SECTION 4

Soil assessment

Introduction

There are two parts to the soil assessment, firstly assessing soil properties which results in a scoring of soil health, and secondly, assessing and scoring soil erosion activity, type and severity. The procedures for selecting and describing the sites for detailed assessment have been outlined in the above sections.

Soil Properties and Health: The tools for assessing soil properties and health are taken from the VS-Fast methodology (McGarry, 2006) and selected VSA methods of Shepherd (2000). Emphasis with VS-Fast is on the assessment, both qualitative and quantitative, of soil physical condition conducted during field visits. The core set of indicators used provides a robust, yet rapid and inexpensive approach to assessing the following soil characteristics:

- description of the soil sample (depth, texture, structure, colour, layering);
- aggregate size distribution;
- soil crust;
- tillage and other pans;
- biota (particularly earthworms and roots);
- slaking and dispersion;
- pH;
- water infiltration;
- organic carbon;
- soil and water salinity.

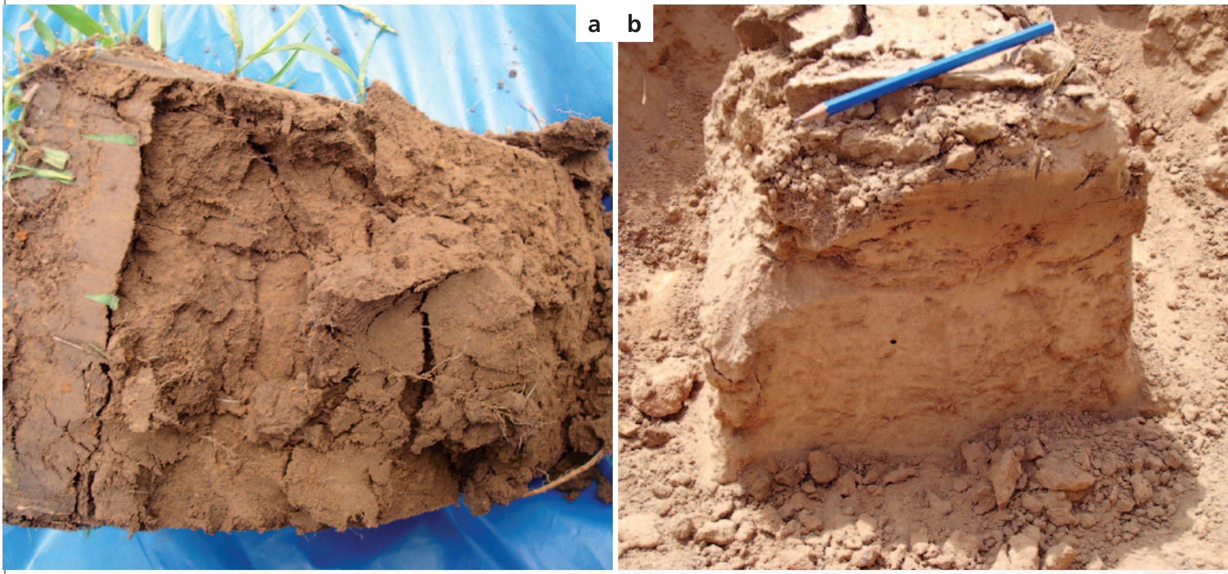
The measures are designed to be reproducible and quickly learned. Additionally, as they are field methods, they provide immediate indications of soil quality, quickly interpretable for the farmers and land owners present during testing. The methodology generates quantitative data on soil quality and condition, also providing guidelines for scoring and ranking the results to enable comparisons to be made between soils at the detailed assessment sites.

The soil zone of greatest interest in terms of VS-Fast occurs from the soil surface to approximately 0.4m depth. This represents the most important zone in cropland and improved pastures for seedbed development, early germination and plant growth. In crop, forest and pasture land, it is the zone with the greatest potential for negative impacts on water infiltration, soil carbon losses etc., due to soil compaction also erosion by wind and water.

Spade technique, hole size and depth: The following procedures (Tool 4.1) are based on the examination of an excavated spadeful of soil at a site selected for detailed assessment.

A spade with a flat (though usually slightly curved) blade is used to remove an intact "block" of soil, commonly up to 0.3 or 0.4m deep and 0.25m wide from the site under investigation. The soil is left on the blade of the spade for subsequent observations. The spade, with the block of soil on the blade, is commonly "propped-up" on a rock or against a car or fence for description, sketch or photograph. A photograph is recommended.

Scoring of soil health: Guidelines are provided for scoring each of these and weighting / integrating the scorings into two measures of soil quality, one based on visual observations (Tool 4.1) and the other based on the soil



G. BÉYE

PHOTO 12 **a) Taking a spadeful of humid soil and b) excavating a block in sandy soil, (Diagaly, Senegal)** measurements (section Tool 4.2). For recording the VS-fast information and data from Tools 4. 1 and 4.2, **score-cards** are included at the end of this section after soil visual indicators (section A) and measurements (section B).

For consistency and comparability, it is important to conduct the complete set of core measurements at all selected detailed assessment sites. If not, then the scores can not be combined to give the integrated scores of quality. Additional measurements can be taken and other indicators used to assess the soil where appropriate or preferred locally.

Soil erosion assessment

A set of simple, field usable indicators and measurements are provided to observe, quantify and report on soil erosion at detailed assessment sites in various land use types (bare field, crop, pasture / rangelands and forest). The basis is simple field observation and measurement of recognized erosion features with the aim of both recording erosion status (type, state, extent and severity) at any one site as well as comparing between sites that differ in soil, climate, land use and management practices, etc. The: measurements of erosion features (dimensions) are optional and can be used where erosion is a significant degradation process to provide quantification of rates and quantity of soil loss in a study area. (Tool 4.3.3). The specific tools to be used can be selected on the basis of the soil erosion features observed in the field during the study area characterisation (Section 1): i.e. sheet erosion, rills, gullies/ravines, exposed rock, sediment deposits, sand dunes, etc..

Direct measurements can be made of the amount of soil eroded by runoff through rill and gully erosion. Indirect measurements can be made of soil erosion by water or wind through:

- ⊗ plant / tree root exposure;
- ⊗ fence post/other structure base exposure
- ⊗ tree mounds;
- ⊗ pedestals
- ⊗ solution notch/rock colouration, and
- ⊗ enrichment ratio;

Further tools are provided and can be used, if appropriate, but involvement of a soil erosion expert is advised as they are more problematic as explained below:

- ⊗ the armour layer (erosion by water);
- ⊗ soil/sand build up against a barrier (erosion by wind);

Tool 4.1. Visual assessment of soil quality

Seven visual indicators of soil quality, determined on the excavated soil block with supporting information from the soil surface around the excavated pit, are recommended for the core LADA-L assessment, these are:

1. Soil depth;
2. Soil texture;
3. Soil structure (tillage pan, aggregate size distribution);
4. Surface crust;
5. Soil colour;
6. Soil life (i.e. earthworms and other biota);
7. Roots.

With the exceptions of soil depth, texture and colour, guidelines are provided below for the scoring of each of these indicators and the integration of these scorings into a soil quality assessment.

1. Soil depth

Soil depth is important as it determines rooting depth. If the soil is shallow, this will be a limiting factor to plant growth (reducing access to water and nutrients) and hence land productivity. Soil erosion and compaction may reduce the soil depth available to the plant.

Firstly, using a measuring tape, ruler or stick graduated in centimetres, assess and measure the location (depth and thickness) of any visible soil layers; in terms of colour, soil structure (see below), root density etc. The depth to any hard compacted layer or "hardpan" should be recorded, this may be caused by mineralization of certain compounds or by repeated hoeing / ploughing at a certain depth.

Record these depths and prepare a sketch of the soil profile, annotated with depth and principal soil features.

2. Soil texture

Soil texture refers to the relative proportions of sand, silt and clay size particles in a sample of soil.

- Clay particles are the smallest particles, less than 0.002 mm in size.
- Silt is a medium size particle between 0.002 and 0.05 mm in size.
- Sand is the largest particle, diameters from 0.05 to 2.00 mm; commonly divided into fine sand (0.05–0.5 mm) and coarse sand (0.5–2.00 mm)

Texture has important effects on a wide variety of soil properties (e.g. soil's water holding capacity, aeration and porosity, hydraulic conductivity, compaction potential, resistance to root penetration, nutrient holding capacity (i.e. cation exchange capacity) and resistance to acidification).

Soils that are dominated by clay are called fine textured soils, while those dominated by larger particles are referred to as coarse textured soils. Soil scientists group soil textures into soil texture classes (Figure 9).

Texture can be determined in the field by taking one or two table-spoonfuls of soil (from a soil layer of interest) in one hand and adding water, drop by drop, to the soil as it is being worked in the hand until a sticky consistency is reached. The soil is then rolled into a ball and texture determined, through ability to form various shapes from the rolled ball. Compare the shape achieved to Table 17 and refer to Figures 8 and 9. Record the texture class determined, on the field sheet.

Figure 10 shows the % of sand, silt and clay in the textural classes. Note: specify diagram for sandy soils (source: FAO, 2006. Guidelines for soil description).

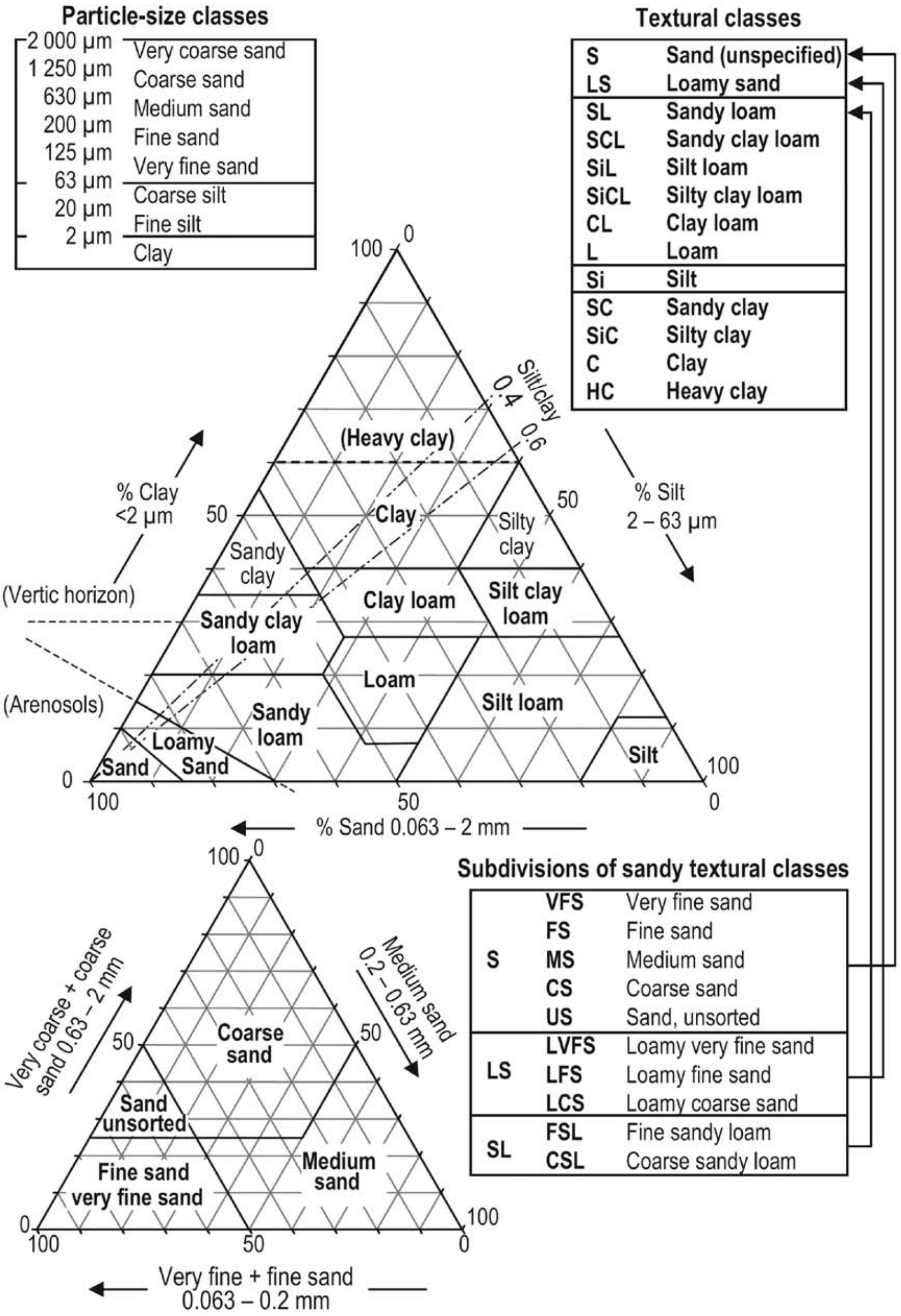
The point at which the soil becomes malleable and can be hand-shaped, indicates its texture (use Figure 10 in conjunction with Table 17).

3. Soil structure

In the VS-Fast system, the description of soil structure focuses on each of: (a) the presence of "pans" in the soil; these being platy and massive, continuous, horizontal layers; and the (b) description of the size and shape of the soil units, present in the excavated cube of soil and exposed for description by manipulating the cube of soil to facilitate breakages along natural lines of weakness.

3a. Tillage and other soil pans

Tillage pans (formed by plough or hoe) and other forms of pans are important negative indicators of soil condition as well as being symptomatic of non-sustainable land management practices. Soil pans are located and described by comparing the lower and upper parts of the excavated spadeful of soil. As an example, the upper layer may be small to medium granular structure, overlying a tillage pan, where the structure is clearly compacted, massive, smeared or "platy" (like large dinner plates).



Textural classes

S	Sand (unspecified)
LS	Loamy sand
SL	Sandy loam
SCL	Sandy clay loam
SiL	Silt loam
SiCL	Silty clay loam
CL	Clay loam
L	Loam
Si	Silt
SC	Sandy clay
SiC	Silty clay
C	Clay
HC	Heavy clay

Subdivisions of sandy textural classes

S	VFS	Very fine sand
	FS	Fine sand
	MS	Medium sand
	CS	Coarse sand
	US	Sand, unsorted
LS	LVFS	Loamy very fine sand
	LFS	Loamy fine sand
	LCS	Loamy coarse sand
SL	FSL	Fine sandy loam
	CSL	Coarse sandy loam

FIGURE 9 **Soil texture classes**

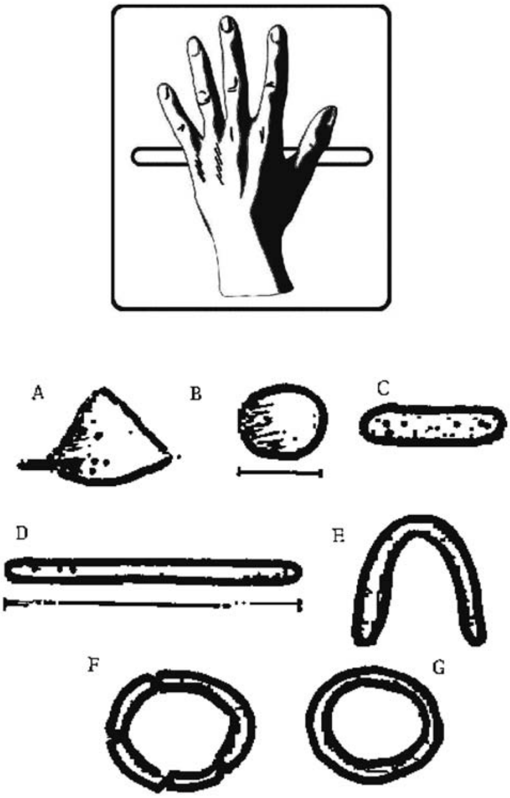


FIGURE 10 **Hand assessment of soil texture**

TABLE 17 **Soil texture descriptions**

A **Sandy**	The soils stays loose and separated and can be accumulated only in the form of a pyramid
B **Sandy loam**	The soil contains enough silt and clay to become sticky, and can be given the shape of an easy-to-take-apart ball
C **Silty loam**	Similar to a sandy loam, but the soil can be shaped by rolling it into a small short cylinder
D **Loam**	Contains almost equal amounts of sand, silt and clay. Can be rolled into approx. 14 cm long cylinder that breaks when bent.
E **Clayey loam**	Similar to the loam, but the rolled cylinder can be bent and given a Ü” shape (without forcing it) without breaking
F **Fine clay**	The soil cylinder can be bent into a circle, but shows some cracks
G **Heavy clay**	The soil can be shaped as a circle without any cracks

Tillage pans only occur in cultivated land, either from metal implements working soil or repeated trafficking by tractors; both giving the worst compaction (tillage pan) when conducted in moist to wet soil.

Other types of “pans” can be found in each of grazing and fodder producing lands (e.g. growing perennial grass swards). In these situations the “pan” is commonly on the immediate soil surface, resulting either from surface “trampling” by animal feet (particularly if animals were present in large numbers in moist to wet soil conditions) or from repeated passes of harvesters and balers, cutting and packing animal fodder; again worsened by random (criss-crossing) traffic in moist to wet soil conditions.

Record the presence, thickness and degree of development of any pan.

Scoring[6] (after Shepherd 2000):

- Good condition (score = 2): no tillage pan (or any other type of pan), with

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[6] Note: that scores in the VS-Fast system are usually 0, 1 and 2, from poor to good. It is possible to score in 0.5 increments where a recorded soil attribute fits between or has components of two scoring classes.

friable structure and soil pores from topsoil to subsoil

- Moderate condition (score = **1**): firm, moderately developed tillage pan in the lower topsoil (or upper subsoil), or surface pan from animals or repeated traffic. The pan is clearly platy or massive but contains one or more of: areas of better soil structure recorded above or below the pan, cracks or continuous pores through the pan.
- Poor condition (score = **0**): a well developed tillage pan in the lower topsoil (or upper subsoil), or surface pan from animals or repeated traffic. The pan has massive or platy structure with firm to extremely firm consistency and very few or no vertical cracks or pores through the pan.

3b. Aggregate size distribution

In order to bring some uniformity to the method of manipulating the soil (on the spade) and to get it to break along natural cleavage planes, Shepherd (2000) has further developed the "drop-shatter" test. In this, a spadeful of soil is dropped three times from a uniform height either onto a plastic sheet (lying on the ground) or into a rectangular shaped "washing-up" basin. If the soil does not completely shatter into individual units, then gentle hand manipulation is used to break the soil along natural breakage lines. Once the soil is broken into its individual aggregates, these are sorted so that the largest are placed at the top and the smallest at the bottom (Figure 11).

Effectively, this is a field method of aggregate size distribution. Degraded soil tends to have a greater proportion of coarse structure units than a well structured soil (Figure 11).

GOOD CONDITION VS = 2
Good distribution of friable finer aggregates with no significant clodding.

MODERATE CONDITION VS = 1
Soil contains significant proportions of both coarse firm clods and friable, fine aggregates.

POOR CONDITION VS = 0
Soil dominated by extremely coarse, very firm clods with very few finer aggregates.

FIGURE 11 **Soil aggregate size distribution test**

Examples of (left) finely structured soil and (right) coarsely aggregated soils are differentiated using the "drop-shatter" test with subsequent arrangement into coarse – fine aggregate size distribution (from Shepherd 2000).

A problem with this test is the strong interdependency between what is achieved with the "drop test" and the current soil water content. The wetter the soil, the less will be achieved when the soil is dropped. Every effort should be made to conduct comparisons at the same water content. Another problem occurs in sandy soils where the aggregates cannot be sorted by hand due to their inherent weakness (i.e. the structure grade is "weak").

Scoring (after Shepherd 2000):

- Good condition (score = **2**): good distribution of friable, smaller aggregates with no significant number of clods
- Moderate condition (score = **1**): soil contains significant proportions of both large, firm clods and friable, small aggregates
- Poor condition (score = **0**): soil dominated by large, extremely firm clods with very few small, friable aggregates

4. Soil crusts

Soil crusts are a soil surface phenomenon, most commonly regarded as a **negative** soil feature, however, in certain circumstances they can have **positive** effects on soil moisture and landscape health. There are two main types:

4a Chemical and physical crusts are inorganic features such as a salt crust or platy surface crust, often formed by trampling. They comprise a consolidated layer commonly <10 mm thick that can be separated from and lifted off the soil beneath, on drying. Inorganic crusting is most common in fine textured soils (loams and sands), though clays with low aggregate stability (see stability test Tool 4.2.1 below) from high sodium levels and/or low organic matter content can also crust. In such soils, soil crusts impact negatively on soil health through reducing water infiltration (hence increased erosion risk, prolonged water ponding in flat and concave areas, and reduced water storage in the soil) as well as reduced seedling germination. The degree of negative impact increases with both greater crust thickness and continuity (i.e. degree of cracking).

4b Biological soil crusts are formed by living organisms and their by-products, creating a crust of soil particles bound together by organic materials at the surface of desert soils. They are predominantly composed of cyanobacteria (formerly called blue-green algae), green and brown algae, mosses, and lichens. Liverworts, fungi, and bacteria can also be important components. (These soil crusts are also known as microbiotic, cryptogamic, cryptobiotic, and microphytic crusts depending on the organisms concerned). See Photos 13 and 14. These are "positive" crusts specific to arid, desert areas (e.g. north west China), where their widespread occurrence has a strong positive impact on the soil and landscape condition through binding the soil surface, hence greatly reducing wind erosion (specifically windblown sand). As they are concentrated in the top 1 to 4 mm of soil, they primarily affect processes that occur at the land surface or soil-air interface. These include soil stability and erosion (both by wind and by water), atmospheric nitrogen-fixation, nutrient contributions to plants, soil-plant-water relations, infiltration, seedling germination, and plant growth.

Aboveground biological crust thickness can reach up to 0.10m. Their appearance in terms of colour, surface topography and surface coverage varies. Mature biological soil crusts are usually darker than the surrounding soil due to the density of the organisms and the often dark colour of cyanobacteria, lichens, and mosses. Biological soil crusts generally cover all soil spaces not occupied by vascular plants, and may be 70% or more of the living cover.

Crust-forming cyanobacteria have filamentous growth forms that bind soil particles. Fungi, both free-living and as a part of lichens, contribute to soil stability by binding soil particles with hyphae. Lichens and mosses assist in soil stability by binding particles with rhizines/rhizoids, increasing resistance to wind and water erosion. The increased surface topography of some crusts, along with increased aggregate stability, further improves resistance to wind and water erosion.

Studies show that biological crusts can alter water infiltration: where crusts greatly increase surface roughness water infiltration may be increased, but where effects on surface roughness are not significant, infiltration is generally reduced due to the presence of cyanobacterial filaments. These effects are site-specific and also related to soil texture and chemical properties. In dryland and grassland regions, such crusts may prevent infiltration into the soil so most rainwater is evaporated, therefore, they potentially affect the hydrological circulation in the upper layer in sandy land.

For measurement and assessment of biological soil crust, 3 indicators can be used:

- coverage (%) of the biological soil crust in the assessment area;
- thickness (mm) of the biological soil crust;
- impacts of the biological soil crust on rainwater infiltration into soil (using a double ring infiltrometer, see Photo 15 below) .

Record observations of surface crusting in the general notes or photograph the surface crust. Observations and scoring are best conducted after a period without rain and on ground that is not cultivated or disturbed by animals.

Scoring

A. Chemical and physical crusting (negative):

- Good condition (score = **2**): little or no surface crusts;
- Moderate condition (score = **1**): Crusts present, up to 3 mm thick, broken by cracking;
- Poor condition (score = **0**): Crusts present, up to 10 mm thick, continuous with almost no cracking.

B. Biological soil crusting (positive) (only relevant in arid / desert lands):

- Good (score = **2**): almost continuous, surface biological crust, commonly with increased soil surface roughness (pinnacle formation);
- Moderate (score = **1**): discontinuous (patchy formation) of biological crust with minimal evidence of pinnacles;
- Poor (score = **0**): no biological crust present.

Biological soil crusts can be monitored using visually defined categories in areas dominated by cyanobacteria. Photo 14 shows six categories selected in the Colorado Plateau, USA. that are easily distinguished by both trained and untrained observers and are closely related to cyanobacterial biomass and the resistance of the soil surface.

5. Soil colour

Soil colour indicates many important soil properties. First and foremost, soil colour provides much information on the source material(s) of the soil and the climatic / human factors that have altered the original rocks and sediments to give the current soil condition.

Secondly, soil colour is a strong indicator of current soil water (or aeration) status. Generally, bright colours, and reds / oranges in particular, show good soil aeration and drainage (the iron in the soil is in the ferric (oxidised) state).

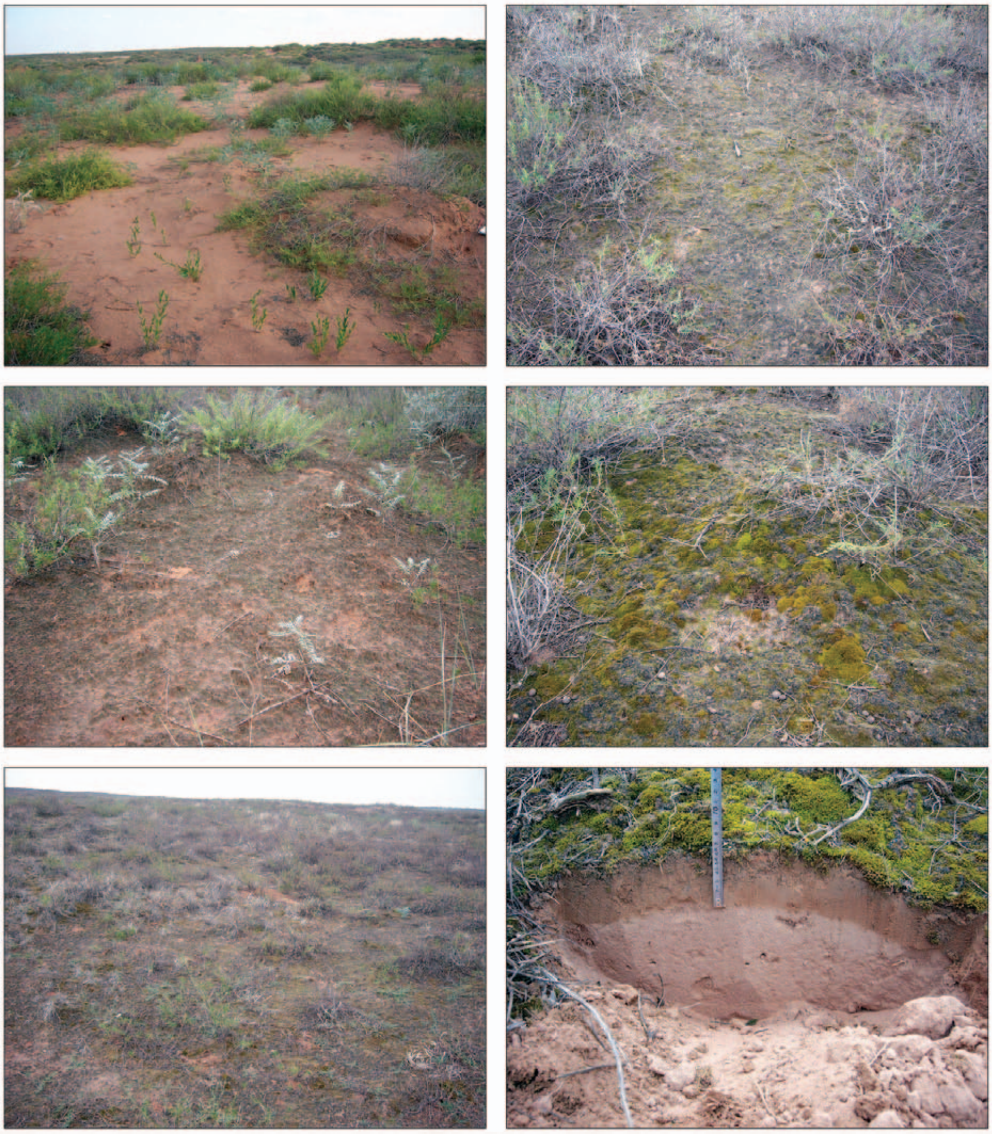


PHOTO 13 **Development of biological soil crust in sandland of dryland region, China**
(photo: Kebin Zhang)

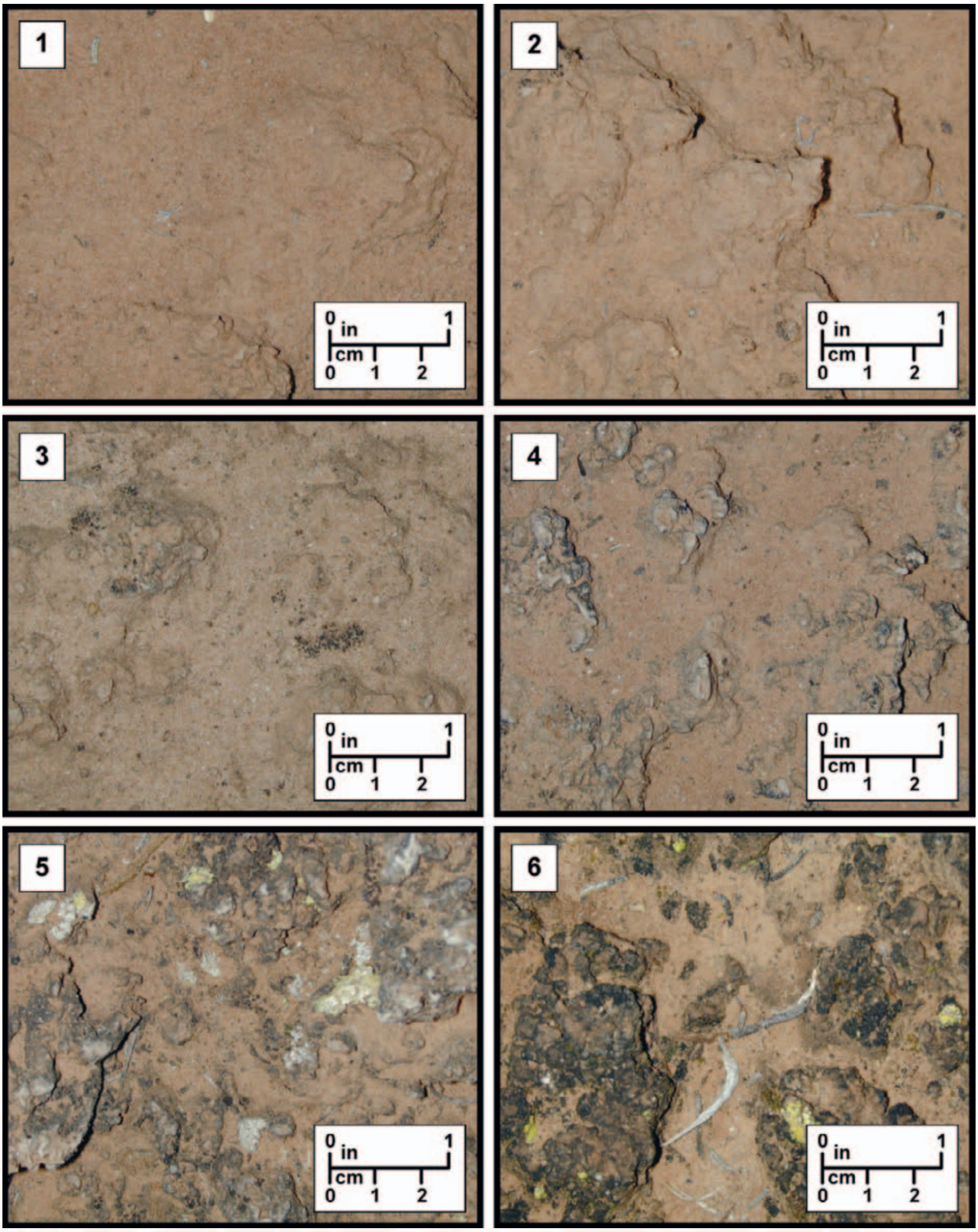
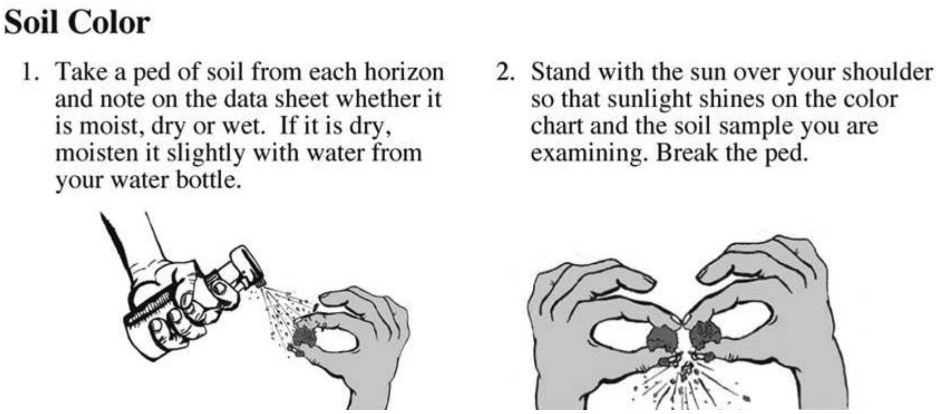


PHOTO 14 **Visual categories of soil crusting (Colorado Plateau, USA)**



Soil Color

1. Take a ped of soil from each horizon and note on the data sheet whether it is moist, dry or wet. If it is dry, moisten it slightly with water from your water bottle.
2. Stand with the sun over your shoulder so that sunlight shines on the color chart and the soil sample you are examining. Break the ped.

FIGURE 12 **Procedure of determining soil colour in the field (from NASA 2004)**

D. MCGARRY

PHOTO 15a **Assessing effect of soil compaction or crusting on water infiltration**

Dull and grey colours show reduced aeration and a tendency for low-oxygen status and waterlogging. The dull grey / black colours in a waterlogged soil often occur as mottles (ie a secondary colour within the main soil colour).

Thirdly, soil colour may reflect the organic matter status of the soil, particularly useful when comparing the topsoils of long term cropping land with treelines and fencelines. Generally, the darker the soil the greater the organic matter content.

How to assess the soil colour?

1. Take a lump of soil from the layer / horizon to be described. Break the lump to expose a fresh face (Figure 11).
2. If the soil is dry, moisten the face by adding water drop by drop.
3. Wait for the water to seep into the soil.
4. Now name the soil colour (e.g. red, brown, grey, black, white etc.).
5. If a soil has more than one colour, record a maximum of two and indicate (1) the main (dominant) colour and the (2) secondary colour.

6. *If available*, match the soil with a chip on the Munsell Soil Colour Chart.Record the soil as the Hue / Value / Chroma and the name of the colour.

Record the soil colour(s) on the field sheet.

6. Earthworms (and other soil biota)

Soil biota are usually an indicator of good quality. Earthworms are particularly good indicators as they incorporate organic matter into the soil and improve aeration with associated improvements in water infiltration and crust prevention. They also increase soil fertility *via* their caste material.

The presence of large numbers of species in good concentrations reflects and integrates many positive aspects of soil condition: good aeration (no waterlogging), structure (no compaction), plentiful food supply (for earthworms, the retained crop residues and stubble) and the lack of disturbance by cultivation (no-till). As such, the presence of biota is a most important, and fortunately in terms of the macro-biota, an easy-to-measure, attribute.

Earthworms are used as indicators here for two reasons:

- they are easily seen and captured; and
- they are good indicator species, indicating the presence of a healthy soil biota and a good soil.

Earthworms are rarely found in sandy soils and may only occur in deep soil layers of arid (infrequently wetted) landscapes, hence are a poor indicator species for soil health in such situations. Termites, ants, beetles and collembolan (commonly called “springtails”) are also considered important indicators of good soil condition, as well as causing the development of fertile soils. Ants are known to move and aerate considerable quantities of soil, while termites affect both nutrient pools and the flow of water into the soil through their interconnected galleries. Currently, research is limited[7] on the link between the presence and abundance of ants and selected termite types and their use in monitoring soil condition.

It is important to recognise that all soil biota are seasonal and migratory animals (seeking warmth, food and moisture). Because of this, it may well be that during a soil inspection earthworms (and other soil indicator fauna) are not found but strong evidence of their earlier presence may be visible (i.e.namely earthworm burrows (large, round and continuous pore spaces) in the soil profile and caste (faecal) material on the soil surface, termite burrows and mounds, buried stores of organic material etc.). In the absence of actually capturing and counting earthworms and other soil fauna, note should be taken of the number and concentration of related soil fauna features.

The assessment team should use local knowledge to decide whether earthworms are the most appropriate animal group to use as an indicator. If not, then they should identify and use a more appropriate group.

Method:

- While manipulating the soil on the spade blade for soil structure description, pick-out and place to one side all earthworms found in the soil sample.
- Observe the presence (number and size) of earthworm burrows and castes.

Record earthworm numbers on a 1 m^2 (a square meter) spade depth basis. So if the spadeful of soil is a 0.2m cube, that equates to a 1/25 square metre of soil, so multiply numbers of earthworms by 25 to convert to a m^2 basis.

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[7] See: http://www.environorth.org.au/windows/all/all_termites.html

Estimating % bare soil (% plant cover/crop residues)

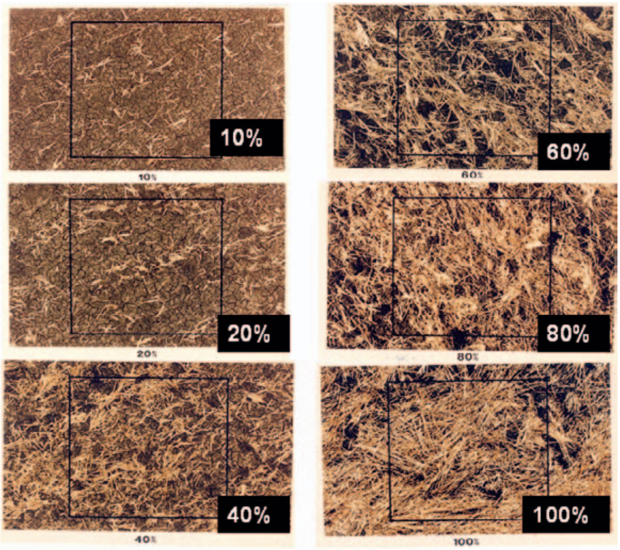

PHOTO 15b **Crop cover is vital to enhancing moisture capture and storage, and reducing water runoff and soil erosion**

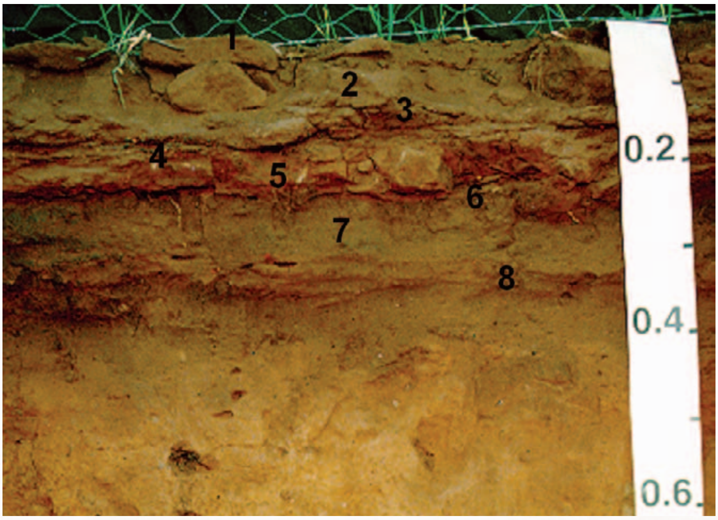

PHOTO 15c **Soil profile to observe depth and distinct layers**
(Photo D. McGarry)

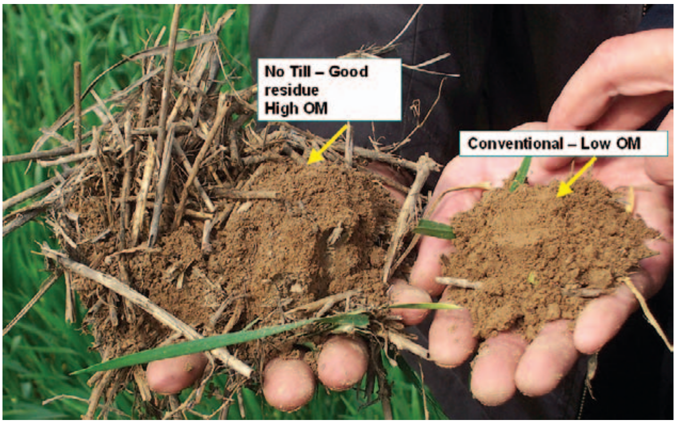

PHOTO 15d **Comparing soil colour under no-till and conventional tillage (Linfen, Shanxi, China)**
Soil visibly darker due to organic matter increase on No-till site (left hand) compared to conventional tillage (right hand)
Photo: D. McGarry

PHOTO 15e **Earthworms in soil after 12 years zero till, Pampas of Argentina**
Earthworm numbers can be counted and compared from a soil block (spade test) from different sites/management practices
Photo: D. McGarry

PHOTO 15f **Restricted root growth**
Soil compaction such as a tillage pan (bottom left) or other obstructions can be observed by bent / deformed plant roots -L shape growth- where roots fail to penetrate.
Photo: D.W. Reeves and D McGarry

Scoring (after Shepherd 2000):

- Earthworms plentiful (score = **2**) if >8 earthworms counted;
- Moderate earthworm numbers (score = **1**) if 4 to 8 earthworms counted;
- Few or no earthworms present (score = **0**) if <4 earthworms counted.

7. Quantifying roots

The development of root systems into the soil are a prime biological indicator of soil and vegetation condition. Where plant root growth is not impeded, it will reach its optimal form (root depth, lateral spread, density of roots and root hairs) and optimise uptake of water and nutrients to meet plant demand. However, when root growth is impeded by rocks, hard or compacted soil layers, high groundwater or saturated conditions, nutrient deficiencies, salinity or toxicity, or water shortage, the result will be visibly stunted or deformed roots, that in turn will lead to restricted growth of above ground parts of the plant. Triangulation with other indicators / observations will help identify the precise causes of the root deformations.

The determination of the extent and development of the plant root system is best done:

1. by examining the root system emanating from the sides of the block of excavated soil (on the spade blade); and
2. then, similarly, as the excavated block of soil is manipulated and broken up for soil structure description;
3. these observations can be supplemented with observations of any exposed soil profiles around the site where plant rooting is visible (e.g. road or drainage cuttings etc.).

Observations (recorded and leading to scoring on the field sheet) will include the following :

- evidence of stunted / deformed roots or acute, sharp changes in root penetration into the soil (the "L" shaped root syndrome, particularly evident in tap rooted crops like cotton and sunflower);
- disproportionate number and concentration of roots in the immediate surface layer, demonstrating that extension into the layers beneath is difficult;
- concentration of roots on ploughpans (hardpans) – at the greatest depth of ploughing;
- evidence of roots "squashed' in fissures between strong soil units, demonstrating their inability to penetrate into these units, and acess water/nutrients within; and / or
- an absence of fine root hairs, or an over-abundance of strong primary roots, showing the difficulty (and hence loss of vigour) experienced by the fine roots, penetrating the soil.

Record observations in the general notes on the field sheet or annotate the photograph or soil profile sketch with root shapes and concentrations.

Scoring (after Shepherd 2000):

- Good condition (score = **2**): unrestricted root development;
- Moderate condition (score = **1**): limited horizontal and/or vertical root development;
- Poor condition (score = **0**): severe restriction of horizontal and vertical root development; presence of "L" shaped roots, over-thickening of roots, or roots squashed between soil units.

Tool 4.2 Soil measurements

Five soil properties are measured or assessed in this section. Each is scored and integrated to give a value for the **soil quality assessment.**

1. Slaking and dispersion (Tool 4.2.1)
2. Soil pH (Tool 4.2.2)
3. Water infiltration (Tool 4.2.3)
4. Organic carbon (labile fraction) (Tool 4.2.4)
5. Soil and water salinity (electrical conductivity) (Tool 4.2.5)

The soil measurements have been chosen for a combination of simplicity, reproducibility and rapidity, focusing on measures that are directly affected by land management. In some cases, assessment teams may wish to carry out more conventional sampling and soil laboratory analysis but these conventional tests are not part of this rapid field assessment.

If possible, the VS-Fast field soil measures and tests should be conducted at the assessment sites. There are two principal reasons for this:

Firstly, it allows an immediate sharing and discussion of findings with land users. Secondly, it is possible to record, in a field photograph, a site record of the pH test (in the porcelain plate) alongside the result of the dispersion test (samples from the same depth in the dispersion dishes) with the soil profile on the blade of the spade. Used in conjunction with the Site Photo and Sketch, this gives an additional lasting record of the site and soil at the time of the assessment.

The one test that lends itself more to "analysis at the end of the working day" is the organic carbon (labile fraction) test. With increased proficiency of use, it may be conducted more widely in the field. However, in early days of using these methodologies, to save time, soil samples can be collected (from the same layers or sites where the other measures were conducted) and the test done later in the day, then information collated into the overall results by the team.

Clearly, not all of the following tests are suitable for all soil types and the interpretation of the results can also change between soils. For example, rapid hydraulic conductivity, that indicates good soil structure in a clay or loam is an unattractive attribute in a sand – showing rapid drying of the soil, following rain or irrigation. These possible ambiguities in the results are discussed in the relevant sections below.

1. Slaking and dispersion (Tool 4.2.1)

The inherent ability of a soil, particularly the soil surface, to withstand the impact of several types of land degradation, principally wind and water erosion, is strongly dependent on the soil's response when wetted.

There are two main types of aggregate collapse when water is added to soil: slaking which describes the breakdown of aggregates into micro aggregates and dispersion which describes the breakdown of aggregates into the primary soil particles of sand, silt and clay.

The differentiation between slaking and dispersion is most important. Generally, the products of slaking can re-form to produce larger aggregates whereas dispersion into primary particles is irreversible and results in an undesirable, massive structure. On the soil surface, dispersed soil appears either as a hard setting layer (or a surface crust) or as loose fine (white) sand grains. Crusts (see section 4.2.4) and sealing are major impediments to both water penetration (causing rain water to pond on the soil surface with strong potential for erosion) and to the germination of seeds. Additionally, fine, loose (dispersed) material on the soil surface has strong potential for wind erosion.

The amount of organic carbon in a soil strongly influences the ability of a soil to maintain aggregation (and not disperse) when wetted. Organic matter binds soil particles together and particularly in sand and loam soils this is the principal material causing aggregation.

The determination of the slaking or dispersive nature of a soil is commonly a laboratory test but an appreciation of the phenomenon can be gained in a short time during soil description in the field (Field *et al.* 1997).

The procedure is as follows. Drop an air-dried aggregate from the layer under investigation into a dish (e.g. a saucer) or a small, clear container (glass or cup) containing water (use rain water or local irrigation water). Ensure the entire aggregate is submerged below the water. After each of 10 minutes and 2 hours (when possible) following immersion, a visual judgement should be made of the degree of dispersion on a scale of 0 – 4 (see Photos 16 and 17).

NOTE 1: The scoring should be the reverse of the scoring in Field et al. (1997), as the VS-Fast methodology gives a higher (not lower) score for better conditions.

NOTE 2: The following descriptors of the degree of dispersion are more suited to clay rich soils (clays to clay loams) where dispersion of the original aggregate gives an obvious "halo" of dispersed clay. Sandy soils, because they contain less clay, do not give such visible clay halos. With these soils, greater emphasis should be given to the degree of aggregate breakdown and whether individual mineral grains become visible (sand and silt).

Scoring:

- No dispersion (though the aggregate may fall apart, i.e. slake) but with no signs of individual mineral grains (score = **4**);
- Slight dispersion, recognised either by a slight milkiness in the water adjacent to the aggregate, and / or the aggregate falls apart with only a few individual mineral grains evident (score = **3**);
- Moderate dispersion with obvious milkiness (score = **2**);
- Strong dispersion with considerable milkiness and about half the original aggregate volume dispersed outwards and / or individual mineral grains separated-out and clearly evident (score = **1**);
- Complete dispersion, the original aggregate completely dispersed into clay, silt and sand (individual mineral) grains (score = **0**).

Record the score value on the field sheet

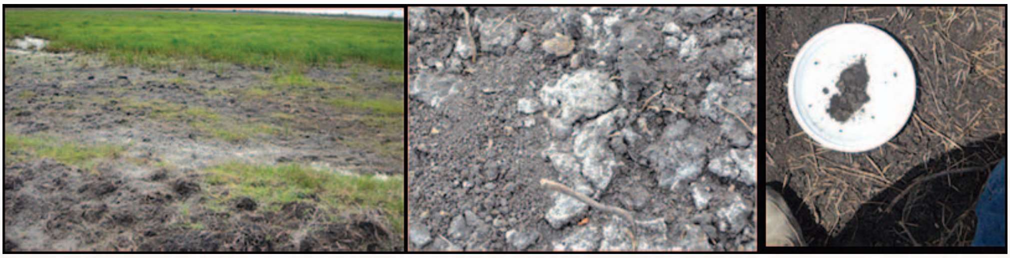

PHOTO 16 **Area severely affected by salinity as seen by strong soil dispersion in water (Granma, Cuba)**

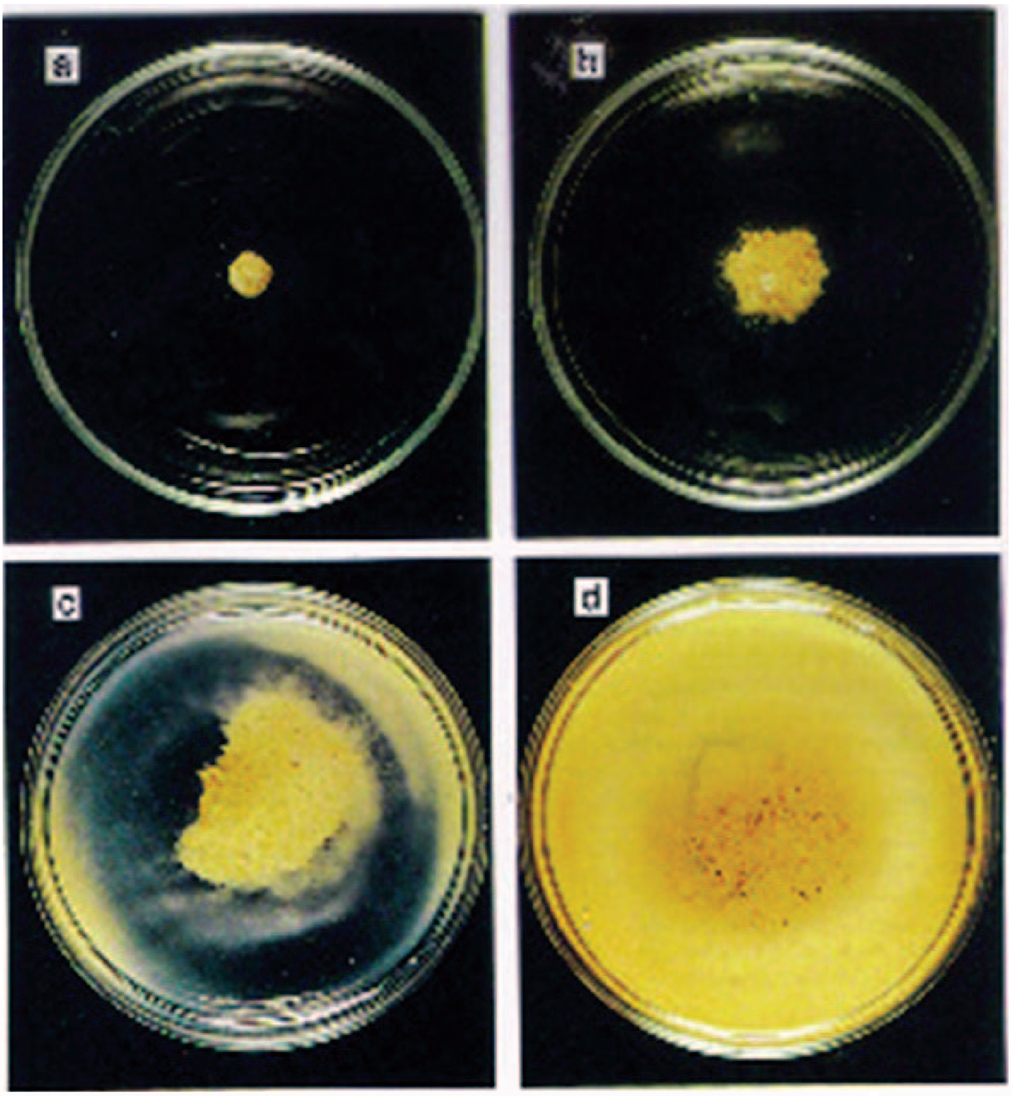

PHOTO 17 **Examples of the nature and the range of dispersion classes in the soil dispersion test for a clay rich soil. (Source: McKenzie *et al.*,1992)**

- the aggregate remained intact with no slaking or dispersion [score = 4];
- a slaked aggregate with no dispersion i.e. no visible individual mineral grains [score = 4];
- the aggregate slaked and moderately dispersed i.e. evident individual mineral grains [score = 2];
- the aggregate completely slaked and dispersed with clearly evident and abundant mineral grains [score = 0].

2. Soil pH (Tool 4.2.2)

Soil pH measures the molar activity (concentration) of hydrogen ions in the soil solution. It is a negative logarithmic scale, so a decrease of 1 pH unit increases the hydrogen ion concentration ten-fold. At a pH of 7 (neutrality), the activity of hydrogen ions is equivalent to the activity of hydroxyl ions. At pH values less than 7, the soil is acidic, whereas at pH values greater than 7, the soil is alkaline.

In summary, strongly acidic soils can have the following negative characteristics:

- aluminium and / or manganese toxicity;
- phosphorus deficiency;
- calcium and / or magnesium deficiency;
- reduced nitrogen mineralisation because of restricted microbial activity;
- reduced boron, zinc, molybdenum and copper availability.

Strongly alkaline soils can have the following negative characteristics:

- surface sealing and crusting problems due to excessive sodium;
- reduced availability of iron, manganese, zinc, phosphorus and copper;
- reduced microbial activity and reduction in fungal population.

The pH test presented here utilises a "field test kit" developed by CSIRO, Australia. It is the field test kit used by Australian field pedologists (soil surveyors).

The pH kit is used in the VS-Fast system, in preference to other methodologies of determining soil pH such as (electrical) meters, principally as the pH kit provides a visible output – the coloured barium sulphate. This visible outcome lends itself to the "alignment" procedure (mentioned above) where the samples from the exposed soil profile are placed in the porcelain dish in the correct (depth) order and positioned beside the exposed soil profile for photography. In this way, a lasting record is provided of pH with the corresponding, visible soil layers / features.

The procedure is as follows:

- Take a small amount of soil from the centre of a layer of interest. Crumb it up and place onto a white tile or piece of flat plastic.
- Add some of the black / purple liquid from the Test Kit (this is Universal "Raupach" indicator).
- Add just enough of the liquid to thoroughly moisten the soil. [It is important not to flood the soil.]
- Mix the soil and the indicator well together with a plastic or wooden rod (e.g. a clean stick or old "biro" pen).
- Let the mixture sit for two minutes (to allow the two to react).
- Using the little "puffer" bottle, gently "puff" a fine layer of the barium sulphate powder over the mix. A colour will develop in the powder.
- Match this colour with the closest match on the Test Kit colour chart.

Record the pH value on the field sheet (to an accuracy of 0.5 of a unit.)

3. Water infiltration (Tool 4.2.3)

A major determinant of the cropping or grazing potential of a soil is the rate and amount of water that can infiltrate both through the soil surface and within the soil profile.

Interpretation of the measured rates of hydraulic conductivity, similar to the interpretation of crust observations (section 4.2.4) changes with soil type. Rapid hydraulic conductivity, that indicates good soil structure in a clay or loam, is an unattractive attribute in a sand – showing rapid drying of the soil, following rain or irrigation, hence loss of water for subsequent plant use. Comparably, on paddy (rice) soils, zero hydraulic conductivity is an attractive soil situation. Hence, two scoring systems will be presented – one solely for use on sandy soils and paddy soils, the other for all other situations.

The following simple but robust method for the rapid estimation of soil hydraulic conductivity. [8] is based on fundamental, globally tested and accepted soil physical principles.

The method (see Photo 18) considers two scenarios:

- in the first, the ring is only pressed a short distance (a few millimetres) into the soil surface (this facilitates 3 dimensional flow – where the water can flow both vertically and horizontally into the soil), and
- in the second, the ring is push in to a considerable depth (> diameter of ring), so that the flow is essentially 1 dimensional (i.e. the water mostly flows vertically into the soil).

Where possible, always use the 3-D method, as results will be obtained more quickly and the time data is more sensitive to the hydraulic conductivity. The 1-D method is more appropriate when soil cracking or the aggregation of the soil makes it difficult to seal the ring onto the soil without leaks occurring.

Field equipment required: a 0.1m (length) x 0.1m (diameter) ring (metal or PVC with a sharpened tip), a container holding exactly 0.4l of water and a watch with a "seconds" hand or digital stopwatch.

The procedure[9] is as follows:

- Select a level area and carefully brush away any loose surface litter. If vegetation is present, clip it close to the soil surface and remove the clippings.
- Place the metal ring on the soil surface and push it a few mm into the soil to get a seal between the ring and the soil surface but ensuring minimal soil disturbance inside the ring.
- Pre-wet the soil surface in the ring by applying 50 to 100 millilitres (ml) of water. This is important, to reduce the initial, commonly rapid and non-steady state infiltration component of hydraulic conductivity, termed sorptivity (where the soil absorbs water due mainly to capillary forces rather than gravity). This pre-wetting reduces errors associated with assumptions in the method.
- After 15 to 30 minutes, add 0.4l of water to the ring; this being equivalent to applying 50 mm water (rainfall or irrigation water). (Note: during this wetting and the pre-wetting the water should not be poured directly onto the soil surface, to minimize changes to the soil surface. One method is to use a squeezable "wash bottle", apply the water to the inner sides of the ring until water ponds on the soil surface, then gently add the remainder of the water to this water surface)
- Note the time for the water to disappear (infiltrate) into the soil.
- Tables 18 a) and b) allow conversion of the infiltration time to a permeability class for each of the 3-D and 1-D scenarios respectively.

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[8] The soil hydraulic conductivity measurement has been devised by Dr Freeman Cook, CSIRO, Australia.

[9] Parts of the method are common with the same procedure in the SCAMP manual of Moody, P. W. and Phan Thi Cong (2008). See also Moody *et al.*, (in press).

PHOTO 18 **Assessing soil hydraulic conductivity rate**

Record whether 1-D or 3-D infiltration was measured and "fast", medium" or "slow" rate using the times in Tables 18.

NOTE: the same "result" in terms of hydraulic conductivity rate needs to be interpreted as "negative" for sands and "positive" for all other soils, as follows:

Scoring (from Tables 17 a and b):

- Fast rate (score = **0** for sands and **2** for
- all other soils);
- Medium rate (score = **1** for all soils);
- Very slow rate (score = **2** for sands and **0** for all other soils).

4. Soil organic carbon – labile fraction (Tool 4.2.4)

Most of the functions associated with soil quality are strongly influenced by the soil organic matter content, especially the small portion that is termed "active organic carbon" or the "labile fraction".

TABLE 18 **Estimation of hydraulic conductivity**

a) Simple estimation of K on the basis of 3-D flow from a pond

Time for 400 ml of water to be gone from ring with radius 50 mm.	**Hydraulic conductivity - K** (mm/hr)	**VS-Fast Score**	
		"negative"= sands	**"positive" = other soils**
< 10 min	> 36 (fast)	0	2
>10 min, < 2 hr	> 3.6 (medium)	1	1
> 2 hr	< 1 (very slow)	2	0

b) Simple estimation of K on the basis of 1-D flow from a pond

Time for 400 ml of water (vol.) to be gone from ring with radius 50 mm.	**Hydraulic conductivity – K** (mm/hr)	**VS-Fast Score**	
		"negative"= sands	**"positive" = other soils**
< 30 min	> 36 (fast)	0	2
>30 min, < 10 hr	> 3.6 (medium)	1	1
> 10 hr	< 1 (very slow)	2	0

BOX 2 Laboratory testing of total soil C versus field testing of labile soil carbon

As the soil labile carbon procedure is time consuming in the field and the calibration of the reagents is rather complicated, LADA countries tended to prefer to analyse the soil carbon in the laboratory. However, the standard lab tests give a value of total soil carbon, which is felt to give a less accurate measure of recent changes in soil organic matter as the labile carbon fraction.

It is suggested that the proposed labile carbon measurement method is used, but either the same day of or the next day after the field survey, in a suitable room with a person experienced in laboratory tests, to test all the soil samples collected from the field. The results will then be available while the team is still in the field, so that the findings can be consolidated and discussed with the land users and community members.

Most (routine) soil chemical laboratories provide a determination of total soil organic matter or soil organic carbon (SOM and SOC). This is reported as something generally between 0.5% and 7% in soil. These cannot be field tests, as they are based either on total (high temperature) combustion of a soil sample or require strong chemical reagents. Another problem is that they are insensitive to management practices because they include recalcitrant (inert) forms of organic matter (such as charcoal) which remain unchanged for decades, regardless of management practices.

Techniques have developed to fractionate carbon on the basis of lability (ease of oxidation), recognising that these sub-pools of "active" carbon may have greater effect on soil physical stability and be more sensitive indicators of carbon dynamics in agricultural systems than total carbon values (Weil *et al.* 2003). The labile fraction of soil carbon is the component of organic matter that feeds the soil food web and is closely associated with nutrient cycling and other important biological functions in the soil.

Weil *et al.* (2003) have developed a "field kit method" for the determination of potassium permanganate ($KMnO_4$) oxidisable carbon. The field procedure has been further refined in the SCAMP manual (Moody and Phan Thi Cong (2008); Moody *et al.*, in press). In this test, a dilute solution of $KMnO_4$ is used to oxidize organic carbon. Generally, in the course of the experimental procedure the greater the loss in colour of the $KMnO_4$, the lower the absorbance reading will be, hence the greater the amount of oxidisable carbon in the soil.

The method[10] requires a field kit consisting of:

Equipment

- 50 ml graduated disposable plastic centrifuge tubes (internal diameter: 30 mm) with screw-on caps;
- plastic rack(s) to hold the tubes vertical;
- 5 ml standard teaspoon (equivalent to 5 g ± 0.5 g soil);
- 550 nm wavelength Hach brand pocket colorimeter (or similar);
- 1 ml graduated pipette (plastic, disposable);
- 25 ml dispenser (plastic syringe) or measuring cylinder;
- deionised or distilled water;
- 1 funnel and cleaned glass wool.

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[10] Parts of the method are common with the same procedure in the SCAMP manual of Moody, P. W. and Phan Thi Cong (2008)

Reagents

Analytical grade reagents should be used.

- 0.1 M $CaCl_2.2H_2O$
- 33 mM $KMnO_4$

Preparation of reagents

- To prepare 0.1 M $CaCl_2$ weigh 1.47 g $CaCl_2.2H_2O$ into a volumetric flask and dilute to 100 mL with deionised water.
- To prepare 33 mM $KMnO_4$, weigh 5.21 g $KMnO_4$ into a small beaker with 200 to 300 mL of deionised water, heat the solution on a hot plate (optional, no hotter than 60° Celsius) and stir until dissolved. Filter the solution through a funnel containing a plug of cleaned glass wool and dilute with deionised water to 1 L in a volumetric flask. Store the solution in an amber glass bottle or in a dark place.

The **soil testing procedure** is as follows:

1. Air-dry 20 g of the soil under investigation (commonly 2 or 3 depths from the 30 cm or 40 cm soil profile on the spade) for 15-30 minutes by laying out on plastic in the sun. In wet / overcast weather, the soil may need to be taken indoors for drying and subsequent analysis.
2. Crumble the soil to approximately 2 mm aggregate size, carefully removing all stones and root and vegetative materials.
3. Add five cc of the crumbled soil with 25 ml of the $KMnO_4$ solution and one ml of the $CaCl_2$ solution (to assist flocculation of the soil particles) in one of the centrifuge tubes, and firmly cap the tube.
4. Shake vigorously for exactly two minutes.
5. Stand upright for 5 minutes, in the plastic rack and protected from direct sunlight.

BOX 3 **The calibration procedure**

The calibration procedure is as follows using varying concentrations of the stock solution:

1. Zero the colorimeter by filling the colorimeter cuvette (to the mark) with deionised water, place cuvette in colorimeter, cover with cap (lightproof), press the “zero” or “tare” button. Readout should be 0.00.
2. Add 25 mL of the stock solution to a centrifuge tube, add 1 mL of the $CaCl_2$ solution.
3. Pipette-off 1 mL of liquid from the solution and dilute in a centrifuge tube to 50 mL with deionised water, ensuring (through repeatedly flushing the contents of the pipette) that all the stock solution is added to the tube.
4. Fill the colorimeter cuvette and place in colorimeter as before. Press “read” button. Note reading. [Note: this is the strongest (darkest) concentration of the $KMn0_4$ solution; representing zero labile organic carbon in subsequent soil samples] (Figure 12).
5. Pour out sufficient of the remaining solution in the centrifuge tube so only 25 mL remains. Make up this remainder to 50 mL with deionised water, pipette off 1 mL and repeat the colorimeter measurement procedure. The reading obtained is for ½ strength $KMn0_4$ (Fig. 19A).
6. Again, pour out sufficient of the remaining solution in the centrifuge tube so only 25 mL remains and make up the remainder to 50 mL with deionised water, pipette off 1 mL and repeat the colorimeter measurement procedure; so gaining a ¼ strength solution (Figure 12).
7. Plot the above data (a straight line fit); as mM of $KMn0_4$ (x-axis) versus the absorbance reading (y-axis), as in Figure 13. A regression line can be fitted to the relationship.

NOTE: *The period of time the soil is in contact with the permanganate solution is critical, therefore 2 minutes shaking and 5 minutes settling time should be strictly adhered to.*

6. Pipette-off 1 ml of liquid from the top 1 cm of the “soil sample” solution and dilute in a centrifuge tube to 50 ml with deionised water, ensuring (through repeatedly flushing the contents of the pipette) that all the “soil sample” solution is added to the tube.
7. Zero the colorimeter using deionised water as in the calibration procedure (above)
8. Measure the absorbance of the sample (soil) as in the calibration procedure
9. From the standard curve (Figure 12), calculate the concentration of $KMnO_4$ (mM) left in the sample after the oxidation period.

NOTE: *If the absorbance of any sample is less than a reading of 0.4 (on the colorimeter at 550 nm), repeat the extraction using 2.5 g soil instead of 5 g soil. The implication is that the soil is rich in labile organic matter, hence a smaller soil quantity needs to be used to achieve oxidisation by the* $KMnO_4$ *solution. Calculation of results need to suitably altered, considering only half the soil quantity was used; i.e. the unit “5” in equation - 1 becomes “2.5”*

Calculation:

It is assumed that 1 *M* MnO_4^- is consumed (reduced from Mn^{7+} to Mn^{2+}) in the oxidation of 0.75 mmol or 9 mg of carbon.

<u>So, the amount of labile Carbon in the soil sample (grams of carbon in a kilogram of soil) is calculated as follows:</u>

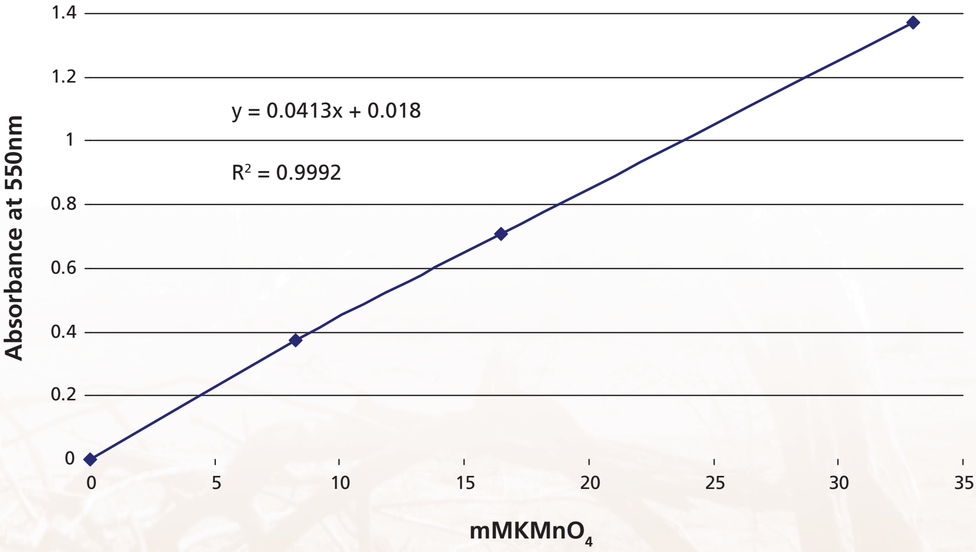

FIGURE 13 **Standard calibration curve of four strengths of 33 mM KMnO4 (x – axis) with colorimeter read-out (y – axis)**

$$C(g/kg) = \frac{(Mo - M1)x26x9}{1000x5} \qquad \text{equation (1)}$$

where:
Mo = initial concentration of $KMnO_4$ (33 mM)
$M1$ = concentration of $KMnO_4$ (mM) after oxidation (calculated from standard calibration curve: Fig. 11A)
Final volume of $KMnO_4$ solution = 26 mL
Weight of soil = 5 g (or as used)

Record the amount of active carbon present (mg/g) using Figure 13.

Scoring (from Table 19 and dependent on soil texture):

- good organic matter status (score = **2**);
- moderate organic matter status (score = **1**);
- poor organic matter status (score = **0**).

This uses the four strengths of 33 mM $KMnO_4$ of Figure 12 and equation 1.

This shows the relationship between "total" organic carbon (%) by the Leco method and active (labile) carbon from the permanganate field method for several soils. (Data and analysis of Dr P. Moody (NR&W, Queensland, Australia) with fitted line & regression equation with R^2.)

The relationship between the measured quantities of labile organic carbon fraction (as determined here) and total soil organic carbon (as commonly required for carbon "trading" and sequestering in consideration of climate change) is not straightforward; being inter-related with soil type, clay content and climate (organic matter weathering and volatisation). Dr Phil Moody (pers. comm.), from analysis of several tropical and semi-arid agricultural soils,

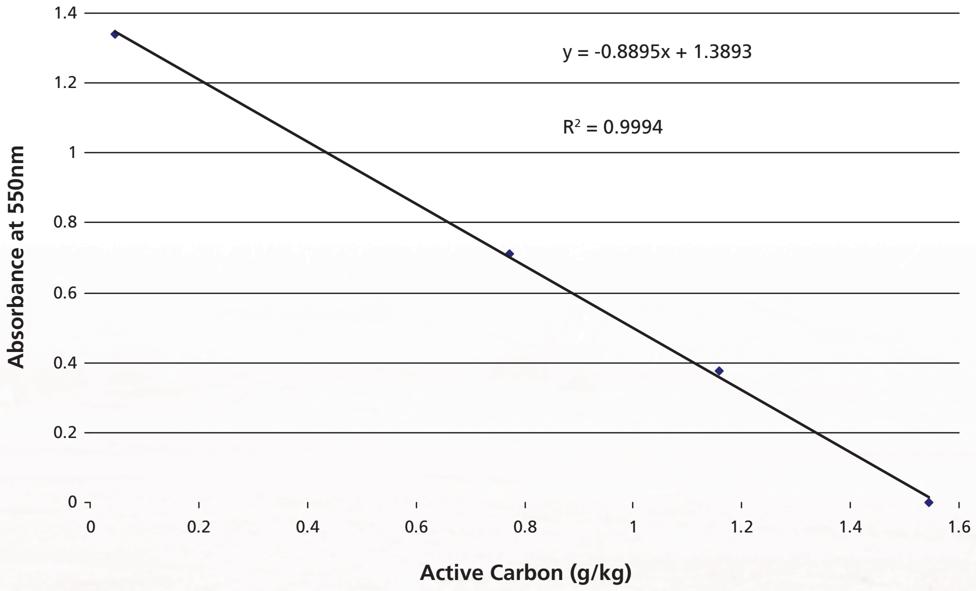

FIGURE 14 **Relationship between the colorimeter readout (absorbance) and the amount of labile ("active") carbon (g/kg)**

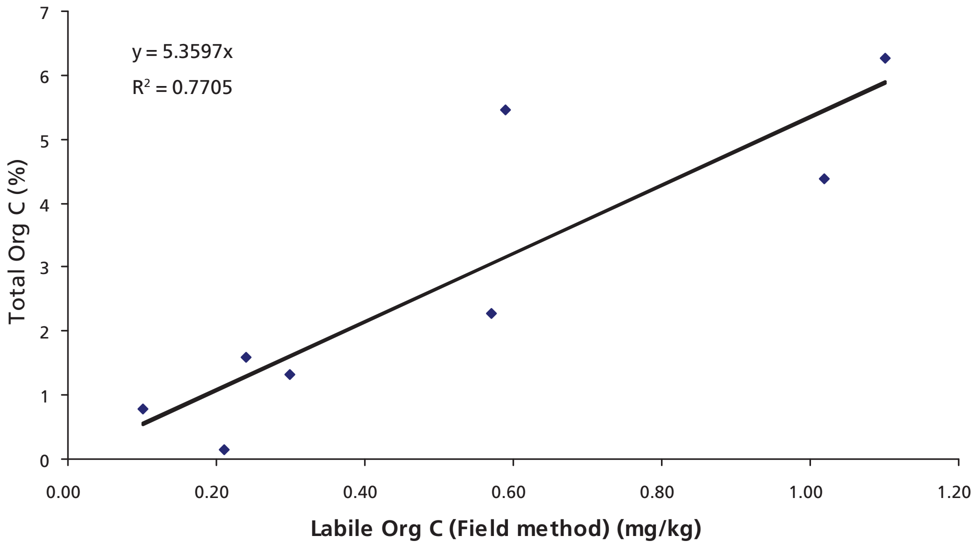

FIGURE 15 **Relationship between "total" organic carbon and active carbon**

TABLE 19 **Permanganate (33 mM) oxidisable carbon contents (g/kg) for soils of various textures**

Soil organic carbon status	Sand	Sandy loam	Loam	Clay loam/Clay
"good"	> 0.2	> 0.28	> 0.36	> 0.4
"moderate"	0.1 – 0.2	0.14 – 0.28	0.18 – 0.36	0.2 – 0.4
"poor"	< 0.1	< 0.14	< 0.18	< 0.24

* Values (mg/g) of labile carbon considered to be "good", "moderate" and "poor" for soils of different textures. The table is taken from Moody and Phan Thi Cong (2008) and the values are based on the analysis of several soils covering a wide range in total organic C.

states that the total organic carbon fraction by the Leco method (%) = 5.36 active C by the 33 *mM* $KMnO_4$ (mg/kg) method as described here). Future studies relating these two fractions of organic carbon will improve the fit and the understanding of this relationship.

5. Soil and water salinity measurements (Electrical conductivity) (Tool 4.2.5)

Salinity is the presence of soluble salts in soils or waters (Shaw and Gordon, 1997). Salinity processes are natural processes, however, human activities can accelerate these, contributing to long term land and water degradation. Salinity becomes a land issue when the concentration of salt adversely affects plant growth or limits plant species selection (to salt tolerant plants) or degrades soil structure (surface crusting and scalding). It becomes a water issue (surface and groundwater) when the potential use of water (for irrigation and human / animal use) is limited by its salt content (Shaw and Gordon, 1997). Tables 20 and 24 give some visual indicators of salinity for the field.

TABLE 20 **Assessing salinity using visual indicators in the field**

Visual indicators	Salinity	Sodicity
Plant indicators	• Salt tolerant species e.g. couch grass (*Cynodon*) and other halophytes (that tolerate or favour an environment with elevated salt concentrations) • Water stress symptoms in a crop (rolled and / or drooping leaves) even though the soil is wet	• Poorer vegetation than normal, few or stunted plants and trees • Variable height growth in a growing crop and yield variations at harvest • Symptoms of water stress not long after a rainfall or irrigation event.
Soil indicators	• Saline soils often exhibit a fluffy surface • Whitish salt crusts often observed on top of mounds, aggregates or slightly elevated areas in the field when the surface is dry	• Hard-setting surface horizon often observed in soils with a sandy loam topsoil. • Surface crusting. • Soapy feel when wetting and working up for texture assessment. • pH >8.5. • Poor penetration of rain or irrigation water into the soil due to surface crusting • Cloudy water in puddles that may form on the soil surface. • Shallow rooting depth.
Water indicators	• Depth to water table and salinity of water (measurements)	
Populations of salt-sensitive plants	• Decreased germination rate, slow growth rate, incomplete life cycle (e.g. plants do not flower), diminished abundance, depressed health (e.g. yellowing and stunting of crop or pasture species), greater susceptibility to disease and decreased seed viability.	

Particularly in sandy and / or arid areas, the presence of a shallow (< 2 m depth) and non-saline (electrical conductivity of <1 dS/m) water table can radically improve the potential agricultural productivity. Conversely, the presence of a shallow water table that is saline can be ruinous to almost all land uses, thus long term sustainability and productivity.

Limitations to field assessment of salinity

If the assessment is taking place in years of below average rainfall, there may be very little plant germination or growth. Thus the use of plants as salt indicators will be restricted. Conversely, in years of above average rainfall the full extent of salinity may be underestimated due to the leaching effect. In both cases, it is preferable to delay the assessment until favourable climatic conditions return.

Salinity in soils and waters can be estimated conveniently from the electrical conductivity (EC) of a soil solution, or directly on a water sample. Many salts dissociate (separate out) to ionic form in water, so the EC of a solution provides a measure of the total concentration of salts (Shaw and Gordon. 1997).

Electrical conductivity is defined as a measure of a solution's ability to conduct electricity, and as such can be used to express salinity levels in soil (a soil extract in water) or water. When salt is dissolved in water the conductivity increases, so the more salt, the greater the EC value. EC is measured by passing an electric current between two metal plates (electrodes) in the solution and measuring how readily current flows (i.e. conducted) between the plates. EC measures the charge carrying ability (i.e. conductance) of liquid in a measuring cell of specific dimensions. It is necessary, therefore, to state the units of both conductance and length in considering EC. EC units vary between institutes and countries but most common is the use of "decisiemen per metre" (dS/m)[11], and commonly at 25°C, as temperature at time of measurement effects result.

Soil salinity generally affects plant growth by increasing osmotic tension in the soil making it more difficult for the plants to absorb water from the soil. Excessive uptake of salts by plants from the soil may also have a direct toxic effect on the plants. Crops vary considerably in their capacity to withstand adverse effects of salinity. Saline water, apart from being unpalatable to humans and stock, can also cause direct damage to crop leaves, depending on the concentration of salts, applied through sprinkler irrigation.

Electrical conductivity (EC) can be measured in the field using a portable EC meter. The Milwaukee® C66 "pen" electrical conductivity meter has been used in LADA assessments to date, as it was found to fulfil many of the requirements of the testing procedure, including operational range (0 to 10 dS/m), waterproof, cost, ease of use, lightweight and being (automatically) temperature compensated.

Methods

The method tests EC on a soil saturation extract (EC_{se}) using a portable field EC meter.

Before measuring EC in the field, ensure that the EC meter has been calibrated against a standard salt solution. The technique is one of manual calibration at 1 point using the small screwdriver supplied with the meter. This procedure is included in the "instruction booklet" provided with each C66 pen, and is as follows:

1. Place electrode into clean water to clean and rinse it;
2. Shake off excess water;
3. Unscrew the battery compartment cap on the top of the meter;
4. Place meter into calibration fluid (commonly used is Milwaukee 1413 µS/m EC solution) until electrodes are covered. (Note: pour just sufficient from the bulk container into a small container for this calibration procedure and then discard the solution; i.e. never re-use the calibration solution or return it to the bulk container);
5. Allow the reading to stabilise and use the small screwdriver supplied with the meter, to turn the small brass screw (the "calibration trimmer") until the readout says 1.41 mS/cm. Note: the Milwaukee C66 pen gives a readout in millisiemens per centimetre (mS/cm). So, these can be read directly as dS/m;
6. Replace the battery compartment cap;
7. The pen is now calibrated.

The technique of determining the EC of a soil sample is as follows:

1. Take 50 to 100 g of soil from the layer(s) of interest (commonly the top and bottom of the spadeful of soil);
2. Remove all stones and organic/vegetative materials;

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[11] To aid in conversions: 1 decisiemen per metre (dS/m) = 100 millisiemens per metre (mS/m) = 1000 microsiemens per metre (µS/m) = 640 parts per million (ppm) of total dissolved salts (TDS). Note: 640 is a commonly accepted average as the correct factor varies from 530 to 900 depending on the type of salt present and its concentration. Note also, ppm is equivalent to mg/L (milligrams per litre).

3. Prepare a soil paste by stirring deionised water into the soil in a tube or cup (wide enough to take the tip of the EC probe) until a smooth paste is obtained. An indicator that the correct amount of water has been added is that the "paste" glistens (mirror-like) and just begins to flow. It is important to standardise this wetness "end point" as the value of EC_{se} changes as the concentration of salts changes (with more or less water added);
4. Ensure that the EC meter has been calibrated against a standard salt solution (Note: EC is influenced by current temperature conditions, however, if the EC probe is temperature-compensated (as in the case of the Milwaukee C66 as recommended here) there is no need for temperature recording and post-compensation of calibration or solution readings);
5. Carefully insert the EC probe into the soil paste until the electrodes are covered and wait for the EC reading to become steady. Record the reading (exactly as displayed on the wand) in dS/m;
6. After reading, remove the probe, wash with deionised water while removing excess soil from around the probes with a soft brush (e.g. a toothbrush), ready for the next soil solution.

Salinity (ECw) in water, whether irrigation, surface or groundwater can be measured directly by collecting a suitable (fresh, non-stagnant) water sample, ensuring calibration of the meter, placing the EC probe directly into the sample and taking the reading in dS/m.

The quality of groundwater is of particular importance in sandy and / or arid areas, where the presence of a shallow (< 2 m depth) and non-saline (electrical conductivity of <1 dS/m) water table can radically improve the potential agricultural productivity. Conversely, the presence of a shallow water table that is saline can be ruinous to almost all land uses and long term sustainability and productivity. Relevant, too, is the measured change in level of such water tables – both short and long term. It is important to determine the linkages between the nature and extent of (local) land use changes and the link (if any) with monitored changes in groundwater levels (perhaps information available from local water authorities).

TABLE 21 **Relative values of ECse, VS-Fast and plant salinity tolerance classes**

Level of soil Salinity	**Plant salt tolerance grouping**	**ECse range** (dS/m)	**VS-Fast score**
"not" saline	sensitive crops	< 1	good = 2
mildly saline	moderately sensitive crops	1 - 2	good = 1.5
moderately saline	moderately tolerant corps	2 - 4.5	moderate = 1
	tolerant crops	4.5 – 8	moderate = 0.5
strongly saline	very tolerant crops	8 –12	poor = 0
very strongly saline	generally too saline for crops	> 12	poor = 0

ECse values, with corresponding VS-Fast class and score, corresponding to the plant salinity tolerance classes of Maas and Hoffman (1977).

Values of soil and water EC can be related to available tables on: (i) plant salinity tolerance classes and the ability of specific crops to tolerate salt respectively (Tables 21 and 25) that is part of the VS-Fast scoring sheet at the end of this section, (ii) plant hazard of salinity in irrigation waters (Table 22), (iii) water quality for domestic use and stock supplies (Table 23). If measured, these values should be noted on the VS Fast score sheet.

TABLE 22 **Plant hazard of salinity in irrigation water (ECw)**

Hazard	dS/m
none	< 0.75
slight	0.75 – 1.5
moderate	1.5 - 3
severe	> 3

Source: Morris and Devitt (1991)

TABLE 23 **Water quality guidelines (ECw) for domestic and stock (animals) supply**

ECw range (dS/m)	**Usefulness of water supply**
0 – 0.8	• Good drinking water for humans (if no organic pollution and minimal suspended clay) • Generally good for irrigation, though above 0.3 dS/m overhead sprinklers may cause leaf scorch on salt sensitive plants. • Suitable for livestock
0.8 – 2.5	• OK for humans - lower half of range preferred • For irrigation, requires special management including suitable soils, good drainage and consideration of salt tolerance of plants. • Suitable for livestock.
2.5 - 10	• Not recommended for humans. Up to 3 dS/m OK if nothing else available • Not suitable for irrigation. Up to 6 dS/m OK on very salt tolerant crops • >6 dS/m - occasional emergency irrigation OK • For poultry and pig supply < 6 dS/m OK. Other stock < 10 dS/m • > 4 dS/m - causes shell cracking in laying hens.
> 10	• Not suitable for human consumption or irrigation • Not suitable for pigs, poultry or any lactating animals. • Beef cattle can use water up to 17 dS/m; adult dry sheep tolerate 23 dS/m

From Anderson and Cummings, 1999

TABLE 24 **Salinity class range**

Level of salinity	Visual indicators	ECe range
S0 (Not Saline)	• No vegetation appears affected by salinity and a wide range of plants present.	< 2 dS/m
S1 (Slightly Saline)	• Salt tolerant species e.g. sea barley grass often abundant. • Salt sensitive plants in general show a reduction in number and vigour especially salt sensitive legumes (eg. white and sub–clover, soybeans, chick pea, etc.). • At the upper end of the range, grasses and shrubs may be prominent in the plant community. • No bare saline patches or salt stain / crystals are evident on bare ground.	2 - 4 dS/m
S2 (Moderately Saline)	• Salt tolerant species begin to dominate the vegetation community and all salt sensitive plants are markedly affected by soil salinity levels. • At the upper end of the range, some slightly tolerant species disappear and are replaced by others with higher salt tolerance. The plant community is dominated by grasses, shrubs and flat weeds. Legumes are almost non-existent. • Small bare areas up to 1 m2 may be present and salt stain/crystals may be visible on bare soil at the upper end of the range.	4 – 8 dS/m
S3 (Highly Saline)	• Salt tolerant species like sea barley grass and buck's horn plantain may dominate large areas and only salt tolerant plants remain unaffected. • In low rainfall areas, unlikely that any improved species will be present; trees may show some effects (i.e. dieback). • Large, bare saline areas may occur showing salt stains or crystals (on some soils a dark organic stain may be visible), or the top soil may be flowery or puffy with some plants surviving on small pedestals and the B horizon may be exposed in some areas. • In moderate to high rainfall areas, bare patches may be minimal but vegetation will be dominated by one or two highly salt-tolerant plant species (e.g. Puccinellia, Spurrey, Gahnia). • In higher rainfall regions, where soils may be waterlogged or flooded for considerable periods, some plant species display both salt tolerance and waterlogging tolerance. In drier areas, salt tolerant plants generally do not have high waterlogging tolerance. • At the upper end of the range, halophytic plants may dominate the plant community and some species may show a reddening of the leaves.	8 – 16 dS/m
S4 (Extremely Saline)	• Only highly salt tolerant plants survive and the community will be dominated by 2 or 3 species. Moderately and highly salt tolerant species may show a reddening of the leaves and at the upper end of the range even highly salt tolerant plants may be scattered and in poor condition. • Trees will be dead or dying. • Extensive bare saline areas occur with salt stains and or crystals evident (on some soils a dark organic stain may be visible). Topsoil may be flowery or puffy with some plants surviving on small pedestals and the B horizon may be exposed in some areas.	> 16 dS/m

Source: Victorian Resources Online: Salinity Class Ranges
http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/water_spotting_soil_salting_class_ranges#s0

TABLE 25 **USDA ratings of relative crop tolerance to salinity**

Plant grouping	High salt tolerance	Medium salt tolerance	Low salt tolerance
Vegetable crops	**EC_{se} = 12–10** Garden beets; Kale; Asparagus;	**EC_{se} = 10–4** Tomato; Broccoli; Cabbage; Bell pepper; Cauliflower; Lettuce; Sweet corn; Potatoes (White rose); Carrot; Onion; Peas; Squash; Cucumber;	**EC_{se} = 4–3** Radish; Celery; Green beans;
Forage crops	**EC_{se} = 18–12** Alkali sacaton; Salt grass; Nuttall alkali grass; Bermuda grass; Rhodes grass; Fescue grass; Canada wild rye; Western wheat grass; Barley (hay); Bird's-foot trefoil;	**EC_{se} = 12–4** White sweet clover; Yellow sweet clover; Perennial rye grass; Mountain brome; Strawberry clover; Dallis grass; Sudan grass; Huban clover; Alfalfa (California common); Tall fescue; Rye (hay); Wheat (hay); Oats (hay); Orchard grass; Blue grama; Meadow fescue; Reed canary; Big trefoil; Smooth brome; Tall meadow oat grass; Cicer milk-vetch; Sour clover; Sickle milk-vetch;	
Field crops	**EC_{se} = 16–10** Barley (grain); Sugarbeet; Rape;	**EC_{se} = 10–4** Rye (grain); Wheat (grain); Oats (grain); Rice; Sorghum (grain); Sugarcane; Corn (field); Sunflower; Castor beans;	**EC_{se} = 4–3** Field beans Flax

Plants are listed within groups in order of decreasing tolerance to salinity. ECse values (dS/m) correspond to 50% decrease in yield.

(EC_{se} = the EC (dS/m) of a saturated soil extract as given in section 4.2.12 Source: Van Lynden *et al*, 2004

FIELD SCORE CARD

Soil Condition Assessed using VS-Fast Methodolgy

PART A: SOIL VISUAL DESCRIPTORS

Date:
Land Use (Current and Past):
Site Location:
Recent Weather Conditions:
Soil Type:
Soil Structure:
Soil Texture:
Soil Colour:
“Walk in” Observations (soil / crop residues):

Soil Profile sketch

Visual Indicator of Soil Quality	**Visual Score (VS)** 0 = Poor Condition 1 = Moderate Condition 2 = Good Condition		**Weighting**	**VS-Fast score**
Tillage pan			x 3	
Aggregate Size Distribution			x 3	
Soil Crusts * ** Score for either “negative” or “positive (biological)” crusts*	**(negative)** 2 = no crust 1 = some cracking 0 = continuous crust	**(positive = biological)** 0 = Poor 1=Moderate 2 = Good	x 2	
Earthworms (or other more pertinent soil fauna)			x 2	
Roots			x 3	
Sum of visual VS-Fast scores				

Soil Visual Assessment	**Sum of visual VS-Fast Scores**
“Poor”	< 7
“Moderate”	7 – 14
“Good”	15 – 26

FIELD SCORE CARD

Soil Condition Assessed using VS-Fast Methodolgy

PART B: FIELD SOIL MEASUREMENTS

Field Measurement	Actual Value	Visual Score (VS)* 0 = Poor Condition 1 = Moderate Condition 2 = Good Condition		Weighting	VS-Fast score
Slaking and Dispersion		(scores: 0-4)		x 1.5	
Soil pH		Not scored		Not scored	
Water Infiltration *“negative” = sands* *“positive” = other soils*		**(negative = sands)** 0 = fast 1 = medium 2 = slow	**(positive = all other soils)** 0 = slow 1 = medium 2 = fast	x 3	
Organic C – labile fraction				x 2	
Soil salinity (EC)				x 3	
Sum of soil measurement VS-Fast scores					

* These scores not applicable to Slake/Dispersion test, where scores range from 0 to 4 (hence ½ weighting value)

Soil Measurement Assessment	Sum of VS-Fast Scores
“Poor”	< 7
“Moderate”	7 – 14
“Good”	15 – 22

Total VS-Fast score (Part A + Part B) scores	
“Poor”	< 14
“Moderate”	14 – 28
“Good”	30 – 48

Other Notes, e.g. Site Photo; Soil Photo or Sketches of soil, pit location…

Tool 4.3 Soil erosion assessment

Introduction

The presence of soil erosion in arable, forest and pasturelands is a prime indicator of soil degradation by water or by wind; often caused by a reduction in protective vegetation cover. It may reflect imbalance in the co-achievement of productive capacity and ecologically sustainable land management, i.e. intensification for increased production without adequate means to restore land resources and ecological functions. Soil erosion through topsoil loss is an indicator and cause of reduced land fertility, and hence potential productivity. It may also hinder access to land for crop/forest production. Moreover, the transported sediments and nutrients may cause problems downstream in terms of sediment deposits and reduced water quality. Despite the recognised importance of controlling and reversing soil erosion through soil and water conservation practices, there are few attempts to systematically observe and measure soil erosion as part of an integrated assessment of degradation and management (soil, vegetation, water and ecosystems) as this manual tries to do.

For the most part, the methods presented here are designed to be used in the field, during the assessment by the multidisciplinary technical team, and in the presence of land users - crop, pasture, forest - and, if possible, representatives of local government. This will aid interpretation of the observed erosion features and their impacts, for example, in regard to recent management, weather patterns and policy and technical interventions, if any.

Soil erosion is a commonly used indicator of negative land quality or condition as it is more visible than some other types of degradation such as nutrient mining or salinization. The immediate causes of soil erosion are wind and water as energy sources that translocate soil particles but unsuitable land use and management practices greatly exacerbate the problem (indirect causes), particularly on land prone to runoff and exposed to strong winds and soil movement (e.g. steeper slopes, loose or bare soil, inappropriate cultivation, etc.).

- **Erosion by water** is the detachment and transport of soil particles downslope through a number of processes, driven principally by the energy and the concentration of the water as it passes over the land.

- **Erosion by wind** is the detachment and transport of soil particles by wind action and commonly considers also the effect of the abrasive action of the particles as they are transported and of the soil deposits or sediments.

Measurement of wind and water erosion may include descriptions and measures of the erosion and deposition **features** but above all should focus on the **impacts** of the soil movement, *e.g.* the effects on the land potential through the loss of soil and nutrients and the effects of the transported and deposited particles, for example: silting of wetlands or floodplains, sandstorms, moving sand dunes, sediment load in rivers and streams). While erosion and hence loss of soil particles and nutrients will negatively impact on land productivity in the upper part of a catchment, it may provide fertile silts and nutrients downstream in the floodplains, i.e. having a positive impact on productivity.

This section is a composite of two sources: the erosion concepts and indicators from Stocking and Murnaghan (2001) as well as a more recent GITEC/ADB/GEF project on Sustainable Pasturelands in Tajikistan by Mulder and McGarry (2010).

What to measure

This section provides a set of simple, field usable indicators and measurements to observe, quantify and report on soil erosion at detailed assessment sites in the various land use systems and land use types (bare field, rainfed or irrigated cropland, pasture / rangelands, natural or planted forests, etc.). The specific tools need to be selected on the basis of the soil erosion features observed in the field: sheet erosion, rills, gullies/ravines, exposed rock, sediment deposits, sand dunes, etc..The field measurements are robust, relatively rapid (once the team members are familiar with the tools), cheap and replicable. The aim is to compare erosion status and trends under different sites (varied topography, exposure, etc.) and different land uses and management practices.

The methods aim to achieve clarity and uniformity in recording visible soil erosion features, in terms of three distinct but inter-related qualifiers and quantifiers:

- field observations that describe soil erosion by wind or water using four descriptors of the erosion feature: type, state, extent and severity; (Tool 4.3.1);
- a field scoring method, based on the descriptors in the field observations, to provide a more quantified basis for inter-site comparisons (Tool 4.3.2). This was developed and tested by the LADA team in Tunisia (DG/ACTA, 2010) and further reviewed (McGarry, 2011); and,
- field measurements of specified dimensions of erosion features to provide quantification of rates and quantity of soil loss in a study area. (Tool 4.3.3). These draw from the Field Guide for Soil Degradation Assessment (Stocking & Murnaghan, 2001).

The information gathered on soil erosion can also be related to the community map (Tool 1.4) and other land use and topographic maps of the study area to understand wider implications of soil erosion in the landscape. Through discussions with land users and informants the assessment team should try to estimate the main effects of the erosion and sedimentation processes on productivity and other ecosystem services, on-site and off-site, including damage to infrastructure and effects on human welfare (e.g. sandstorms).

The outputs of the soil erosion assessment could include:

a. an overview of the major erosion features (type, state, extent and severity) affecting different land use types and land use systems in a selected study area and, to the extent possible, an indication of their potential impacts on- and off- site (productive land area lost, reduced productivity etc.);

b. identification and understanding of the main direct and indirect causes of erosion in the study area through observations of local causative factors and their interactions and cumulative effects:
   - rainfall amount and intensity,
   - slope of land,
   - soil type (sands and silts being more erosion prone than clays and loams;

   degree of soil cover (litter, crop, tree, residues) as related to land use, time of the year (bare fields post harvest or after land preparation), crop/ pasture/forest age and management practices (young, emerging crops, and young or well-thinned forest have less cover to protect the soil), extent of land clearing, etc.

c. the planning and design of soil and water conservation measures and land management practices for:
   - the affected sites to prevent or mitigate the main causes of erosion identified in the study area (direct and indirect) and, where feasible, to repair the erosion features and restore productivity or
   - new areas being opened up to production or undergoing land use changes, to ensure minimal erosion problems from the intervention (e.g. biofuel production, conversion of marginal lands to forest land, pasture or cropping, conversion of agro-pastoral areas to intensive cropping or ranching).

d. a baseline for subsequent monitoring of the status of erosion features by repeating the given observations and measurements on a specified time period, for a given area i.e. to monitor continued degradation in a "non-intervention" scenario (control) compared to an area with interventions that lead to reduced erosion, prevention of erosion, or restoration of eroded lands.

Part 1 section 6 Shows how analysis of the qualitative and quantitative information on vegetation, soil properties, soil erosion, water resources and the land use and management practices of different types of land users/ farmers and land degradation processes and conservation measures can be brought together as an integrated landscape and ecosystem assessment

Tool 4.3.1 Field observations of erosion – type, state, extent and severity

How to select observation sites

The following process is foreseen to identify areas for the required erosion observations and measurements in order to understand cause, type, extent, severity, etc. and, in turn, enable to propose and plan improved land management or rehabilitation actions:

1) conduct if possible a "desktop" study of the intended study areas using any available maps and remote sensing images ((topographic and cadastral maps, Google Earth®, air photos, satellite imagery, digital elevation models -DEM, soil/ geology maps, etc.) and previous studies and reports to elucidate any major erosion features, their place in the landscape (land unit, slope) and their association with recognizable land uses in the area, etc.

2) seek out representative sites in the various land use types (LUT) in the area under consideration (e.g. cropping land, forest, pasture or fodder producing land, orchard, vegetable production, etc); and

3) be led by locals who live or work in the area (i.e. land users, farmers, herders, forestry workers, state farm managers, etc. as a follow up to the Community Focus Group Discussion, see Tool 1.1) to those areas that they believe are most degraded, or on which they are most dependent (e.g. for food production, forest replanting, winter pasture regrowth, etc.) or previously eroded areas that have been effectively restored through effective management measures.

It is important to collect information on timescales of relevance to soil formation and erosion processes in order to understand the impact of the different erosion types/ processes and particularly the capacity to repair or diminish their impact.

- sheetwash may be an annual event or more frequent occurrence;
- rills may form after a series of heavy rainfall events on ploughed land;

- gullies and ravines are most commonly the effect of several seasons or years of water concentration that result in deep incisions;
- landslides and mudflows are often rare events but these more serious erosion types are more likely to occur on certain soil types and sedimentary materials.

Repair strategies, therefore must be prepared and designed for relevant timescales. For example, rills may be readily ploughed out and can be prevented by appropriate vegetation cover and soil and water management practices but gullies will require years to reclaim by installing physical barriers (e.g. gabions and check dams) and through vegetation enrichment with suitable trees, shrubs and grasses.

The "secondary data" from maps, images and reports can be validated and updated in the study area using the observations and measurements outlined below (Tools 4.3.1 to 4.3.3). This on-site ground truthing should be backed up by interviews/ discussions with land users/other knowledgeable persons to cross-reference the observed types, extent and severity of erosion features with recent and historic land practices and weather observations; rainfall periodicity and intensities for water erosion and wind intensity for wind erosion features. This should provide good understanding of the processes, timescales and causes that have resulted in the currently observed erosion features.

Describing soil erosion on the community sketch map - initial observations STEP 1

As described in Tool 1.4, the community sketch map that is prepared with land users as part of the community focus group discussion should highlight major visible features in the area to be evaluated, in terms of terrain, land use, soils / geology, water resources, their relative proportion of the total land area; degradation features, including soil erosion (sheet erosion, rills, gullies) and causes (overgrazing, intensive cropping, wetland encroachment, etc.) and existing conservation / sustainable land management measures and their effects (negative and positive) on land productivity. If the sketch map has not clearly indicated erosion features or if more specific information is required for a selected study area, a few community members can be asked to reassess these issues and highlight if and where erosion by water or wind is a significant factor and the main causes.

Once the main erosion features are drawn on the "community sketch map", each soil erosion area can be qualified in terms of four descriptors: type, state, extent and severity. Each of these is defined below to the extent possible (though wider application of the tools and feedback is envisaged to lead to better definition of the classes and terms).

On the community sketch map (Figure 15), which reflects the landscape view showed on Photo 19, discussion with locals led to

PHOTO 19 **Example of a "distant view" of an area of land to be investigated for erosion features (just north of Dushanbe, Tajikistan)**

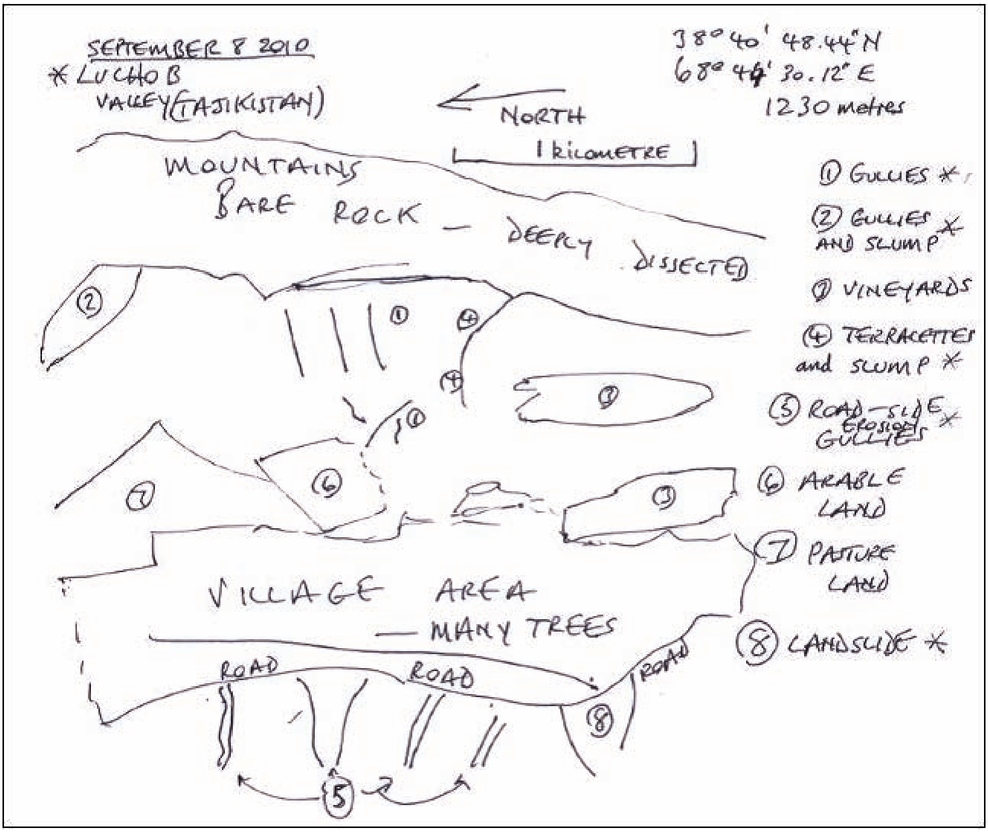

FIGURE 16 **"Community map" sketched on-site, overlooking the area in Photo 19**

delineation and description of the main erosion features, other relevant information (vegetation, main land uses, slopes, villages, roads, streams, etc) and location (latitude, longitude, elevation and north point) of the observation point using a GPS unit.

Erosion Type, STEP 2: Erosion types are specified progressing from those that are the least evident to those that are most evident i.e. from (rain) splash and sheet wash, to rills, to gullies, to ravines and landslides and other mass movements (see Annex 1). It is important to specify that "type", as used in this guide, describes the physical nature of an erosion feature and indicates the boundaries that determine when one erosion type becomes another (e.g. When does a rill become a gully?). This will ensure more commonality of erosion type definition, hence replicability between users and geographic areas.

TABLE 26 **Types of Soil Erosion – definitions, indicators and boundaries**[12]

Type of soil erosion & Score	Code	Definition	Indicators (How to recognize
Splash (1)	SP	Raindrop impact displaces soil particles vertically and downslope	Soil particles on lower parts of plants and/or a compacted (or dispersed) soil surface crust
Sheet wash/ Sheet (2)	S	Erosion of the top layer /sheet of the soil as differentiated from linear erosion (rill, gully, ravine)	Gravel/stones protruding from soil surface; root exposure; loss of darker topsoil horizon; subsoil exposure
Rill (2)	R	Irregular, downslope, linear channels, shallow (up to 0.3 m deep and wide)	Shallow, commonly long channels running downslope
Gully (4)	G	Irregular, V-shaped, steep-sided, linear channel formed in loose material, deep (0.3 – 2.0 m deep) formed by water erosion	Deep, pronounced channels
Ravine (4)	A	As in the definition for "gully" but very deep and wide (> 2m deep and wide)	Very deep and wide, pronounced channels
Landslide (4)	L	Sudden downslope movement of a concentrated mass of soil and rock, mainly under influence of gravity, triggered by water saturation or earthquakes (sometimes termed mass movement)	Almost vertical sides; rounded head (gully has narrow or sharp head)
Slumping (2)	SL	Slow, irregular, downward progression or of a thin (< 1m) layer of soil, due to water saturation, but possibly in combination with freezing-thawing	Rounded scar; irregular, uneven, downslope surface
Rotational slumping (3)	RS	A form of mass movement where rock and soil move downwards along a concave face. The rock or soil rotates backwards as it moves in a rotational slip. They always have a concave sliding plane and multiple scars (while slides have relatively straight shear planes).	Series of irregular scars and wide cracks
Terracettes (2)	T	Irregular small step-like formations, from a combination of slumping and preferential animal movements (tracks) on the surface of moderate to steep slopes	Irregular on-contour steps of about 0.1 to 0.2 m height on moderate to steep slopes in grasslands

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12 Note: Annexe 3 provides more detailed descriptors of the nature and causalities of many of these erosion types, that may be used to aid identification.

TABLE 26 **Types of Soil Erosion – definitions, indicators and boundaries** *(continued)*

Type of soil erosion & Score	Code	Definition	Indicators (How to recognize
Tunnel (3)	TU	Sometimes hidden, sub-surface holes and tunnels that can break-through to form surface gullies	Often hidden but may break through the soil surface as potholes and gullies
Roadside erosion (2 or 3)	RE	Erosion (mostly gullies) caused by concentrated water flow over the impervious road surface; cutting back into the road and causing damage to roads or erosion downslope. Score depends on gully or tunnel intensity	Erosion features below the point where water runs off the road
Stream bank erosion (2 or 3)	SE	Undercutting of streambank by running water. Score depends on gully or tunnel intensity	Fresh cuts in banks; exposed tree roots; collapsed structures
Wind erosion (Variable)	WE	Detachment and transport of soil particles by wind. Score difficult as the features observed are almost always "effects" of wind erosion: dunes, scouring of vegetation, posts, etc	Scouring on windward side or deposits at leeward side of obstacles. Sand dunes (stable or moving)

Erosion State: STEP 3, For each erosion type, one of four classes below is used to describe the level of activity:

(i) **active** – erosion feature is increasing in size or extent;

(ii) **partly stabilized** – between active and stable;

(iii) **stable** – it is either an historic (relic) feature from past climate and land use, or a more recent erosion feature for which recent anthropogenic interventions (e.g. contour bunds or change in land management) have slowed or stopped the erosion process;

(iv) **decreasing** – where recent anthropogenic interventions have begun to reverse the erosion process i.e. rock, sediment and vegetation filling of gullies, leading to stabilization and increased soil organic matter and plant growth.

Erosion Extent, STEP 4: An estimation is made of the spatial extent of each erosion type. The intent is less to measure actual areas, in hectares or square metres (though some may choose to do this) and more to provide a good estimate of the area under consideration that is affected by the erosion types recorded. As such, it is considered that **extent** (used in this way) implies the proportion of a stated area that is affected by the recorded erosion type. The five terms used to define extent are:

- **negligible** (0-2% of the area under study)
- **localised** (3-15% of the area)
- **moderate** (16-30% of the area)
- **widespread** (typically 31-50% of the area)

Note that the class "widespread" is intentionally maximised at 50% of the area under consideration. This reflects that each erosion type is classed individually, so it is possible (in one area) that there is, for example, sheet wash, terracettes and gullies, with localised (10%), widespread (50%) and moderate extent (20%) respectively – showing that 80% of the area is eroded but by these three different erosion types.

There are various ways to record extent.

1. The areas affected by the specified erosion types can be drawn on a "community map" as in Figure 2.
2. Where available, the erosion features can be either located or drawn onto available maps (topographic, soil, etc), aerial photos, ortho-photos, satellite images, Google Earth® images, etc.
3. If required for detailed study, a theodolite or dumpy level can be used for accurate mapping and geo-placement of recorded erosion features; though this requires a high level skill set with related expense and time considerations.

Erosion Severity, STEP 5: Severity in terms of soil erosion is often defined as the "degree of the effect of the (specified) erosion type". A more pragmatic definition is the rate or "average amount of soil that is moved by water or wind", expressed as units of mass/ area/time (Leys, 2010). Based on this definition, a field usable estimate of erosion severity is made using five classes, recognising that the mass of soil loss will rarely be known (particularly with historic erosion features) (Leys, 2010). Over time with wider usage, these classes may be better defined and perhaps oriented to specific geographic areas.

- **low** – minimal erosion types evident; most commonly splash or rill erosion
- **moderate** – evidence of erosion but eroded sediment remains within the area under study
- **high** – evidence that sediment is being exported off site
- **severe** – sediment is exported off site and surface lowering < 0.1 m
- **extreme** – sediment exported off site and surface lowering > 0.1 m.

An important consideration is that certain erosion types, by their nature, will never be described as of "low" or "moderate" severity. The most obvious examples (from Table 26) are gully, ravine, landslide, tunnelling – all of which immediately fall into the severe and extreme classes as the erosion feature is >0.1 m deep. Nonetheless, it is important to bear in mind that insidious sheet or rill erosion, that is continuous throughout rainy seasons and year by year over large areas, may be equally or more serious to widely spaced gully erosion in terms of total soil loss and impacts, especially in shallow soils.

Tool 4.3.2 Field scoring method for soil erosion features

A simple scoring system is presented for the erosion types present and recorded in a study area. This scoring system has been substantially adapted from a first version developed and tested by the LADA team in Tunisia as part of an earlier version of the LADA-Local manual (FAO 2010). As such the scoring aims to provide a quantitative judgment of erosion and to allocate an erosion class. The aim is to provide a basis for inter-comparisons of erosion status and trends that may vary between land uses, management practices, topography, etc. and over time.

The scoring system is based on the classifications of type, state, extent and severity as defined above. Each of the classes in these four sets of descriptors will be allocated a score and the **sum** of the scores (for any one area, however defined) will allow the allocation of an erosion class (Table 28).

Important is that this scoring system is taken and used for what it is: a simple methodology of better quantifying erosion degradation for a given area. There are several, recognised problems with the scoring system, some of which will be covered here, so users should be aware of these in interpreting the cumulative scores obtained and the resultant allocation of an erosion class :

- The allocation of the score classes to the erosion types (Table 27) is somewhat arbitrary. The concept is that either end of the scale (1 and 4) is readily ascribed. In most circumstances splash erosion is a minor feature (score = 1), whereas gully, ravine, landslide, tunnel erosion are considered very serious landscape features as they cannot be readily repaired (score = 4). Between the two extremes, the current score allocations are based on the author's experience and may change with time and wider use of this system
- As discussed above, certain erosion types, by their very nature, will never be describable as of "low" or "moderate" severity. The most obvious examples (from Table 26) are gully, ravine, landslide and tunnel – all of which fall into the severe and extreme classes, as the erosion features are >0.1 m deep. So, not only do these erosion types score "4" for type, they also immediately score "3" or "4" for severity (rate).
- If several types of erosion are found in the area under investigation, the current system scores each type separately, then sums the individual scores to give a composite score. The basis for this summation approach is both that each of the types of land degradation is inter-related, and their presence in one area has an additive, negative effect on land productivity. This composite scoring system may change in the future with time and wider use of this system.

Table 28 gives the final erosion class for any one erosion type in a study area, arrived at by summing the score value of each of the **four** categories of type, state, extent and severity. Where more than one erosion type exists in

TABLE 27 **Scores for the individual descriptors of a) state, b) extent and c) severity of the soil erosion types**

State	score	Extent	score	Severity	score
				extreme	**4**
active	**3**	widespread	**3**	severe	**3**
partly stabilised	**2**	moderate	**2**	high	**3**
stable	**1**	localised	**1**	moderate	**2**
decreasing	**0**	negligible	**0**	low	**1**

TABLE 28 **Erosion classes**

Erosion class :	negligible or decreasing	low /weak	moderate	severe	very severe
Score :	0-1	2-5	7-10	10-12	13 +

one area, the class values of Table 28 are added together for each erosion type – to give a composite score. It is evident that in situations where two or more erosion types are present in an area, the erosion class will almost always be «severe » (i.e. a score of >13).

The erosion classes are derived by **adding - up** the individual scores for each of type, state, extent and severity of Tables 26 and 27).

Worked examples of scoring erosion features
Five examples will be given, based on the descriptors in section 4.4.1, the individual scores in Table 27 and the classes of the summed scores in Table 28.

- **Example 1** presents the scores for the incidence of gully erosion (score 4) that is active (score 3), widespread in extent (score 3) with extreme severity as the soil loss in eroding areas is over 1 m deep (score 4). The total (summed) score = **14.**
  So, the overall erosion class is **very severe.**

- **Example 2** is one of rill erosion (score 2) that is partly stabilized (score 2), localized in extent (score 1) with moderate severity (score 2). The total (summed) score = 7.
  So, the overall erosion class is **moderate.**

- **Example 3** is one of ravine erosion (score 4) that is decreasing in state (score 0), moderate in extent (score 2) with severe severity (score 3). The total (summed) score = **9.**
  So, the overall erosion class is **moderate.**

- **Example 4** scores an area that has two erosion types: (i) splash (score 1) that is active (score 3) localized in extent (score 1) with low severity (score 1); Total score = **6**; and (ii) *landslide* (score 4) that is stable (score 1), localised in extent (score 1) with extreme severity (score 4); total = **10**; The total (summed) score = **16.**
  So, the overall erosion class is **very severe.**

- **Example 5** scores an area that has three erosion types: (i) *sheet wash* (score 2) that is active (score 3) localized in extent (score 1) with moderate severity (score 2); Total score = **8**; (ii) *terracettes* (score 2) that are active (score 3), localised in extent (score 1) with moderate severity (score 2); total = **8**; and *gullies* (4) that are partly stabilized (2), localized (1) and extreme (4); total = **11**. The total (summed) score = **27.**
  So, the overall erosion class is **very severe.**

Note that, though the between-examples scoring gives some basis for comparisons of the impact of the erosion features, it is complex to definitively compare scores between such physically different types of erosion, as rills and gullies. A whole landscape may be covered in rills, and the resulting soil loss may be very large with important implications on soil depth and fertility, but a few large ravines in the same unit area would give quite different management problems (e.g. access for timber removal, thinning of stands and the cutting of roads that impair general access) and will require major, expensive interventions to repair and conserve.

Additionally, although generally scored low the cumulative effects of sheet and rill erosion should not be underestimated, particularly as they strip away the all important surface soil layers that are generally richer in organic matter and nutrients from plant residues, litter accumulation and vegetative growth.

Field measurements of erosion features to quantify rates and amount of soil loss (Tools 4.3.3 and 4.3.4).

This section provides field techniques to measure soil erosion features with the aim of gaining more quantified data on rates of soil erosion.[13] Such quantification would be valuable if soil erosion is identified as being a major degradation process in the study area and to understand the implications in terms of rate and quantity of soil loss, effects on productivity and off site implications in terms of nutrient and sediment load of water resources, siltation of valley bottoms/floodplains and wetlands, etc. However, it is an optional tool for the local level assessment according to the importance of erosion and the time and budget of the assessment team.

Of the 13 erosion types in Table 26, only 3 erosion types - rill, gully and ravine - lend themselves to a direct, rapid and simple method of field determination of **amount of soil loss** (**Tool 4.3.3**). Rates and quantities of soil loss from the other erosion types listed in Table 26 can be estimated indirectly by measuring the **effects** of erosion (**Tool 4.3.4**).

Tool 4.3.3 Direct measurement of erosion

1. Measurement of rill erosion

The estimate of the soil loss through rill erosion is based on measuring the space volume from which the soil has been eroded, to arrive at the mass of soil now missing from the rill. The measurement of soil loss from rills assumes that the depression forms a regular geometric shape that is estimated to be triangular, semi-circular or rectangular in cross-sections, as determined by field observation.

To calculate the quantity of soil lost, measurement is made of the depth, width and length of the rill. It is important to collect a number of measurements of both the width and depth of any one rill and of many rills in the study area to get an average cross-sectional area. The average catchment area for the rills in any one area must also be estimated, i.e. the area of land that contributes material to the rill. If it is known how long it has taken for the rill to form (if, for example the land was last cultivated two months or two years ago, or has only recently been cleared of forest) then an annual rate of soil loss can be estimated. Note, that the combination of the averaging of many field measurements, and the estimation of the cross-sectional shape of the rills (in any one area) to be predominantly triangular, semicircular or rectangular causes the soil loss calculation to be only an estimate of the actual soil loss.

Method: Using the average measurements of width and depth, calculate the average cross-sectional area of the rill, using the formula for the appropriate cross-section:

- triangle = ½ horizontal width x depth
- semi-circle (1.57 x width x depth)
- rectangle (width x depth).

Worked example:

a. For an area where the average dimensions of many measured rills is:
width = 0.12 m, depth = 0.042 m,

b. The average cross-sectional area of the rills in a study area, assuming a triangular cross-section is:
$½ * 0.12 * 0.042 = 0.00252\ m^2$

c. Assuming the average rill length in the study area was 2.5 m, the volume of soil lost from an average rill is:
$0.00252 * 2.5\ m = 0.0063\ m^3$

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[13] This sections is based almost entirely on the original concepts of quantification of field observed erosion features as detailed in Stocking and Murnaghan (2001).

d. The volume of soil lost, from the estimated catchment area (here 12 m^2) is converted to a volume per square metre :

$$0.0063 / 12 = 0.000525 \text{ m}^{3}/\text{m}^{2}$$

e. The volume per square metre is converted to tonnes per hectare, using an estimated soil bulk density value of 1.3 t/ m^3:

$$0.000525 * 1.3 * 10{,}000 = 6.9 \text{ t/ha}$$

Hence in this worked example, 6.9 tonnes / ha have been lost in rill erosion, alone.

2. Measurement of gully and ravine erosion

Gullies and ravines have the same, general shape of a flat floor and sloping sides, hence the bottom of these features (the floor) is less wide than the top (parallel to the soil surface). Such a shape is best estimated as that of a trapezium[14] (Fig. 3). Calculation of soil loss, therefore, is generally similar to rills, except with a different cross-sectional shape. As with rills, the measurement of the dimensions of the gullies and ravines gives an estimate of the amount of soil displaced from the area

To calculate the quantity of soil lost from a gully or ravine, measurement is made of the depth, width at lip (the top of the feature) and base, as well as the length of the feature. Equipment used to collect these measurements will vary between operators, but could be a laser-based rangefinder (expensive) for large gullies and ravines, or a 30 to 100 m tape for smaller features. It is important to collect a number of measurements of both the width and depth along any one feature and also of many gullies in the study area to achieve a representative sample. An annual rate of soil loss from gullies and ravines is more feasible than from rills, as the former are more or less permanent features of the landscape.

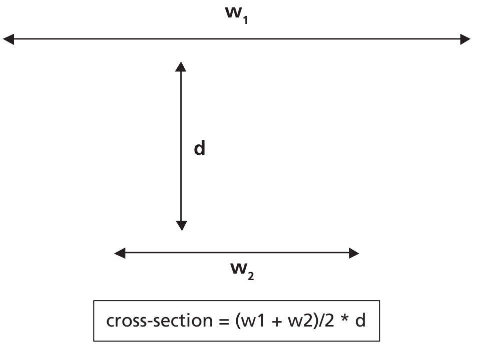

FIGURE 17 **Calculation of the cross-section of the trapezoid shape of gullies/ ravines**

Information on soil loss over time can be achieved in various ways, including repeated visits (particularly if permanent monitoring stakes can be installed as reference points), and time series of aerial photographs and/or satellite imagery. Even with such methods over a known time period, the annual rate of soil loss is "at best' an estimate due to such factors as:

(i) different rates of soil loss will occur as the gully/ravine deepens and different layers of soil are exposed;
(ii) rainfall totals and periodicity will vary annually, particularly the incidence of rain with vegetative state around the gully or ravine;
(iii) change in forest density with time (both growth and thinning/clearing phases) will influence erosion rates;
(iv) tunneling may also occur on the sides of the gullies and ravines, greatly exacerbating soil loss in some years.

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[14] A trapezium is a quadrilateral that has only one pair of parallel sides.

Method: Using the average measurements of width at lip and width at base, and depth, calculate the average cross-sectional area of the gully or ravine (considering the cross-sectional shape is trapezoid; Fig. 3), using the formula:

(width at lip (m) + width at base (m) / 2) * depth (m)

Worked example:

a. For an area where the average dimensions of many measured gullies or ravines is :
   width at lip = 10.2 m, width at base = 4.8 m, depth = 2.0

b. The average cross-sectional area of the rills in a study area, assuming a trapezoidal cross-section (Figure 16) is :
   $((10.2 + 4.8)/2) * 2.0 = 15\ m^2$

c. Assuming the average gully or ravine length in the study area is 200 m, the volume of soil lost from an average gully or ravine is:
   $15 * 200\ m = 3000\ m^3$

d. The volume of soil lost, from the estimated catchment area (here 1 km^2) is converted to a volume per square meter :
   $3000 / 1{,}000{,}000 = 0.003\ m^3/m^2$

e. The volume per square meter is converted to tonnes per hectare, using an estimated soil bulk density value of 1.3 t/ m^3:
   $0.003 * 1.3 * 10{,}000 = 39$ t/ha

Hence, in this worked example, 39 tonnes / ha have been lost in gully or ravine erosion.

Tool 4.3.4 Indirect measurements of erosion

Indirect measurements of soil erosion rely on features observed and measured in the field that demonstrate the « effects » of soil erosion. In total, seven erosion proxies will be presented here: plant/tree root exposure; fence post and similar structures' base exposure; tree mounds; pedestals; solution notches and rock colouration; armour layer; and soil build up against a barrier. The erosion types that most commonly lead to these erosion effects are splash, sheet wash and wind erosion (Table 26).

With all but the last of these indicators (soil build up against a barrier), the general mode of measuring soil loss from erosion is to measure the current (eroded) soil level against the evident location of the original (or at least a recently previous) topsoil level. Particularly in terms of measuring soil loss against living objects such as trees or plants, if the planting date is known then an estimate of annual soil loss is possible. The same is also true if the date of installing fences, poles, walls, houses, etc. are known.

In measuring soil build up against a barrier the reverse is measured, i.e. the accumulation of eroded sediments behind a physical barrier such as a hedge or fence. The depth of this deposited soil is measured relative to the current topsoil level. The amount of soil loss can only be estimated if the area contributing eroded material and the area of deposition can be determined.

3. Plant / tree root exposure

The removal of soil particles by water or wind can lead to the exposure of the roots of trees, and other plants as erosion lowers the overall soil level. Close inspection of the lower portion of the tree trunk or plant stem may reveal a mark indicating the level of the original soil surface. By measuring the vertical difference (with a ruler) between this mark and the present soil surface, an estimate can be made as to how much soil has been lost[15]. (see Photos 20 and 21) In the case of lateral roots away from the tree trunk, the upper surface of the most exposed roots is usually taken as the former soil surface. For forests and perennial crops, the soil loss estimate would cover the period from when the crop/tree was planted. In areas of degraded natural vegetation (scrubby forest and bush land), it may not be so easy to relate the measured soil loss to a particular number of years. In the case of an annual crop an estimate of soil loss in one growing season can be estimated.

Care is needed as some roots give a deceptive impression of soil loss such as the aerial roots of maize plants (see Photo 22)

Difference between original soil level when the tree was planted and the soil level at the time of observation.

PHOTO 20 **Tree root exposure, Vietnam (source Stocking)**

PHOTO 21 **Tree root exposure by erosion (Library on soil erosion processes UNEP/FAO)**

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[15] 1 mm of soil loss is equivalent to 13 t/ha where the bulk density is 1.3 g/cm^3

PHOTO 22 **Exposed aerial roots of maize, Brazil**

As with measurements of erosion features (above) several examples of exposed tree / plant roots need to be measured and averaged, to improve the site-representativeness of the measurements. Additionally, the data should also be cross-checked with other erosion indicators (as below) to determine, whether the estimated soil loss is realistic.

There are several cautionary notes that with common sense will ensure greater validity of the data collected.

- Differences in root exposure may reflect different erosion processes (e.g. rain-splash and sheet wash) occurring in the same field.
- Roots and stems may act as an obstacle to runoff and may cause channeling of erosive water flows, thus increasing the soil loss around the obstacle, or it may slow down the surface flow, allowing deposition to occur. Likewise roots and stems may trap and allow the accumulation of windblown material. Therefore extrapolated soil losses, calculated solely by reference to plant/ tree root exposure, may be either over- or under-stated.
- Some plants have a tendency to lift themselves out of the ground as they grow, thereby giving a spurious impression of high soil loss. This effect is often indicated in stony soils, especially where larger platy fragments occur. Look for evidence in the alignment of stones as tree growth may force a rearrangement of stones so that they become tilted, with the raised end nearest to the trunk.
- Tree roots may expand in diameter as the tree grows, so roots running parallel to the soil surface may rise to/above soil level, giving the impression of more erosion than actual.

Method: Using the average of the measurements of the height difference between the top of the exposed tree/ plant roots or stem and the current soil surface.

Worked example :

a. For an area where the average depth of soil loss is :
5.88 mm

b. This drop in soil level is converted to tonnes per hectare, using an estimated soil bulk density value of 13 t/ha[16]:
5.88 * 13 = 99.23 t/ha

c. If the average age of the plants or tree where the soil level change was measured was 4 years, then the estimated annual soil loss is:
99.23 / 4 = 24.8 t/ha/yr

Hence in this worked example, ~25 tonnes / ha year have been lost to soil erosion.

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[16] A bulk density of 13 t/ha is equivalent to 1.3 g/cm^3 for 1 mm depth of soil

4. Fence post (and similar structures') base exposure

Similar to plant / tree exposure, the exposure of the bases of anthropogenic structures such as fence posts, house and bridge foundations, telegraph poles, etc. can provide indicators of soil loss, principally, again, from splash, sheet and wind erosion.

The measurement strategy depends on the object used for establishing the original ground level. For fence posts and poles this can be established by determining the height of the exposed part of the post/pole and/or the length buried into the ground. Often standard post/pole lengths are used in any one area. If not, it is necessary to determine a typical value by measuring the above ground length of posts in those sites that appear to have been least affected by soil erosion. The distance between the new ground surface and the point on the post that would originally have been at ground level can be measured using a ruler. In some instances erosion may remove soil equivalent to the depth of the below ground portion of the post in which case, providing it is certain that the post was not broken and that no part remains below ground, a minimum rate of erosion can be estimated. In other cases, the post may be entirely free of the soil but held in position by taut wire and hence the full extent of erosion can be determined.

Cautionary notes with interpretation of these measurements include the following.

- The age of the structure (fence installation, house and bridge construction, etc.) is required to present data on an annual soil loss basis.
- Any of these anthropogenic structures can actively promote erosion or sedimentation and may act differently, depending on rainfall amounts, intensity and periodicity, as well as wind direction and strength in the case of wind erosion.
- It will be important to have close discussions with locals to better ascertain the weather modalities since the structure was put in place.

Method and calculations: as per the plant / tree root exposure example above.

5. Tree mound

In contrast to the above two indices, the use of tree mounds to provide measures of soil loss depends on the umbrella- and raindrop energy-absorbing properties of tree canopies. This often causes the soil under a tree canopy to be at a higher level than the soil in the surrounding area, as it has been protected from raindrop impact and subsequent splash and sheet erosion.

The difference in height between the soil surface under the tree and in the surrounding area provides an indicator of the amount of soil loss that has occurred during the life of the tree (tree age gained from forest records or by talking to locals). It is recommended that such measurements are recorded for a range of trees of different size and age in the study area as there is large variation in the capacity of the canopies of different species to protect the underlying soil, and some varieties may be leafless during the peak rainy season, for example. (see Photo 23).

Cautionary notes with interpreting soil loss data, based on tree mounds include the following.

- Mounds around the base of trees, shrubs and other plants may have been caused by factors other than erosion, e.g. termite mounds or sediment (water and wind) and tree litter build up against the tree trunks.

PHOTO 23 **Tree mounds (Stocking and Murnaghan, 2001)**

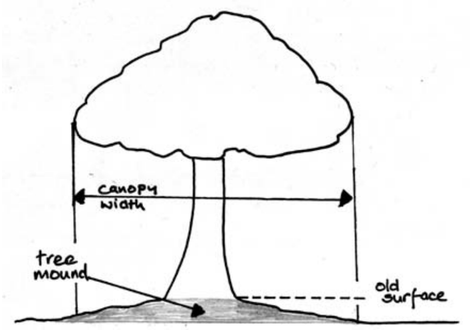

FIGURE 18 **Sketch of tree mound (Stocking and Murnaghan, 2001)**

- Some trees may lift the soil around them as they grow, thus giving natural mounds and an appearance of higher levels of soil loss than actual.
- Tree canopy size and density changes as the tree grows, hence the tree mound will not be at a constant height above the level of the surrounding soil. Thus, it is important to take measurements at different points from the edge of the mound towards the tree trunk.

Method and calculations: as per the plant / tree root exposure example above.

6. Pedestals

A pedestal is a column of soil standing out from the general eroded surface, protected by a cap of resistant material (such as a stone or root). Bunch grasses can also protect the soil immediately under them (comparable to tree canopies and tree mounds, above) and give a pedestal-like feature. Care is required, however, in interpreting these latter observations.

Pedestals are caused by differential rainsplash erosion, which dislodges soil particles surrounding the pedestal but not under the

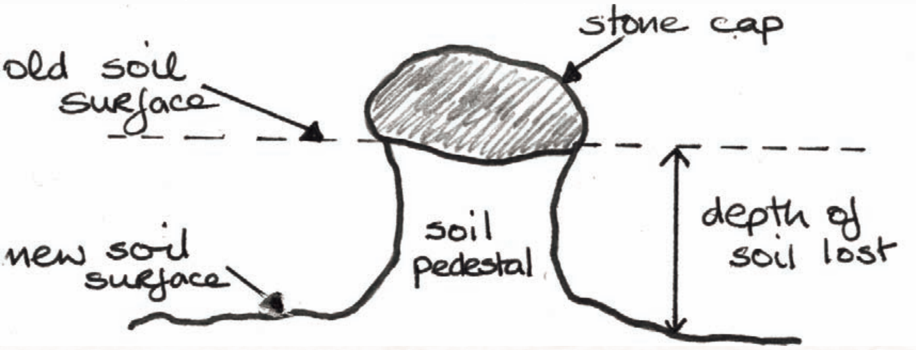

FIGURE 19 **Sketch of a soil pedestal capped by a stone (Stocking and Murnaghan, 2001)**

resistant capping material that absorbs the energy of the raindrops (Figure 18). (Note: Pedestals can be artificially simulated by using bottle tops pressed into the soil. Pedestals are created, as the bottle top protects the soil beneath from erosion, whereas the surrounding soil is exposed. They give a ready indicator to monitor surfaces where erosion rates are very large due to high intensity rainfall).

Measurement of pedestals is done using a ruler and it is important that a number of measurements are taken in the study area, even to the extent of dividing up the area and averaging pedestal height in each of the subdivisions, seeking across-site variability. Assuming that the cap was at the surface when erosion started, the measurement should be from the base of the stone or other capping material to the base of the pedestal, where it meets the general soil surface around. This measurement represents the soil loss since the soil was last disturbed (through forest clearing or cultivation). Therefore, by knowing the timing of the disturbance, it is possible to estimate an annual rate of soil loss.

Cautionary notes with pedestal height measurement and interpretation of data include the following.

- Pedestals often form under trees or crops where intercepted rainfall falls to the ground as a larger drop. If this is the only location in which pedestals are found they would provide an unreliable estimate of the level of soil loss for a larger area.
- Measurement of pedestals in association with clumps of vegetation should be avoided as the vegetation can accumulate soil.
- Capping stones may have originally been buried in the soil and are now exposed with an underlying pedestal; hence the pedestal height will underestimate erosion.
- Localised redistribution of material eroded from under the stone requires accounting for local accumulation, hence needs to be subtracted from the calculated soil loss.

Method and calculations: as per the plant / tree root exposure example above.

7. Solution notches and rock colouration

Solution notches are indentations found on rocks that indicate historic soil levels (Fig. 5). They arise because of chemical reactions between the soil, air and the rock and particularly mark the level of past topsoils that due to their greater organic matter content (hence humic acids) etched a notch at the air/soil interface The definition is extended here to include stone or rock discoloration, that again may indicate historic soil levels, where the soil (now eroded) discolored the rock, so leaving evidence of earlier soil levels. Solution notches are most likely to occur on limestone and calcareous rocks as they are more susceptible to acid organic chemicals, see Photo 24.

PHOTO 24 **A solution notch on a limestone rock (Stocking and Murnaghan, 2001)**

The solution notch also coincides with an obvious change from the stained (iron oxide and humus materials) to the original grey rock colour, above.

Measurement is made of the distance from the notch or colour change to the current soil level, using a ruler, to give an indication of how much soil has been eroded. It is important that a number of measurements are taken in the study area. One difficulty with soil notches is determining the time over which soil loss has occurred, though calibration with other soil loss indicators (e.g. tree trunks of known age) to estimate a rate of soil loss.

Method and calculations: as per the plant / tree root exposure example above.

PHOTO 25 **Removal of a portion of an armour layer. (Stocking and Murnaghan, 2001)**

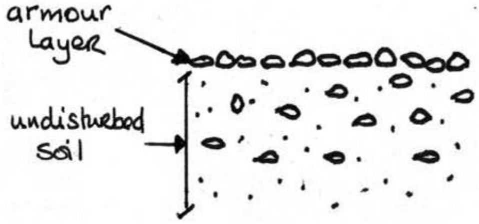

FIGURE 20 **Diagram of an armour layer**

8. Armour layer

An armour layer is the concentration, on the soil surface, of coarser soil particles that would ordinarily be randomly distributed throughout the topsoil (Figure 20).

The concentration of coarse material in the armour layer is interpreted as indicating that finer soil particles have been selectively removed by the energy of wind or water, leaving behind the coarser particles. The armour layer can be measured by digging a small hole to reveal the depth of the coarse top layer. Several measurements at different places in the field should be made in order to calculate the average depth of the armour layer. The approximate proportion of stones/coarse particles in the topsoil below the armour layer is judged by taking a handful of topsoil from below the armour layer and separating the coarse particles from the rest of the soil. In the palm of the hand, an estimate is made of the percentage of coarse particles in the original soil. Again, this estimation should be repeated at different points in the field. The depth of the armour layer is then compared to the amount of topsoil that would have contained that quantity of coarse material. The amount of finer soil particles that have been lost through erosion can then be estimated. See Photo 25.

Cautionary notes with interpretation of the measurement of armour layers are many.

- Stones on the surface may arise for other reasons, such as the exhumation of a concentration of stones in the subsurface soil by animals or frost action.
- Accurate measurement (to mm tolerance) of the thickness of the armour layer is critical, as for every 1 mm, the equivalent soil loss is 13 t/ha (assuming an average bulk density of 1.3g/cm^3).
- As well as erosion processes, repeated shallow tilling of the soil may concentrate more stones near the surface. Where this happens, the erosion rate will be exaggerated, unless the percentage concentration of stones in the original soil is based on an estimate well below the (tilled) topsoil.

Method: Using the average of the measurements (mm) of the thickness of the armour layer.

Worked example:

a. Convert the average soil loss (1mm) to equivalent in metres:
$1.0 * 0.001 = 0.001$ m

b. Calculate the depth of soil required to generate the 0.001 m of armour layer, where the proportion of coarse material in the topsoil was determined as 20% on average (i.e. a 1:5 ratio)
$0.001 * 20\% (= 1/5\text{th}) = 0.005$ m

c. Calculate the depth (m) soil lost :
$0.005 – 0.001 = 0.004$ m

d. This drop in soil level is converted to tonnes per hectare, using an estimated soil bulk density value of 1.3g/cm^3 (or 1.3 t/m^3), where 1 mm of soil loss is equivalent to 13 t/ha, so 1m soil loss would be equivalent to 13,000 t/ha
$0.004 * 13{,}000 = 52$ t/ha

Hence in this worked example, 52 tonnes / ha have been lost to soil erosion.

9. Soil / sand build-up against a barrier

The build-up of eroded material against a barrier is a measure of the movement of soil across an area of interest rather than loss from that area. In this case, the eroded materials are halted by an obstruction, and the materials deposited against the obstruction as the water slows (see Photo 26). The result is a build-up of sediment against the barrier.

Method: The volume of soil trapped behind the barrier can be calculated by measuring the depth of the soil deposited and the area over which it is deposited. Where the build up is against a continuous barrier such as a fence or hedge the measurement will give an approximation of soil loss from the field. A visual examination of the area close to the barrier will indicate how far the deposition extends into the field. This distance

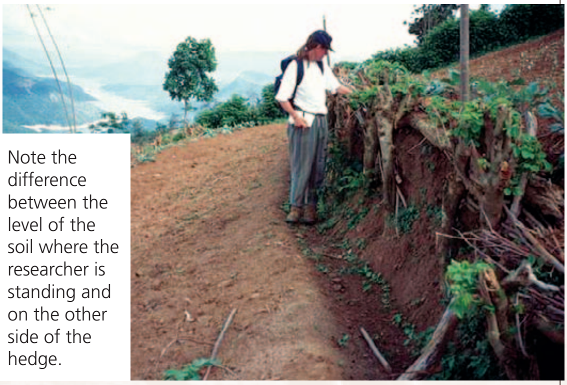
Note the difference between the level of the soil where the researcher is standing and on the other side of the hedge.

PHOTO 26 **Build up of soil behind a Gliricidia hedge (Sri Lanka)** (length) should be measured at a number of points. The depth of the soil accumulated against the barrier can be determined by examining the soil level against the barrier on the other side from the accumulation. In order to calculate the amount of soil accumulated a linear slope is assumed and the « wedge » of soil behind the barrier is regarded as a triangle.

Estimating soil erosion: The amount of soil accumulated behind a barrier represents a build-up over time. The annual rate of soil loss from a hillside can be arrived at by dividing the quantity of accumulated soil by the number of years that a barrier has been in existence.

Cautionary notes with interpretation of the measurement of accumulations behind barriers are many:

- There is a danger that because of soil erosion on the lower side the soil level next to the barrier will have been lowered.
- The depth of the accumulation of soil behind the barrier is not constant. Rather the depth of accumulated soil becomes thinner (less deep) with distance away (up slope) from the barriers.
- The calculations do not differentiate between sediment that results from in-field erosion and sediment that results from erosion further upslope and outside the immediate field, which may lead to an overestimation of the soil loss per field.
- Not all materials transported in runoff will be deposited at a barrier. The speed, volume and direction of runoff all influence the level of deposition. Therefore, the estimated soil loss may be understated by the amount of soil carried beyond the barrier.
- Forest clearing may increase the soil depth behind barriers, particularly where conservation techniques such as terracing have been introduced to lessen the effect of slope. If the slope was convex before the barrier was constructed, the estimate of soil loss will be understated as it assumes a linear slope.
- The soil level below the barrier may not be the original soil level. As evident in Figure 26, excavation and leveling of the area immediately below the fence has occurred for road building.

Method: Using the average measurements of depth of the deposit at a barrier of 7 metres length, and the length of the accumulation up slope of the barrier of 0.945 m, the average cross-sectional area of deposit (considering it is triangular) is calculated using the formula:

depth at barrier (m) * (horizontal length (m) / 2)

Worked example:

a. For an accumulation against a barrier that has:
   depth at barrier = 0.16 m, length of accumulation = 0.945 m

b. The average cross-sectional area of the deposit behind the fence, assuming a triangular cross-section is :
   $(½ * 0.16) * 0.945 = 0.07560 \text{ m}^2$

c. For a barrier that is 7 m in length, the volume of soil accumulated behind the barrier is:
   $0.07560 * 7 \text{ m} = 0.5292 \text{ m}^3$

d. The volume of soil lost, from the estimated catchment area (here 70 m^2) is converted to a volume per square meter :
   $0.5292 / 70 = 0.00756 \text{ m}^3 / \text{m}^2$

e. The volume per square meter is converted to tonnes per hectare, using a estimated soil bulk density value of 1.3 t/ m^3:
   $0.00756 * 1.3 * 10{,}000 = 98.3 \text{ t/ha}$

f. If the barrier is known to have been constructed three years before the measurements were collected, the annual soil loss as represented by the soil accumulated behind the barrier is:
98.3 / 3 = 33 t/ha/yr

Hence in this worked example, 33 tonnes / ha /year have been lost from this site and accumulated behind the barrier.

10. Enrichment ratio

Indicator: Comparison between the higher levels of nutrients to be found in the areas where the fines are deposited, and the nutrients in the area from which they have been eroded, is referred to as the enrichment ratio.

Process: Wind and water erosion can selectively remove the finer soil particles and lighter organic matter, both of which contain relatively higher levels of nutrients than the coarser mineral deposits left behind. The effect of this selective erosion process is to progressively reduce the inherent fertility of the remaining soil. When the finer particles are deposited downstream or downwind then they will enrich the location in which they settle. This may just be a local redistribution within the same field, for instance where sediments are trapped by cross slope barriers or against field boundaries, or transported further and accumulate in drains, valley floors, local reservoirs and ultimately the sea.

Method: This type of erosion is normally assessed by measuring the quantity of nutrients found in the deposited sediment and comparing this to the quantity in the original soil from which the material was eroded. For the purposes of making a quick field assessment the proportions of finer soil particles can be used as a proxy measure, as these are closely related to nutrient levels and in themselves are also good variables for assessment of enrichment. This involves taking equal quantities of soil from the eroded and the depositional locations, and visually observing them in the palm of the hand so as to estimate the proportion of coarse material to fine material in both samples. This should be repeated a number of times.

Estimating the redistribution of fines also known as the enrichment ratio. The average percentage of fine materials in both the enriched soil and the eroded soil should then be calculated. The enrichment ratio is the ratio comparing the percentage of fine particles in the enriched soil, to the percentage of fine particles in the eroded soil. It should also be possible to quickly identify by hand texturing the different samples whether the selective removal and subsequent deposition of fines is taking place within a field. A field form is provided in Table 29 for recording measurements.

Potential for Error

1) The technique for assessing the enrichment ratio requires considerable field experience because estimation of proportions of soil particle sizes is difficult. The novice field assessor is best advised to accompany an experienced person.

2) As the selective removal of fines is a natural process care must be exercised to ensure that the observed trends relate to the land management practices and not to features inherited from prior conditions. For example, ant hills, termite mounds and earthworm casts often contain higher proportions of finer material than the topsoil. Because erosion of these structures may result in the redistribution of this finer material

downslope, any observed increase in fines may have little to do with existing land management practices.

3) Estimates undertaken solely by visual inspection of fine particles are very approximate. If possible, laboratory determination of macronutrient (Total N, P or K) content or of organic matter should be done to corroborate findings. This is particularly the case for clayey materials.

4) The enrichment ratio can be understated where not all the eroded material is deposited in the site where the enriched soil is identified. The finest particles may have been carried away completely from the site.

5) Understatement of the seriousness of erosion may also occur where deposition from upslope occurs on the eroded soil, thus masking the full extent of finer materials lost.

Similarly, the enrichment ratio may be overstated where run-on to the site from further upslope increases the level of fine particles in runoff thus contributing to the enriched soil.

Erosion measurement intensity, frequency and reporting

In terms of advising on the intensity, frequency and reporting protocols for observations and measurements of erosion features in drylands, it is difficult to be prescriptive due to the variety of circumstances where these data will be collected. In particular, timescales of erosion vary greatly depending on climate, soil type, slope and current vegetative cover. Accordingly, observations and measures to record the various degrees of effect and the intensity and frequency required to capture erosion correctly will vary widely.

There is, however, the over-riding consideration in terms of recording dryland erosion of establishing protocols of "benchmarking and monitoring". With this, the first observations and data collected act as the baseline for all subsequent observations and measurements, to record continuing degradation or improvements with time. Critical is to apply the same set of observations and measures (detailed above) to provide a true "change with time" evaluation. As stated earlier, monitoring considers both non-intervention scenarios (where the erosion is allowed to continue) as well as interventionist scenarios, where some physical or vegetative barrier is created to begin to mitigate the negative impact of the observed erosion. Frequency of monitoring observations is commonly different between the two scenarios. Non-intervention scenarios are commonly monitored on a fixed interval basis that is governed by the intensity of the erosion process; annually in active erosion situations or sensitive watershed/crop land scenarios and perhaps every 5 or 10 years where erosion is less active and widespread. Intervention scenarios are monitored as required to capture the effect of the intervention; commonly more observations soon after implementing the intervention, then less often with time once the improvement trend is captured.

Intensity of observations considers the number of observations to be conducted at one time in an area of interest. Again, a prescriptive approach is impossible due to the many situations that may be experienced. However, the observation and measurement protocols given above provide many "entry levels" to the type and intensity of observations that could be conducted on any one occasion.

Worked example

TABLE 29 **Field form - Enrichment ratio**

Site:
Date:

Measurement	**% of fine particles in eroded soil:** i.e. soil remaining in-field	**% of fine particles in enriched soil:** i.e. soil caught downslope and deposited
1	20	28
2	25	25
3	15	30
4	22	30
5	20	35
6	20	35
7	22	35
8	19	25
9	20	30
10	20	28
11	18	28
12	20	32
13	18	30
14	22	32
15	22	28
16	20	28
17	18	26
18	20	30
19	20	35
20	19	30
Sum	400.00	600.00
Average*	ERODED = 20.00%	ENRICHED = 30.00%

NB: To obtain an average divide the sum of all the measurements by the number of measurements made.

Calculations:
(1) Calculate the ratio of fine materials in the eroded soil to fine materials in the enriched soil

ENRICHED	30%	÷	ERODED	20%	=	ENRICHMENT RATIO	1.50

At the simplest level, a "community map" could be sketched rapidly for short time time intervals, then the time sequence of sketches compared to investigate the more active or widespread areas and types of erosion features, for closer investigation.

The next level is to solely describe and class the erosion features present in an area of interest, using Tables 1, 2 and 3.

Lastly, the measurements of soil loss (section 3, above) take the longest time, so tend to be used less often and less intensively.

Intensity of observations is also governed by the types of erosion features that occur in a study area. For example, if there are only 5 to 10 gullies in a given LUT, then the tendency would be to describe and measure all of these in some detail, even installing fixed measuring posts to exactly measure soil loss and gully encroachment. At the other end of the scale, in a heavily degraded, recently cleared, steeply sloping land in the monsoon season there may be all of sheet wash, rills, gullies and landslides. Most often human resources are inadequate to comprehensively describe and record so many types that are changing so rapidly. Photography and community sketches would be the best approach as these can be subsequently analysed to capture the rapidly changing situation.

It is important to identify relationships between the various erosion types recorded and current or recent management activities that contributed to the type, state, extent and severity of the erosion. Such linkages will provide a more proactive consideration of soil erosion with consideration of the potential to repair or diminish the recorded erosion, lessen the chance of its re-occurrence and, particularly in areas being newly opened up for production, to initiate from the outset improved management strategies to avoid or minimise erosion.

This section aims to provide a field usable and scientifically robust set of methods for describing the various types of erosion, scoring the degree of negative impact of each type and estimating the quantities of soil lost. The results should then be considered together with other type of degradation (of soil properties, vegetation and water quality and water resources) to assess impacts on productivity, other ecosystem services and resilience.

The analysis of the qualitative and quantitative information on soil erosion can be subsequently related to the community map and other land use and topographic maps of the study area to understand wider implications of soil erosion in the landscape.