depending on the types of apps you have installed on your phone)
10. Click on open with MAPS.ME. The app will open, and a message will pop "Bookmarks loaded successfully! You can find them on the map or on the bookmarks Manager". The message will disappear in less than 20 seconds.
11. The points will be displayed by their name, which will be coordinate of the sampling point. To change the name of the sampling point to the sampling point ID such that the points are displayed by their name, rather than by their coordinates, you edit the name of sampling points:
12. Select ☆ in the menu bar and click the file name to open.
13. All the points in the file will be displayed by the coordinates as name. Select the ⋮ for "more" at the far right end of the point that you want to change the name off.
14. A menu will pop up and select "Edit"
15. A new screen will appear with the Name, Set and a placeholder where you can add "Your Description"
16. Select the name (click on the name, which are the coordinates at this point still)
17. Delete the coordinate and enter the sampling point ID corresponding to this particular point.
18. Click on SAVE (to save the changes)
19. Repeat step 12 to 17 for all points in the file.
20. Go back to the main menu and you see all the points displayed by their sampling point-ID (SP-ID)

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3 Safety and Security issues

Ensuring security during fieldwork is a crucial aspect that requires careful consideration to protect both lives and property. Here are some important guidelines to follow:

- Always work in pairs, with at least two individuals. This not only boosts security but also allows team members to assist each other when needed.
- Get acquainted with the security conditions in the area where the survey will take place. If you identify any significant concerns, please inform the country supervisor at CARI.
- As a surveyor (SP), it's your responsibility to address any potential hazards you might encounter. Take proactive measures to eliminate, minimize, or report these risks, and adhere to safety and health protocols as appropriate.
- Before conducting any sampling in the field, ensure you have the consent of the community leader, village head, or their representatives. Introduce yourself and clearly explain your purpose for being there. If you meet with the farmer or plantation manager at the sampling site, obtain their permission as well.
- Local security, such as community vigilantes, can often be arranged at a minimal cost and can be especially beneficial since they are familiar with the farmers in the area.
- Exclude any areas that require more than an hour of walking to access, as well as any restricted or unsafe locations, from your survey. Utilize the available backup sample locations in such cases.
- Always carry your accreditation letter during fieldwork. It's generally a good idea to introduce yourself to local authorities and community leaders to explain the purpose of the soil survey you are conducting.
- Assess how close you can safely travel by car to specific sampling locations, as this can significantly impact the efficiency of your surveys and minimize security risks, such as getting lost.
- Before heading into the field, make sure you have the following important contact numbers:
  - The phone number of local security personnel in the area where you'll be working
  - The phone number of a trusted relative or family member who is aware of your mission
  - The phone number of the country supervisor
  - Join the dedicated WhatsApp group for the Soils4Liberia Field Campaign, which has been established.
  - Optionally, have the number of a local authority or head from a community or town nearest to your sampling area.

When you follow these guidelines, you can help ensure a safer and more effective fieldwork experience.

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4 Navigating in the field

Effective field navigation is crucial, accounting for 60% of the overall effort required for the survey. This skill directly affects both the effectiveness and efficiency of the work. The number of sampling points you can complete in a day is closely tied to how well you can navigate. This section will guide you on using your phone for navigation when a handheld GPS isn't available, as well as on using a handheld GPS effectively in the field. There are various methods to achieve this, from traditional topographic maps to modern GPS navigation tools. We'll focus on the latter, specifically GPS handheld devices, the Google Maps app, and the maps.me app. It's essential to load the sampling points into any device or application you choose for navigation. For detailed instructions on how to upload these points, please refer to section 2.1

4.1 Navigating using a handheld GPS device

Navigating with a handheld GPS device follows the same steps regardless of the type of device. Now that you have loaded all the points assigned to you on the GPS device, travel to a known location near the point. Switch on the GPS device as soon as you are unsure of your direction. An example of how to navigate using Garmin Etrex 10 device is provided below. The GPS can be used while still in the car to indicate direction and distance to a point, but the instructions are intended particularly for navigating in the field on foot or by motorcycle.

1. On the GPS device, scroll to "Waypoint Manager" and select the waypoint manager

2. Select any of the points you wish to go to (Advisable to do the points closer to you first)

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3. A new page will appear with the 'Go' highlighted and showing the coordinates of the point. Select the "Go" and follow the arrow (move in the direction the arrow points). Direction and distance to the point are indicated. If the distance is still large it is advised to find and use existing foot paths that bring you nearer to the point and navigate directly to the point, traversing the fields, when the point is in sight (within 50 – 100 m, for example)

4. You can use the arrow keys on the device to zoom in and out for ease of navigation. Your device will either make a sound (Arrive at the point) or read "0 m" when you are at the point for sampling. Please take the soil samples as soon as the distance to the point is 10 m or less.

4.2 Navigate in the field using MAPS.ME app

1. Open the MAPS.ME app
2. Select  in the menu bar and click the file name to open

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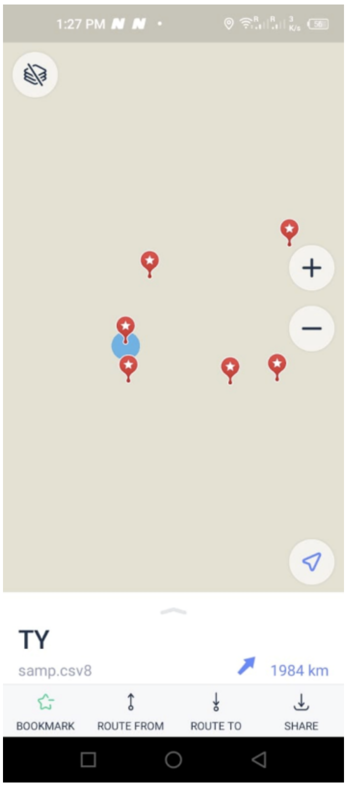
3. Select the point you want to navigate to. A screen will appear as in the example below (left)



4. Click on "Route To". A line connecting your location with the selected point appears (see the picture above, right), select Car  or walk .
5. Select car if you are far away from the point (>500 m) and the distance is motorable otherwise select . A start bar will appear, click on "START" and begin navigating. Follow tracks in the field rather than cutting through the bushes. The app will indicate whether you are getting any closer.

5 The Sampling design and criteria for secondary or tertiary sampling unit rejection

Sampling design

The sampling design, based on spatial coverage sampling, is a nested design with three levels, each representing a sampling unit. Sampling locations are clustered at the third level to increase operational efficiency. Good spatial coverage is achieved by constructing compact geographical strata (CGS) using a clustering algorithm. The algorithm produces a set of geographic strata of approximately equal size that are as spatially compact as possible. Geographic stratification will yield more precise predictions when the variable of interest is spatially structured, as is the case with soil (Brus, 2022).

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Primary sampling units

Different sampling densities are needed for the breadbasket lands compared to other agricultural lands, so the CGS were created separately for each area. These CGS serve as the primary sampling units (PSUs). Figure 1 illustrates the CGS covering the survey area. There are 167 CGS within the breadbasket area and 143 CGS in the other agricultural area. The average size of a CGS is 111 km² in the breadbasket area and 166 km² in the other agricultural area. This means that the sampling density in the breadbasket area is 1.5 times higher than in the other agricultural area.

Secondary sampling units

The secondary sampling units (SSUs) constitute the second level of the sampling design. Each SSU is defined as a 2 x 2 km area. The SSU is the centered on the centroid of the PSU such that the centroid of the CSG forms the center of the 2 x 2 km area.

Tertiary sampling units

Within the SSU, three sampling locations are selected for soil sampling. These locations constitute the third level of the sampling design and are referred to as the tertiary sampling units (TSUs). Each TSU is a 1 m by 1 m area. The first TSU is located at the SSU center (and thus at the center of the PSU), ensuring optimal spatial coverage. The other two TSUs are selected randomly within the SSU, subject to a minimum separation distance of 250 m between TSUs. Because all TSUs are situated within a 2 x 2 km area, they are within walking distance from each other.

Backup sampling units

Each Primary Sampling Unit (PSU) includes four backup Secondary Sampling Units (SSUs) in case the planned SSU at the PSU center cannot be sampled. These backup units are randomly selected from within each PSU. Because the PSUs are relatively small compared to the size of an SSU, the five SSUs (one planned for sampling and four backups) within a PSU may overlap. Figure 2 illustrates the configuration of the five SSUs within a single PSU.

Within each SSU, three backup Tertiary Sampling Units (TSUs) are included in case one or more of the planned TSUs cannot be sampled. Therefore, a total of six TSUs are selected within each SSU: three designated for sampling and three serving as backups. The backup TSUs are also selected randomly, while maintaining a minimum separation distance of 250 meters. Figure 3 depicts the configuration of the six TSUs within one SSU.

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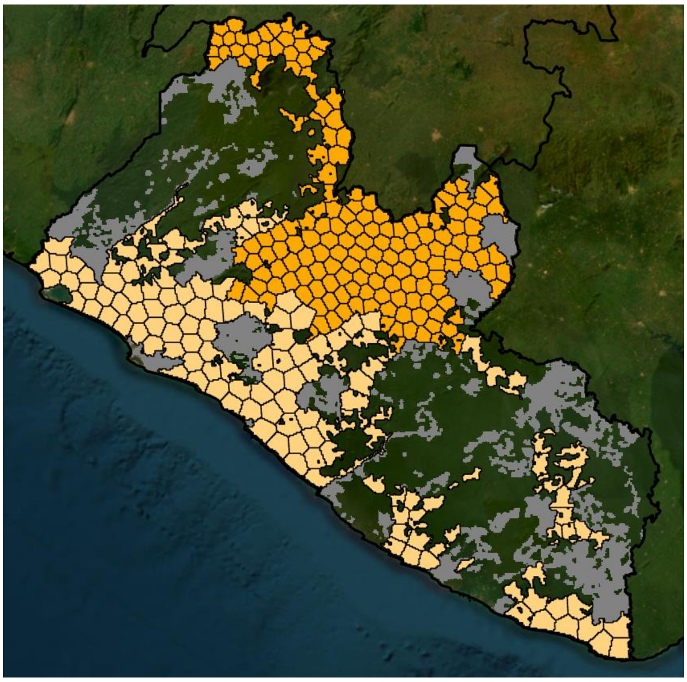

Figure 1. Compact geographic strata that serve as the primary sampling units of the sampling design.

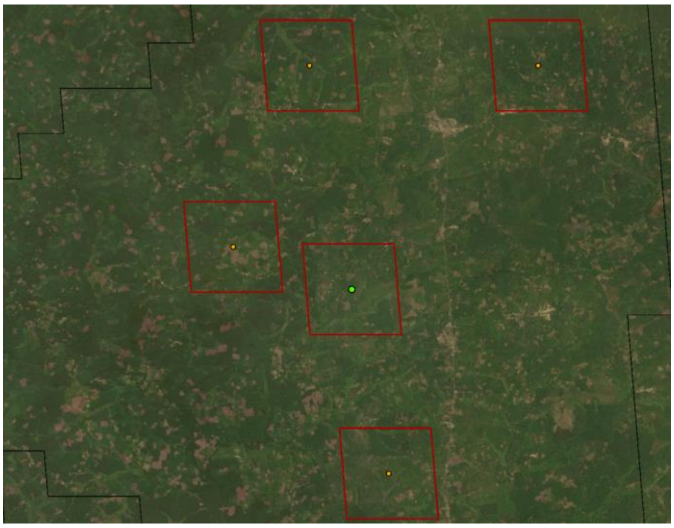

Figure 2. Location of five SSUs within one PSU (black outline). Each SSU is a 2 x 2 km area that is delinated by a square bounding box. The SSU with the large, green point is the planned SSU situated in the center of the PSU. The other four are backup SSUs (orange points designate the SSU centers).

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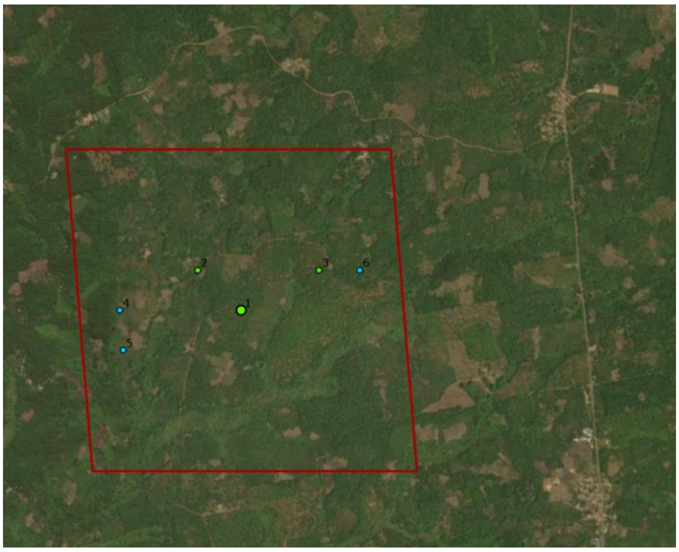

Figure 3. SSU (2 x 2 km area delinated by the squre bounding box) with six TSUs. The first three are planned for sampling (1-3), the others (4-6) are backup TSUs.

Sampling order

Each PSU contains five SSUs, and each SSU contains six TSUs. Both SSUs and TSUs are assigned sequential numbers (1-5 for SSUs and 1-6 for TSUs) that determine the sampling order. In principle, SSU number 1 should be sampled. If it is not possible, SSU number 2 (the first backup) should be considered. If SSU number 2 cannot be sampled, SSU number 3 should be used, and so on in sequential order.

Similarly, TSUs numbered 1 to 3 are the primary sampling locations and must be sampled. If any of these cannot be sampled (e.g., because of denied access, the site being located on a road, etc.), TSU number 4 (the first backup) should be sampled, followed by numbers 5 and six in that specific order, if necessary.

Adhering to this sequence prevents preferential site selection, which could introduce selection bias and reduce the overall information content of the dataset. Such bias may ultimately compromise the quality of the soil maps derived from the data.

Validation

Sampling units must be validated before going into the field to assess whether they can be sampled. This process reduces the risk that field surveyors travel to a site to find out that sampling is not feasible because of constraints, such as inaccessibility due to difficult terrain.

Validation takes place at the level of the SSU and is conducted using the Survey Data Management Tool (SDMT) and this is the responsibility of CARI/CS. Based on inspection of aerial imagery, the field survey lead must determine whether an SSU can reasonably be visited. Some SSUs are located close to roads, where accessibility is unlikely to pose a problem. Others may be located farther from the road network. For these SSUs, the field survey lead must assess whether the site can be reached with a reasonable amount of effort. Including SSUs that are farther from the road network is important to avoid selection bias.

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If the CS determines that a selected SSU cannot be visited, it may be rejected for sampling. The SDMT will then display the next (backup) SSU in the predefined sequence for validation.

Validation of the TSUs is typically carried out by the field surveyor based on on-site conditions. Surveyors are strongly encouraged to make a reasonable effort to reach planned TSUs that are located farther from the vehicle parking location. This is essential to avoid introducing selection bias and compromising the representativeness and integrity of the sample.

Below are the options the surveyor can choose to indicate the reason for rejecting either the TSU. The various reasons are categorised into four groups/classes

Attribute: Reason for rejecting sampling unit (Code: SPrej)

Category	*Code*	*Details*
Restricted access	**RA**	
	RA01	• Fenced off areas used for other purposes than for agriculture (e.g., airports and other public services)
	RA02	• National parks and other protected areas
	RA03	• Private estate/farm with access being denied
Security challenge	**SC**	
	SC01	• Areas officially recognised as insecure areas
	SC02	• Local security threats area
	SC03	• Presence of wild animals in an area
Inaccessible terrain	**TI**	
	TI01	• Dense impenetrable vegetation
	TI02	• Swamps and other wetland areas
	TI03	• Obstacles in the terrain (e.g., streams, escarpments)
Non-cultivated managed land	**NCL**	
	NCL01	• Private gardens
	NCL02	• Sport fields
	NCL03	• Religious camps
	NCL04	• Park and Parklands
	NCL05	• Managed lawns
Miscellaneous land use	**MLU**	
	MLU01	• Alluvial land - Areas of unconsolidated alluvium recently deposited and subject to frequent changes
	MLU02	• Badlands - steep to very steep barren land, with active geological erosion, also rough broken land
	MLU03	• Beaches
	MLU04	• Blown-out land - Area with most of the soil material removed by wind - extreme degree of erosion

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MLU05	• Colluvial land: Unconsolidated recent colluvium - heterogeneous deposit of soil material, rock fragments
MLU06	• Ditches and spoil banks - ditches and rock waste banks and dumps from excavations
MLU07	• Dumps - Area of uneven accumulation or piles of waste rock, including tailings
MLU08	• Marsh - Periodically flooded areas with grasses, cattails, rushes or other
MLU09	• Oil-waste land: Accumulation of liquid oily wastes
MLU10	• Pits and Open excavations from which soil and underlying material has been removed
MLU11	• Rock land - Area having rock outcrop and very shallow soil (rock outcrop between 25 - 90%)
MLU12	• Rock-outcrop Exposure of bare rock
MLU13	• Swamp - Naturally wooded areas which are covered with water most of the time
MLU14	• Stony land - Areas with enough stones and boulders to submerge other soil characteristics
MLU15	• Shifting sands

The project has procedures for excluding sampling units, especially PSUs, in areas of known security challenges or with restricted access (like national parks or other protected areas) and these sampling units will not be part of the list of sampling points offered to the surveyor. But areas with local security challenges are often less known and that information might reach the surveyor only when he is in the field. In such cases, the surveyor will inform the CS to reject the SSU before proceeding to field locations and will subsequently be unable to record the reasons for rejection while filling the ODK forms in the field. In such cases, the Surveyor will contact the CS to explain why the sampling units will not be surveyed, and, if the CS agrees, he/she will confirm the decision by flagging the sampling points in the SDMT for exclusion from the survey.

The CS needs to confirm the decision not to include those points and will make the corresponding annotation in the SDMT.

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6 Soil sample collection

This section describes the general layout of the sampling plot, provides instructions for taking samples with the various tools, and outlines bagging and labelling the soil samples.

6.1 Layout of the sampling plot

A Soils4Liberia sampling plot measures 100 by 100 m. In this sampling plot, soil samples are taken at four (4) sub-locations according to the configuration in the Fig. 4. One sub-sample is taken at the centre of the plot and the other three sub-samples are taken on a circle with a radius of about 5 m from the centre point at equidistance from each other. The 5 m is measured by taking three steps from the centre point (these are normal steps; small people need to stretch a little to reach the approx. 70 cm per step). Thus, sub-samples are collected in a Y-frame.

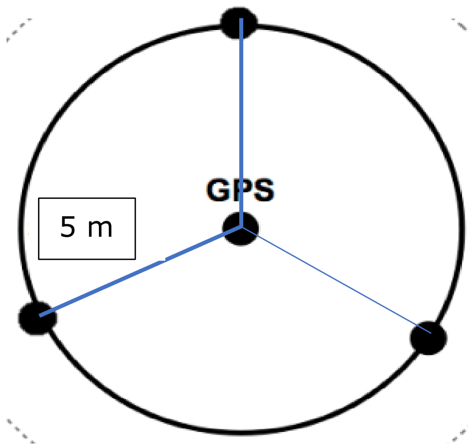

Figure 4. Configuration of the sampling plot

Soil samples are taken at two depths: 0-20 cm (topsoil sample) and 20-50 cm (subsoil sample). Topsoil samples from the four sub-locations are collected in the bucket labelled 'TopSoil", and thoroughly mixed. The four (4) subsoil samples are also bulked and thoroughly mixed using the bucket labelled "SubSoil" to provide for one composite subsoil sample (see the section on how to make composite samples). Sample collection can be done with an auger, spade, or pipe or corer, depending on which one you have but the use of an auger is preferred.

In cases of soil depth restrictions, samples are still collected if it is possible to obtain sufficient soil from at least two of the four sub-locations. In practice, this means that you must be able to auger to at least 10 cm within the soil layer. That is to 10cm from the soil surface for the topsoil sample and that is to 30cm depth at least for the subsoil sample. The depth restriction needs to be indicated at all times to avoid confusion in interpreting the results of the soil analysis.

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6.2 Disturbed soil Sample Collection

6.2.1 Sample collection using an auger

1. Clear away any litter or vegetation from the sampling area.
2. Insert the auger straight down into the ground, ensuring it remains vertical and does not tilt sideways.
3. Collect the topsoil sample from the center of the plot and place it in a designated bucket for topsoil.
4. When sampling the subsoil, ensure that no surface (topsoil) material falls into the auger hole. To prevent this, always remove the upper one-third of the soil from the auger and discard it. Repeat this step each time you collect subsoil.
5. Avoid overfilling the auger when taking the subsoil sample, as this could distort the volume of the auger hole. To mitigate this, empty the auger regularly at depth increments of 10 cm (for example, at 20-30 cm, 30-40 cm, and 40-50 cm).
6. Ideally, collect the topsoil samples from all four sub-sampling locations before collecting the subsoil samples. Clean the soil auger before moving on to the subsoil samples.
7. Combine (pool) the topsoil samples from each subplot into one bucket, and do the same for the subsoil samples in a separate bucket labeled "subsoil."
8. Thoroughly mix the soil in the buckets using a trowel.
9. Take approximately 1.5 kilograms for each composite sample topsoil and subsoil. This is roughly 4 handfuls of soil per sample. Place the soil in a plastic bag, tie it securely with a knot, or use a stapler to seal it. Store the bag with the topsoil sample in the topsoil bucket and the bag with the subsoil sample in the subsoil bucket, labelling them appropriately.
10. Clean the soil auger using grass or leaves found at the sampling site before proceeding to the next sampling location.

6.3 Undisturbed soil Sample Collection

Use the soil sampling rings already supplied to take the bulk density samples. Ensure that the area has not been disturbed. Avoid sampling near roots, stones, cracks, or termite channels. Reject samples showing visible compression or incomplete filling.

Collect the undisturbed samples as follows:

- Carefully remove surface litter (leaves, crop residues) without disturbing the mineral soil.
- Excavate a small pit to expose the desired sampling depth (e.g., 0–20 cm) and take the sample within the topsoil layer
- Place the core cylinder vertically against a flat, undisturbed soil face.
- Gently press the cylinder into the soil by hand to ensure alignment.
- Using a rubber mallet and driving head, carefully drive the cylinder into the soil until it is fully inserted.
- Avoid excessive hammering and prevent tilting or compaction during insertion.
- Ensure the soil fills the entire core without visible gaps.

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- Carefully excavate soil around the cylinder using a knife or small shovel.
- Remove the core slowly to prevent disturbance.
- Trim excess soil from both ends using a sharp knife so that soil is flush with the cylinder edges.
- Ensure no compression or voids are visible.
- Collect at sample in triplicates
- Protect from direct sunlight and excessive heat and transport to laboratory as soon as possible.

6.4 Labelling and bagging

Bagging and labelling are important aspects of quality assurance. They must be done properly to ensure that soil samples are correctly identified throughout handling and analysis, so that the results of the analysis are not attributed to the wrong samples. The sample from each bucket is placed in a different bag. The bucket used to collect topsoil samples should be the same for all sampling points. The same applies to the bucket used for the sub-soil sample. And this should not change from one location to another or from one day to the next to avoid confusion. Always indicate 'BD' on the bulk density bag.

6.4.1 Bagging

The samples collected should be double bagged, with a plastic bag as the inner bag to contain moisture and a cloth or paper bag to provide strength and prevent the plastic bag from tearing. The inner bag needs to be closed by either tying or by stapling, depending on the type of plastic (if thick and hard, it needs to be stapled). The label (the soil sample ID) is placed between the inner and outer bags (ensure the barcode is scanned before it is placed in the bag). The outer bag (cloth or paper) needs to be closed as well. For the paper bag a stapler is best used. The cloth bag is tied with the cord that comes with it (otherwise fold and staple). a rope.

6.4.2 Labelling

1. Scan the barcode with the smartphone into the appropriate section on the ODK form.
2. Insert the QR/barcode in between the inner and outer bag.
3. On the outer bag, write the sampling point ID legibly and indicate "T" for topsoil samples and "S" for subsoil samples. Write with a permanent marker.
4. The soil sample ID consists of a 2-letter country code and a random sequence of alphanumeric characters, which can be either in lower or upper case. The bar code comes in duplicates (two identical QR codes on the same piece of paper) and should also be entered as a duplicate soil sample ID in the sampling bag. The SS-IDs are provided (made available) to the surveyors. If they are printed only (not laminated), the duplicate barcode needs to be placed in the small plastic pouch (zip file), sealed/zipped to prevent it from getting wet, and then placed in the sampling bag.

6.5 Leaving the site

When the work is done, please leave the site neat and clean. The auger hole (pit) needs to be closed and left in a condition as close as possible to before opening the pit

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(before augering). Try to get the soil back into the pit/hole, such that animals do not easily step in the hole and break their leg. Please make sure that no plastic, paper, or other materials are left at the site!

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7 Field Observations – Soil and Site Characteristics

Field observation data will be collected from the designated sampling locations. Observations will focus on various soil properties, including soil depth, stoniness, and drainage. Additionally, assessments will be made of soil surface characteristics, including erosion caused by water and wind, and the presence of stones.

Observations will also consider the land and terrain characteristics, including landform and slope. Either of the four sub-sampling locations can be used for these observations. If the centre point in the plot layout is unsuitable (e.g., due to depth restrictions, stones in the profile, or other obstacles), one of the other sub-sampling locations should be utilised to ensure valid observations. Specific observations to be made for each category are outlined below.

7.1 Soil depth determination

Soil depth is measured using an auger. The depth is recorded at the point where restrictions prevent further augering, even when considerable force is applied. These restrictions may be caused by hitting rock, encountering gravel and stones, or finding types of hardpan (such as iron pan, dense clay layer, or plough pan).

To determine soil depth, use the auger until you encounter any restrictions. Apply significant force to confirm that it is not possible to go deeper. Record the depth at which these restrictions occur. Depth classes are defined according to the classification system provided in the table below, which is adapted from RECARE 2018, Europe's soil research hub.

The auger has depth markings at 20 cm and 50 cm, which help to determine the depth class. It is 120 cm long, and there is a 100 cm mark located 20 cm below the handlebar. Record the depth class and specify the cause of the restriction in the ODK form. If there are no restrictions within the 120 cm depth, select "very deep" on the ODK form.

Attribute: Effective Soil Depth (Attr. Code: SDE)

Code	Depth (cm)	Indicator
SD1	0 – 25	Very shallow
SD2	25 – 50	Shallow
SD3	50 – 100	Moderately deep
SD4	100 – 120	Deep
SD5	>120	Very deep

Type of soil depth restriction (Attr. code: SDRN)

The nature of the restriction that prevents deeper augering is identified. This restriction may occur due to hitting solid rock or a layer of broken rock fragments, which can vary in size and may include fragments as small as gravel. In such cases, the depth measured is the actual soil depth.

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Another possibility for a restriction is encountering a cemented or compacted layer (horizon) within the soil profile that cannot be penetrated by the soil auger. The specifics of the cementation or compaction must be noted. For example, cementation may occur due to iron, leading to the formation of an iron pan or hardened plinthite, or it may be caused by clay, in the case of compacted horizons with a high clay content. Mechanical action, such as ploughing, can also create an abrupt transition to a compacted layer at a depth of 20 to 30 cm, which cannot be attributed to either cementation or an increase in clay content.

Additionally, iron and manganese concretions, commonly found in many soils, can restrict augering. While these nodules may not entirely prevent further augering, they can hinder root development if the layer is predominantly composed of such nodules. This layer is often classified as 'nodular' and may also include concretions formed from lime or carbonates.

If groundwater is encountered within 120 cm of depth, it is also considered a restriction for rooting or effective soil depth and should be recorded. Finally, there is an option to indicate when the nature or type of restriction is unknown.

Attribute: Soil depth restriction nature (code: SDRN)

Causes	**Code**
Bedrock or rotten rock (with dominant stones or gravel)	BRR
Iron pan or hard plinthite	Fe
Pisoplinthites (Fe and Mn concretions)	FeMn
Strong compaction or hard clay	Clay
Plough pan/Mechanical	PP
Ground water	GW
Not known	NK

7.2 Soil texture, colour, stoniness, and presence of mottles

Observations on soil texture, colour of the soil matrix, stoniness, and the presence of mottles are made for the soil layers 0-20cm, 20-50cm, and 50-120cm. The soil texture is specified only in general terms, and since the texture is in principle, determined in the lab, it is used for cross-referencing mainly:

- Sandy
- Loamy
- Clayey
- Silty

The soil colour refers to the colour of the soil matrix and the colour of mottles, if present, are not recorded. For sake of convenience, the dominant colour of the soil when moist is indicated:

- Blackish
- Blueish/greenish or greyish

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- Brownish
- Reddish
- Whitish
- Yellowish

Stoniness is recorded in terms of stoniness class, based on the estimated volumetric content of gravel or stones:

- None
- Very few (0-2%)
- Few (2-5%)
- Common (5-15%)
- Many (15-40%
- Abundant (40-80%)
- Dominant (> 80%)

Mottles are only recorded by their presence (Y/N) and serves mainly to countercheck with the drainage class presented in the next sections

7.3 Soil drainage class determination

Soil drainage is a natural process in which water moves through, across, and out of the soil due to the force of gravity. The drainage class of soil is determined by examining visible signs in the soil profile that indicate the soil remains saturated with water for a significant portion of the year.

One key indicator of soil drainage is the presence or absence of mottles. Mottles are spots or blotches of different colours, usually grey or orange, that are interspersed within the main soil colour. They result from the processes of oxidation and reduction in the soil. When the soil is waterlogged, air is not available, leading to the reduction of various elements and compounds—especially iron (Fe)—which causes greyish colours. Conversely, when the soil is drained (at least for part of the year), oxidation occurs, resulting in orange and reddish colours.

The accompanying picture displays a typical pattern of mottles in the soil. However, mottles may not be clearly visible in soil removed with a soil auger; rather, discolorations can be observed. This discoloration can help break up the clump of soil taken out of the auger. Therefore, while augering to determine soil depth, it is important to inspect the soil extracted at various depth layers for mottles and/or clear discolorations. The drainage class is assessed based on the prevalence of mottles and the depth at which they are found, according to the specifications outlined in the provided table.

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Attribute: Soil Drainage class (Code: SDrain)

Code	Class	Description/specification
D0	Very poorly drained	Water table remains at or on the surface for considerable time of the year, greater part of the time Visible sign: You find water on the soil surface after 24 hours of rain; the soil matrix has greyish colours
D1	Poorly drained	Water removed slowly and remains wet for larger part of the time; water table at or near surface for considerable part of the year; high water table or slow permeable layer in soil profile or seepage Visible sign: You find many mottles in the topsoil
D2	Imperfectly drained	Water removed slowly to keep it wet for significant periods; mottles below 15 cm or evidence of gleying directly below A horizon; requires drainage to make suitable Visible sign: You find few mottles on the topsoil but increasingly within the subsoil
D3	Moderately well drained	Uniform colour in A and upper B horizon, with mottling in the lower B and C horizons Visible sign: You find mottles only in the subsoil beyond 20 cm depth, but few
D4	Well drained	Uniform colour no mottles. Water removed readily but not rapidly. May be gley mottled deep in the C horizon or below 120 cm depth. Visible sign: You find very few mottles only in the subsoil or no mottles at all, but the soil is not excessively drained
D5	Excessively drained	Water removed rapidly, little horizon differentiation sandy and porous soils Visible sign: No mottles within the soil and the soil is completely sand or loamy sand

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7.4 Soil erosion

Erosion caused by water movement at the soil surface (runoff) is classified into three types: sheet erosion, rill erosion, and gully erosion.

Sheet erosion occurs when soil is removed and transported across the surface as a thin layer of water. It is often difficult to detect, especially in worked land. However, the presence of stone pedestals is a visible sign of sheet erosion, which can be observed even when rills and gullies are not present. This type of erosion occurs when raindrop impact loosens the soil, allowing it to be washed away by surface runoff. Soil that is protected by stones does not erode, resulting in the formation of pedestals.

Another phenomenon related to erosion is the formation of stone pavements, which can occur due to deflation. This happens when soils containing stones are eroded, causing stones to accumulate at the surface over a prolonged period. Even on worked soil, high concentrations of stones can still be found on the surface.

Visible signs of rill erosion and gully erosion are clearer than those of sheet erosion, although it can be difficult to determine whether they indicate active erosion or are remnants of past events. The off-site effects of water erosion include sediment deposition, which is categorized separately.

Another type of erosion is caused by wind. This is evident in the visible signs of wind erosion, which may reflect both soil material removed and deposited. Shifting sands, a form of wind erosion, do not qualify as agricultural land and thus are not included in this classification; sampling points in such areas are rejected. However, salt deposited by wind erosion is considered a separate category.
The options to choose from for recording of soil erosion are given in the table below

Attribute: Soil erosion category (Code: SECat)

Code	Title	Definition
WE00	No erosion	No visible signs of erosion are observed
WE01	Rill erosion	A rill is a linear depression or channel in soil that carries water after recent rainfall. The channels are not more than a few cm deep (max 3 to 4cm). They are removed and not visible on land that has been tilled or ploughed. The rills point in the same directions and distance between

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consecutive rills can be up to meters

WE02 Gully erosion

Gully erosion is a deep depression or channel in a landscape, looking like a recent and very active extension to a natural drainage channel. It is a consequence of water that cuts into the soil along the line of flow. In contrast to rills, they cannot be obliterated by ordinary tillage.

WE03 Stone pedestals

Soil under a small stone or boulder is protected from the impact of rain drops, whereas the soil surface surrounding that stone is not, and where the soil is slowly washed away, resulting in pedestals that are easily observed.

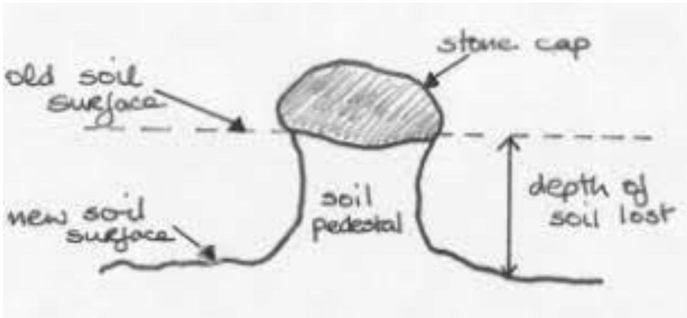

Figure 1 Drawing explaining the origin of stone pedestals (source: M. Stocking)

Picture 1 Illustration of stone pedestals (source John F. Williams); in the field isolated stonepedestal are observed generally.

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WE04	Stone pavement	If soils have stones within their profile, these stones will emerge at the soil surface upon removal of the topsoil by erosion, resulting in a stone pavement, sometimes referred to as desert pavement or armour layer. Mostly different stages of deflation are observed rather than the surface being completely paved. It will still be recorded as such when observed. Even when the land is ploughed it may still be observed.

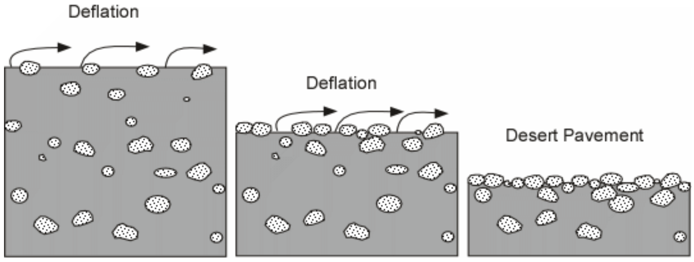

Figure 2 Picture explaining the process of desert pavement formation (source Tulane Univ.)


Picture 2 Exaple of armoured layer (courtesy: Tim McCabe USDA/NRCS)

EWSM	Wind erosion Y/N	Visible signs of wind erosion are blown out land, looking as if the soil surface has been abraded and/or fine sand deposited in the wind shadow of plants or other small obstacles.
EWSD	Salt deposition	Deposition by wind, not salt flats or plains resulting from salt lakes that are not classified as agricultural land

7.5 Soil surface sealing and crusting

Soil surface sealing results from slaking of soil surface components or may result from sedimentation or deposition and results in a compacted surface layer with reduced porosity. We talk about sealing when no drying and hardening has taken place and of crusting when drying and hardening has taken place. No distinction is made between the different type of crusting, whether soil crust, chemical (salt) crust of biological crust, or to the process involved. It is just recorded whether there are clear signs of

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surface sealing or crusting. The accumulation of salt at the surface (cover percentage, and type of salt) is also not recorded, even though the presence of salt in the soils is an important consideration in soil quality monitoring for arid or semi-arid regions. For agricultural land, these observations are not considered that relevant and difficult to measure accurately. Further information on salt content and salinity will be accessed through the lab analysis of the samples.

Attribute: Soil surface sealing and crusting (SSSCrust)

Code	Description	Illustration
Y/N	Notable presence of surface sealing (crust) Y/N	 (source: http://soilquality.org/indicators/soil_crusts.html)

7.6 Surface stoniness

Stoniness refers to the percentage of the soil surface covered by stones. Stones can vary in size, ranging from gravel to boulders; however, the specific size class is not recorded. A photograph of the soil surface will indicate the size class. To accurately estimate the percentage of surface area occupied by stones, you must adjust your observation window according to the size class. For large stones, a significant area must be considered specifically, a circular area with a radius of 10 meters or more.

The chart below (Figure 5) provides a guide for estimating surface cover percentages, which will help determine the stoniness class based on the specifications provided below. The stoniness class is only recorded if stones, boulders, or large boulders are present.

Stoniness class

0 No stones: surface cover of less than 0.01%. There are not enough stones to interfere with tillage.

1 Slightly stony: soil surface covered: 0.01 - 2%; enough stones to interfere with tillage, but not to make it impracticable (e.g., stones of 36cm diameter with an average distance of 10m gives 0.1% surface cover).

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2 Stony: surface area cover percentage: 2 - 5%; makes tillage impractical, but still possible when tillage by hand depending of the size of the stones and can be used for pasture or other crops (tree crops).

3 Very stony: surface area covered: 5 - 15% Makes use of any kind of machinery impractical except for handheld tools.

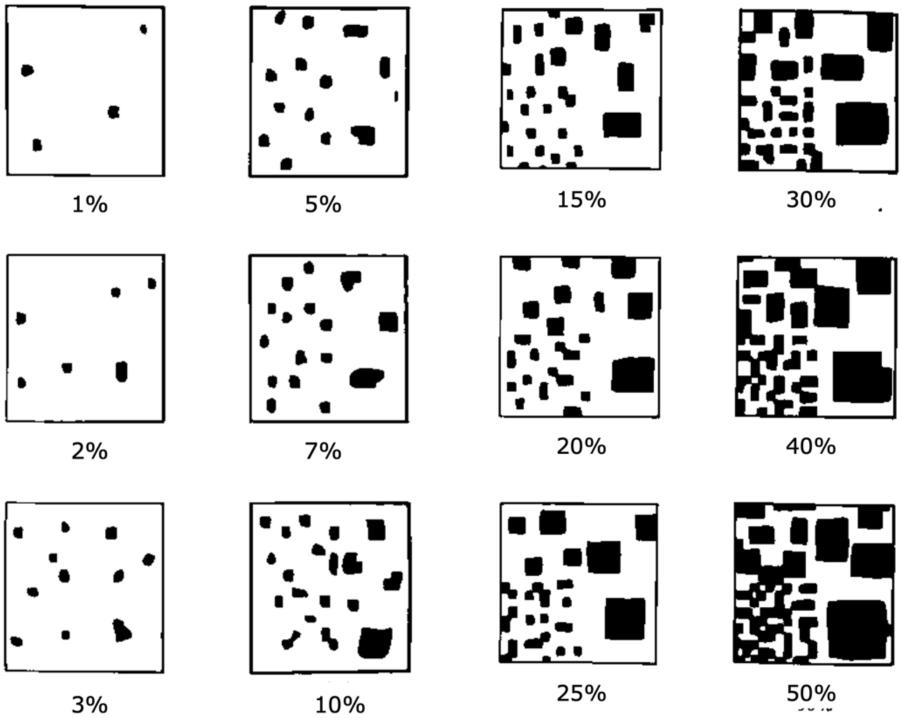

Figure 5 Graphs depicting cover percentages to be used as reference for estimating ground cover percentages in the field

4 Extremely Stony: surface area covered >15%

(Classes adapted from Soil survey Manual -USDA and in alignment with the FAO guidelines for soil description)

7.7 Landform and slope class

This section explains how to describe general landforms and slopes. When describing landforms, a broad observation area is utilized, extending beyond the immediate point of observation and often encompassing the entire Primary Soil Unit (PSU). We differentiate between flat, sloping, and steep land, which typically refers to mountainous regions.

For sloping land, we further categorize the slopes based on their steepness and orientation. This is particularly relevant for ridges, where slopes may face in two opposite directions.

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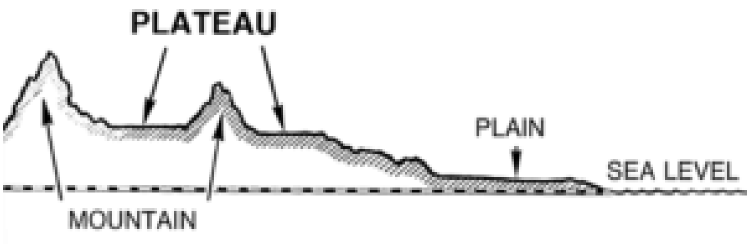
Landforms are defined by the shape of the land's surface without considering their genetic origin or the processes that created them. Using the SOTER approach, the various categories are assigned based on visual assessment of the physical environment. For example, gently sloping terrain has slopes not exceeding 10%, while moderate sloping terrain has slopes generally not exceeding 15%. Steep land is characterised by slopes that may exceed 30%. Codes are provided for the development of the Soil Data Management Tool (SDMT), which will be used to enter data on the Data Knowledge (DK) forms.

The figure below illustrates the differences between a plain and a plateau.

Attribute: Landform (Code: LandF)

Code	Landform	Subcategory
LP	Level land	Plain
LL		Plateau
LD		Depression
LV		Valley floor
SE	Sloping land	Escarpment zone
SH		Hilly landscape; undulating to rolling terrain
SP		Dissected plain
SV		Low or medium gradient valley



Slope class: The topography is described by the slope class; that is the range in slope percentage that the dominant slope within the 1-ha window of observation falls within. The 1-ha window of observation can be taken as the circular area with a radius of 50 to 60m approximately. It does not refer to the slope at the specific location of the sampling point. The surveyor needs to practice in the visual assessment of the slope percentage. For practical purpose, to estimate the slope percentage you walk down the slope until you are at eye height level with the point where you started from, estimate the distance to that point and divide your height (m) by the distance (m); multiply by 100 and you get the percentage. The following slope classes apply:

Attribute: Slope class (code: SlpCls)

Code	Class	Slope percentage
0	Flat to almost flat	0 – 0.5%
1	Very gently sloping	0.5 – 2.0%

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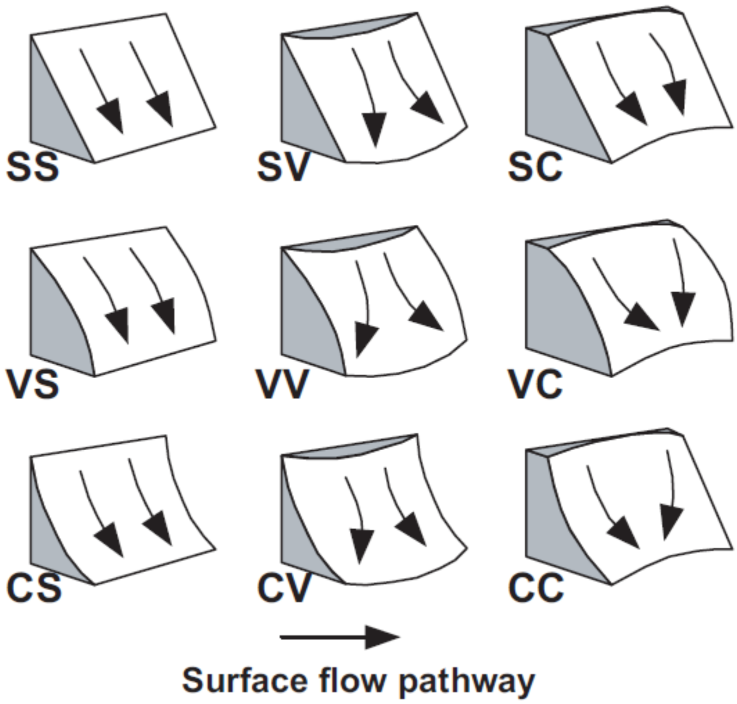
2	Gently sloping	2 – 5%
3	Sloping (undulating and gently rolling terrain)	5 – 10%
4	Strongly sloping (rolling terrain)	10 – 15%
5	Moderately steep (hilly terrain)	15 – 30%
6	Steep (very hilly or strongly dissected terrain)	30 - 60%
7	Very steep (very hilly and strongly dissected terrain)	>60%

Slope form and pathway: The slope form refers to the general shape of the slope in both the vertical and horizontal directions (See the figure below), and pathways indicate whether the slopes are converging or diverging. The graph below (FAO 2006, Guidelines for soil description) show the combination of both together with the codes for each of the categories.

Attribute: Slope form and pathway (code: SlpFP)

Slope forms and surface pathways (from FAO 2006 guidelines for soil description)

- SS – Straight-Straight
- SV – Straight-Convex
- SC – Straight-Concave
- VS – Convex-Straight
- VV – Convex-Convex
- VC – Convex-Concave
- CS – Concave-Straight
- CV – Concave-Convex
- CC – Concave-Concave



Slope position: The relative position of the site within the land should be indicated. The position affects the hydrological conditions of the site (external and internal drainage, e.g., subsurface runoff), which may be interpreted as being predominantly water receiving, water shedding or neither of these.

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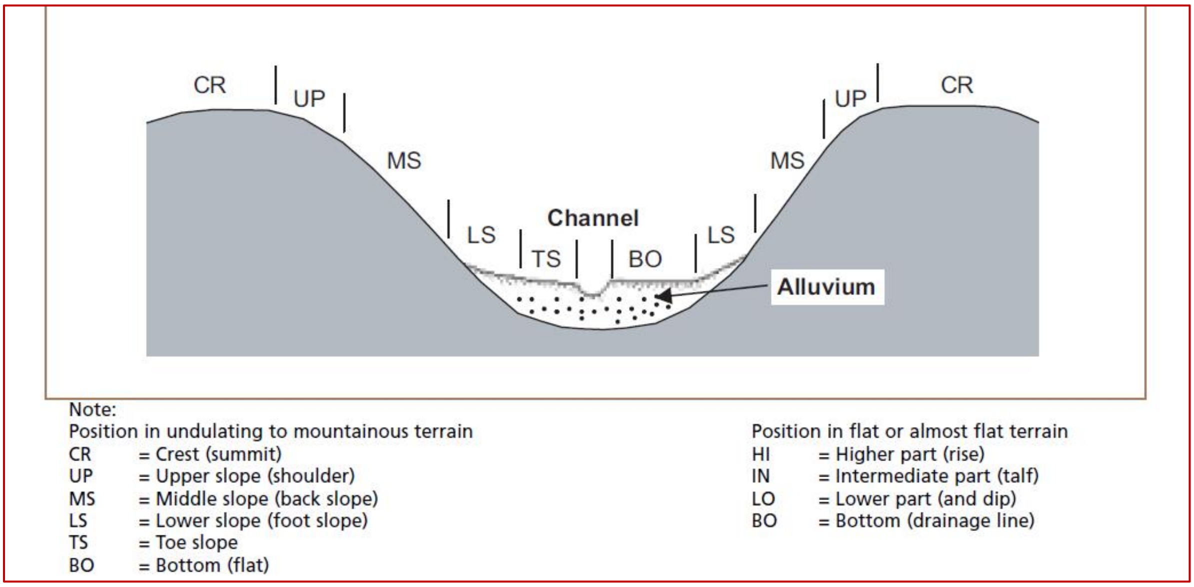

Slope positions in undulating and mountainous terrain (FAO 2006 guidelines for soil description)

7.8 Pictures of the soil surface and terrain

As part of the field observations three pictures are expected to be taken, to get additional pictorial data of the soil surface characteristics, the land use and land cover characteristics and the landform. The first picture is a vertically downward picture of the soil surface. Use a pencil, knife, booklet or jotter as reference for determining the scale. This picture will enable us to verify the surface characteristics of the soil as against what is filled into the form. The second picture is taken slanting downwards such that the furthest part still to be seen on the picture is 20 to 30 m away at least. Picture should be taken in the direction perpendicular to the slope direction. The third picture is taken in horizontal direction and likewise perpendicular to the slope direction. It serves to give an idea of the terrain and landscape.

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8. Protocol for making observations on land use, land cover and land & water management

This section provides instructions for observing land use and land cover. These observations focus on agricultural land and aim to assess soil quality, primarily by evaluating soil cover. Additionally, field observations on land and crop management are conducted to gather information on land-use intensity, which is crucial for interpreting and evaluating changes in soil condition and quality. The land management observations include various soil conservation measures and practices. Furthermore, observations on water management are made to identify methods to increase water supply to crops, such as irrigation.

8.1 Observations on land use

8.1.1 Observation unit (scale and window of observation)

Observations on land use are made at the TSU level. However, a 1-ha area might be difficult to oversee in some cases; therefore, an area of about 1000 m^2 surrounding the sampling point may be used as a practical observation window. This corresponds to a circular area with a radius of 17.8, let's say about 20m.

8.1.2 Main land use class

For the Soils4Liberia project, 60% of the observations are made for the agricultural domain and the other 40% are for the other land use domains. The land use can then belong to one of the four main land use categories only, and the main land use category is the first that needs to be determined. The main land use categories are the following:

- Cultivated and Managed Terrestrial Area (CMTA): This class refers to areas where the natural vegetation has been removed or modified and replaced by other types of vegetative, artificial cover that requires human activity to maintain and manage it. This can be any kind of crop, but also includes 'agricultural grassland' that has been sown, that is intensely grazed and/or mowed.
- Semi-natural vegetation (SNV): This refers to vegetation that is not planted but influenced by human actions and that may result from grazing, selective logging, or regenerative vegetation on previously cultivated areas. It includes areas of secondary regrowth during fallow periods in shifting cultivation systems.
- Cultivated aquatic (CAA) or regularly flooded areas: This includes areas where an aquatic crop is planted, cultivated, and harvested, generally referring to paddy rice, tidal rice or deep-water rice. Irrigated cultivated areas are excluded from this class but included in the Cultivated and Managed Terrestrial Areas.
- Natural forest or forest margins (NFA): These are areas under natural forest vegetation or areas that fall within forest transition zones with no clear or major anthropogenic influence.

For each of these main land use categories, a different set of attributes is considered that serve as classifiers for the land use class, and for which the attribute values are recorded in the field

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8.1.3 Dominant life form (Cultivated and Managed terrestrial area [CMTA] and Cultivated aquatic [CAA])

The concept of the dominant life form is applicable to both CMTA and CAA, although in the latter case, the dominant life form is usually limited to graminoids, such as rice.The concept of the dominant life form is applicable to both CMTA and CAA, although in the latter case, the dominant life form is usually limited to graminoids, such as rice.

The dominant life form is the life form of the uppermost canopy layer and of the crop that is the most relevant economically (the crop that represents the main purpose of the farming activities). For example, in a shaded coffee plantation, the dominant life form is "tree", being the life form of coffee, irrespective of whether the shade trees are commercially exploited as well, or whether there is an undergrowth, or whether a second crop (intercrop) is grown with some economic value. The options are the following:

1. Tree: Trees are defined as plants with a well-defined woody stem that is taller than 3m when full grown. In general, the criterion for distinguishing between tree and shrub life form is a height of 5 m. However, if the plant is smaller than 5m (but taller than 3m) and has the distinct physiognomy of a tree, then it is still classified as a tree.
2. Shrub: A shrub is a woody plant with persistent woody stems, but not with one defined main stem. It does not grow taller than 5m.
3. Herbaceous – Graminoids: Herbaceous plants are plants without a persistent stem or shoots and lacking a firm structure. Graminoids are herbaceous grasses and narrow-leafed grass-like plants. It includes cereals, grasses, rice, reeds and bamboos. Bamboos, though officially a graminoid, is classified under shrubs because of its physiognomy.
4. Herbaceous – Non-Graminoids: Includes all broad-leaved herbaceous plants and non-graminoid herbaceous plants. It can be subdivided into the following categories of crops: 1. herbaceous, 2. Bananas and other tree-like herbaceous plants, 3. cover crops, and 4. hops and other perennial herbaceous vines.

8.1.4 Purpose and crop type

For all the above the dominant life forms the purpose for which the crop is grown is indicated, which at the same time determines the crop type. They are divided into two main categories: Food crops and Non-food crops. The following crop types are defined.

1. Cereals
2. Fibre crops
3. Fodder plants
4. Fruits
5. Semi-luxury foods (tea, cocoa, coffee and nuts)
6. Oil crop
7. Pulses
8. Roots and Tubers
9. Vegetables
10. Other crops (e.g., rubber)
11. Nursery stock

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8.1.5 Spatial aspect (field size and spatial distribution)

The spatial aspect, because it refers to field size and pattern only applies to CMTA and CAA. We include two classifiers under the spatial aspect; that is field size and spatial distribution pattern. Both these classifiers imply other aspects, like mechanisation and cropping intensity for example, and provide relevant data for the information on land use intensity. The scale of the observation is smaller (window of observation is larger); that is, it applies to a considerable larger area than the unit of observation for the above-mentioned observations. It can refer to an area of 1 km^2 or larger, if that can be overseen from the point where the observation is made. Field size and field pattern can be easily verified from high resolution satellite imagery.

8.1.5.1 Field size

The size is specified in acres as well as in hectares (approximate corresponding area in ha). For reference, a football pitch measures about one and a half acres (the area between the lines demarcating the football pitch) and with the immediately surrounding land that goes with it, it covers about 2 acres. The field size class is given for the dominant field size, assuming a more or less even distribution of the field size in the area.

Attribute: Field size (Code: FldSz)

Class name	***Size range (acres/ha)***	***Class code***
Very small	Less than 1 acre (< ± 0.4 ha)	(1)
Small	Less than 2 acres (< ± 0.8 ha)	(2)
Somewhat small	2 to 5 acres (± 0.8 ha to ± 2 ha)	(3)
Intermediate	5 -12 acres (± 2 ha to ± 5 ha)	(4)
Large	More than 12 acres (> ± 5 ha)	(5)

8.1.5.2 Field distribution pattern

The field distribution pattern is defined by the percentage of cultivated field and by the arrangement and shape of the fields. If fields are of the same shape and arrange in a regular pattern it indicates that there is a certain organisation in place, like is the case with irrigation schemes or plantations, and it is indicative of a more intensive land use system generally. In the same way, when field are not continuous it indicates a lower cropping intensity and lower intensity of land use. Field occupying less than 50% of the area indicates that other land use and land cover types are present and dominant within the area.

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Attribute: Field pattern (Code: FldPn

Class	Description	Class code
Structured and planned field pattern	Contiguous fields; > 70% – regular pattern	(1)
Unstructured continuous field pattern	Contiguous fields; > 50% – irregular pattern and shape	(2)
Clustered fields	Fields: 20 – 50%; clustered – irregular pattern and shape	(3)
Scattered fields	Fields: < 20%; scattered	(4)

8.2 Land cover characteristics

8.2.1 Ground cover percentage of the structural vegetation layers

The land cover characteristics are described by the ground cover percentages for each of the structural layers of the vegetation. It applies, in first instance, to the "semi - natural vegetation" main land use category but will likewise be used for the other main land use categories, especially the cultivated and managed terrestrial areas, where trees as part of the agricultural landscape are so characteristics for the Soudan savanna and other tree savanna zones in Africa, for example

The cover percentage or cover class is specified for each of the different life forms and including bare soil (percentage of the area where soil surface is exposed). The following specification are given for the different life forms:

- Trees (> 15 m)
- Trees (3 m – 15 m)
- Shrubs (0.3 m – 5 m)
- Herbaceous (0.03 m – 3 m)
- Bare soil (vegetation absent, whether cleared land or naturally bare due to degradation)

For estimating cover percentage use the graphs provided in Figure 3 as reference. The ground cover classes are defined as follows:

Attribute: Structural Vegetation Layer Ground Cover (Code:SVLGCov)

Class name	Range (percentage)	Class code
Absent	0 - 1	(0)
Scattered	1 - 4	(1)
Sparse	4 - 15	(2)
Very open	15 - 40	(3)
Open	40 – 65	(4)
Closed	> 65	(5)

8.2.1 Signs of grazing

We treat 'grazing' as part of the land use and land cover assessment because 'grazing' identifies the purpose for which the land is being used, including land in open range.

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Open-range land is land that is not managed, often implying that it is overgrazed and degraded. In other situations, 'grazing' would be an aspect of land management. Therefore, signs of overgrazing have been included in the observations on grazing. For these observations, the observation window is widened beyond the soil sampling plot. Signs of grazing, insofar as this relates to grassland with livestock grazing and infrastructure present in the field, are included to cater for those situations in which the land is cultivated and managed, to distinguish between grassland that is used as a hayfield only and that which is being grazed.

Parameter	Description	Code / Response
Signs of grazing	Relates to signs of an area being used for grazing or to signs of impact of grazing. Either one of the following: ➢ Where animals (livestock) are out in the field grazing ➢ When there is infrastructure for grazing of cattle or other livestock: Fences, drinking troughs, stables, or sheds. ➢ Droppings/faeces are seen (often concentrated), left over from fodder – feeding operation ➢ Signs of poaching by livestock (removal of grass or vegetation), spots of trampling and compaction of the soil are visible.	Y/N
Signs of overgrazing	Either one of the following: ➢ Short grass height over large areas ➢ Frequent observation of areas of bare or poached ground ➢ Large amounts of dung ➢ Frequently uprooted vegetation	Y/N

8.3 Land and Crop Management

For land management, data are collected on land preparation; information on crop management concerns the use of inputs. Both provide information on land use intensity, though not very specific. For these two classifiers, the information can be obtained through field observations. Other aspects of land preparation, such as land clearing, and crop management, such as pest and disease management, are not included because these data cannot be obtained from visual field assessment alone.

8.3.1 Land preparation

For land preparation, visible signs of ploughing will be recorded, and, if visible, the direction of ploughing. The signs might refer to land that has been ploughed in the past or to recently ploughed fields. In land that has been previously cultivated, but where we find secondary regrowth, signs of the land having been ploughed might still be visible and are indicative of agricultural use in the past (and therefore belong to 'agricultural area'). Whether the ploughing has been done manually, by animal traction, or with a tractor can be observed from the distance between the plough ridges and the pattern, whether regular and straight or irregular and not straight, which will

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be visible to the trained eye. Also, it is easy to find out what is common practice in the area, and the surveyor will indicate the most likely option.

Land preparation in smallholder farming in Africa generally involves ploughing, leaving ridges on which the crop is planted. If a seedbed has been prepared (as in commercial, mechanised farming operations), the ridges might no longer be visible. In that case, you still enter 'signs of field recently tilled'. The planting lines might not be indicative of the directions of ploughing, and the direction of the planting lines is entered as the 'Direction of ploughing'.

The direction of ploughing is to provide information on practices for soil conservation, and could, as such, also be grouped under that category of observations

Parameter	***Description***	***Code / response***
Signs of ploughing/tillage	➢ No visible signs of tillage ➢ No-till ➢ Signs of tillage in the past: ridges visible forming a pattern, but ridges less pronounced/flattened ➢ Signs of field recently tilled: patterns of ridges clearly visible that form a pattern	(0) (1) (2) (3)
Direction of ploughing	➢ Not applicable ➢ Along contours ➢ In slope direction, tangent to contour	(0) (1) (2)
Tillage mode	➢ Not applicable ➢ Manual (hoe) ➢ Animal traction (buffalo, bullock, cow, horse, mule/donkey) ➢ Mechanical (tractor)	(0) (1) (2) (3)

8.3.2 Use of inputs

With the use of inputs, reference is made only to the use of fertiliser (both organic and inorganic). It is sometimes difficult to recognise the visual signs of the various types of input that might have been used, or there may be none visible at the time the survey is conducted. In that case, we may assume that the common practice for the area might also be applied in the field where the point/unit of observation is located, if the land use and crop observed at that point is consistent with the crop for which the practice applies. Crop residues, if left in the field, are readily observed in crops like maize, sorghum, and millet, and it is also quite common to use them in certain regions. The same applies to the use of farmyard manure, which might be quite common in certain regions. It can be observed in the heaps of manure they put on the field, which they spread out before planting. It will still be visible in the field, with a standing crop, as remnants of the manure that have not decomposed and have not been worked into the soil. Likewise, for the use of inorganic fertilisers, it is difficult to spot in the field, but the practice is most likely used when it is common in that area. And if the surveyor is from that area, s/he will know and will indicate the most likely option.

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Parameter	Options	Code / Response
Signs of input use	No visible signs	Y/N
	Crop residues	Y/N
	Green manures and/or compost	Y/N
	Manure (FYM, cattle manure, chicken manure, etc.)	Y/N
	Inorganic fertilizer	Y/N

8.4 Water management/ irrigation

Water management applies to the 'cultivated and managed terrestrial areas'. It does not apply to the (semi-)natural vegetation areas, and for the cultivated aquatic areas, the water management is inherent in this type of land use and does not need to be further specified. This section addresses cultural practices related to water supply for the crop. First, it is indicated whether you have a rainfed system, a post-flooding system, or an irrigation system. The post-flooding is when the land is being cultivated after is has been flooded, with the crop making use of the residual soil moisture. It is generally found in river floodplains, not in artificially flooded areas. Obviously, it can only be observed at the right time when the water has subsided. However, a surveyor familiar with the area's cultural practices will know. For irrigated systems, this may refer to fully irrigated systems or to systems intended for supplementary water supply, in addition to water supplied by rain. Water harvesting is not explicitly included as a separate option as a technique for water management but is inherent in the choices for type of irrigation and source of irrigation. For example, half-moon or zaï systems make use of (cone-shaped) pits to harvest water and is a specific from of surface irrigation, even though it is part of rainfed agriculture. It could be made explicit if it is considered an important technique and much applied practice in certain regions. much-applied cultural practice.

Parameter	Description/ options	Code/ response
Water supply	Rainfed	(1)
	Post-flooding/ residual moisture	(2)
	Irrigated	(3)
Type of irrigation	Surface / gravity (can be by use borders, basins, furrow, corrugation (i.e., parallel ridges and grooves, wild flooding, etc.)	(1)
	Sprinkler (different types of sprinklers: central pivot, fixed set of sprinklers, travelling gun irrigation system, etc.)	(2)
	Drip irrigation (trickle, dribble, or localized irrigation in which the water trickles onto or into the soil near the plant)	(3)
	Not applicable	(4)
Delivery system	Canal	(1)
	Ditch	(2)

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	Pipeline	(3)
	Other / not identifiable	(4)
	Not applicable	(5)
Source of irrigation	Well (groundwater)	(1)
	Pond/lake/reservoir (still water)	(2)
	Stream/canal/ditch (running water)	(3)
	Lagoon / wastewater (wastewater)	(4)
	Other / non identifiable	(5)
	Not applicable	(6)

8.5 Soil and water conservation

Recording of soil and water conservation measures applies to the cultivated and managed terrestrial areas and to 'cultivated aquatic and temporarily flooded' areas. For example, paddy rice fields can be found on completely terraced terrain, though this is not very common in Africa. Also, for the semi-natural vegetated areas used for grazing and therefore part of agricultural land, measures to control erosion may have been taken. This might refer to stone lines that may even date back to when the land was cultivated. A distinction is made between vegetative and structural measures. Vegetative measures make use of planting barriers (vegetative strips), life fences and wind barriers, whereas structural measures involve mechanical work to modify the slope, construct banks, dig ditches, and other measures that change the physical appearance of the land surface. Conservation measures related to agronomic practices and farming methods are not included because they are difficult to observe directly in the field.

(See: https://infonet-biovision.org/EnvironmentalHealth/Introduction-soil-conservation-measures for pictures).

Classifier/Attribute	**Options / Attrib. Values**	**Code / Value**
Conservation Measure	No conservation measures	(0)
	Vegetative in nature	(1)
	Structural	(2)
Type of Conservations Measure	Stone line	(1)
	Bench terrace	(2)
	Graded terrace	(3)
	Contour bunds	(4)
	Graded bunch	(5)
	Drains, ditches, and furrows (for retention of water and/or soil)	(6)
	Grass strips (vegetated strips)	(7)
	Not applicable	(8)

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9.0 What to do in special situations

9.1 Sampling a cultivated farm with prominent ridges or heaps

In a cultivated land with prominent ridges, the topsoil mainly the 0 -20 cm depth has already been scooped up to make the ridge or heap. The furrow of the ridges therefore represents the subsoil (20 cm depth downward). This is true especially when the ridge is fresh, that is, the ridge was made recently. As time passes, part of the topsoil will be washed down into the furrow by raindrop impacts thereby creating another thin layer of topsoil in the furrow. Under this condition sample the soil as follows:

- Sample the heap/ridge as the topsoil (0-20 cm)
- To get the subsoil, sample the furrow as the subsoil taking the surface of the furrow at the point 20 cm only if the heap is fresh or recently made.
- If the heap is not fresh or it was not made recently, then drill out the first 10cm layer on the furrow and discard. Then drill down to 40 cm on the mark on the auger. This represents the 20-50cm depth of the soil which is the subsoil sample.

9.2 Sampling point at border between fields or at the transition of one land use type to the other.

A sampling point may be located at the edge of a field or just between, or it may be at the edge of the road, or track. The general rule is that any sampling point should be located at minimum 5 meters from the edge of the field (field boundary). Therefore, in such cases move the point 5 meters into the field. In case the proposed sampling location falls on a road, within a compound, or other, move to the field that is closest by, but should be within a 25 m distance. In case a point falls exactly between two fields or on a point where the neighbouring fields are at the same distance, the "look north" rule applies. From the proposed sampling location, we look north and the field that is found in that direction will be sampled.
Similar considerations apply when at the exact proposed sampling location, a rock is found, or there is a tree or any object that prevents from taking soil samples. In such case you may relocate the sampling point location, moving north in first instance and remain within 25m distance from the original point, and if the land use and land cover characteristics remain the same. If not, search a point in the same field and with the same land use characteristics as for the original sampling location.

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11.0 Protocols for the reference sites – Soil profile distribution and pesticide residue

Please see the soil profile description manual

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12.0 Guidelines for the laboratory soil analysis

The main purpose is to obtain information on the distribution and level of variation of soil properties, so that this knowledge can be deployed to
utilise, protect and conserve the soils. Once the samples have been collected in the field, they will be transported to the University of Liberia's soil testing lab for analysis.
Three different levels of analysis will be carried out, namely:

- Traditional "wet chemistry" analyses on all samples
- Spectral analysis (mid infra-red or MIR, 4000-400 cm-1) on all samples.
- Pesticide residues and plastic analysis may be done on selected samples from the 90 reference sites. Analysis will be done in Wageningen as soon as an opportunity arises.

The wet-chemistry analysis results will also be used as correlation data alongside the spectral results. The spectroscopy analysis will be performed according to the GLOSOLAN protocols.
Here, we provide the essential soil chemical properties that must be determined in the laboratory.

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Soil Properties	Method of Analysis	Unit
Soil pH (H_2O)	pH in water (1:2.5) using glass electrode	
Soil pH (KCl)	pH in 1M KCl using glass electrode	
Electrical Conductivity (EC)	EC in water extract	dS m^{-1}
Organic Carbon (OC)	Walkley Black wet oxidation method	g kg^{-1}
Total Nitrogen (Total N)	Kjeldahl digestion method	g kg^{-1}
Available Phosphorus (Bray I)	Bray I extraction method	mg kg^{-1}
Exchangeable Calcium (Ca)	1M NH_4OAc extraction (pH 7.0)	$cmol^+$ kg^{-1}
Exchangeable Magnesium (Mg)	1M NH_4OAc extraction (pH 7.0)	$cmol^+$ kg^{-1}
Exchangeable Potassium (K)	1M NH_4OAc extraction (pH 7.0)	$cmol^+$ kg^{-1}
Exchangeable Sodium (Na)	1M NH_4OAc extraction (pH 7.0)	$Cmol^+$ kg^{-1}
Cation Exchange Capacity (CEC)	1M NH_4OAc saturation method (pH 7.0)	$Cmol^+$ kg^{-1}
Exchangeable Acidity	1M KCL extraction	$cmol^+$ kg^{-1}
Base Saturation	Calculated from exchangeable bases and CEC	%
Particle Size Distribution (Sand, Silt, Clay)	Hydrometer method	%
Bulk Density	Core method (oven dry at 105°C)	g cm^{-3}
Available Micronutrients (Fe, Mn, Zn, Cu)	Mehlich 3 extraction method, Blue molybdate, UV- visible spectrometer	mg kg^{-1}
Available Sulphur (S)	Mehlich 3 extraction method	mg kg^{-1}
Total Elemental Composition (Fe, Al, Cu, Co, Cr, As, Zn, V, Sb, Hg, Cd, Mn)	Aqua regia digestion	mg kg^{-1}

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