CHAPTER 4: INDICATORS OF SOIL LOSS

Land degradation encompasses a vast array of biophysical and socio-economic processes, which make its assessment difficult to encapsulate in a few simple measures. It occurs over a variety of timescales – from a single storm to many decades. It happens over many spatial scales – from the site of impact of a single raindrop through to whole fields and catchments. Without extreme care, measurements undertaken at one set of scales cannot be compared with measurements at another. This is why this publication:

- adopts a farmer-perspective; and hence the type of assessments at field and farm level, and timescales that have significance for the farmer (though, of course, these also vary according to individual circumstances – for example, the impact of erosion on the current crop, or concerns for long-term sustainability);
- focuses on the concerns of land users – primarily, the way that land degradation makes farming more difficult, and the impact of degradation on productivity;
- concentrates on relatively simple field indicators, some of which can be quantified into absolute rates of soil loss, but none of which should be taken in isolation. The indicators are ones that farmers have told us they notice, and therefore information on them is more readily available. The indicators are also readily discerned in the field, although they are more apparent at some times of year and in some environmental circumstances.

This chapter addresses this last point above – the development of field indicators of soil loss. The following pages have been organised to present a set of indicators: what they are, what processes lead to their biophysical formation in the field, and, crucially, how to measure and interpret their meaning for land degradation. It will be seen that they apply to different timescales: an armour layer forms after one or two heavy storms in the early growing season, while tree mounds may take 50 or more years to form. They apply to different spatial scales: a soil pedestal may be only 3 mm across, whereas a gully can in exceptional cases be 5 km long. It should be clear, then, that none of these measures are directly comparable with each other. However, after careful scrutiny, they can be used to ascertain general trends in land degradation. Tree mounds formed under trees of different ages can tell us whether degradation is getting worse, staying more or less the same, or even starting to reverse. Rock exposures and solution notches can also yield information useful over longer timescales. In contrast, the build up of soil against field barriers such as boundary walls tells us what has happened in that field since the walls were constructed.

Box 4.1: Indicators of Soil Loss from Rangelands

Much of what is described in this chapter applies principally to cropland. Rangeland degradation, however, has been a major concern of scientists and land planners for at least two reasons. First, it tends to happen in dry areas where vegetation associations are extremely fragile and degradation rates probably at their highest. So it is a real process that is clear to see. Secondly, domestic animals, especially goats, have often been condemned as degraders of drylands. There have been many efforts at trying to destock to reduce rangeland degradation – usually with little success.

The principles, and some of the specific techniques, described in this chapter can all be used on rangeland. Vegetation, especially bare patches, and evidence of wind erosion are further indicators that can easily be developed for rangeland conditions.

The following pages cannot accommodate all the observations that could potentially be made. In addition, they do not cover all the possible sources of error. For example, the value used for bulk density can affect the calculations of soil loss (see Box 4.2). Experience has suggested that where one indicator is identified, the keen observer then starts to see many more. Where the field assessor has been alerted to possible measurement errors, common-sense will find many more and mitigation measures can be designed to minimise the unreliability. On the *PLEC* project in Yunnan, China, a short training course with local professionals found twelve different indicators in one field of 3 hectares in less than an hour. Our collaborators told us they had never before seen these features, and now wonder how they overlooked them! We advise that field assessors should start by using this chapter as a checklist of possible pieces of evidence of land degradation – we are sure they will find many more.

Box 4.2: Typical Measures of Bulk Density

Typical measures of bulk density are set out in the table below. For the purposes of these Guidelines an average bulk density of 1.3 g/cm^3 has been used.

Soil	*Average Bulk Density*	*Typical Range of Bulk Densities*
Recently cultivated	1.1 g/cm^3	0.9 – 1.2 g/cm^3
Surface mineral soils - not recently cultivated and not compacted	1.3 g/cm^3	1.1 – 1.4 g/cm^3
Compacted		
- sands & loams	1.7 g/cm^3	1.6 – 1.8 g/cm^3
- silts	1.5 g/cm^3	1.4 – 1.6 g/cm^3
- clays	1.3 g/cm^3	very variable

Source: Booker

4.1 Rills

What are they? A rill is a shallow linear depression or channel in soil that carries water after recent rainfall. Rills are usually aligned perpendicular to the slope and occur in a series of parallel rill lines (see Figure 4.1c)

How do they occur? A rill is caused by the action of water. Runoff is channelled into depressions which deepen over time to form rills. A rill is, then, a product of the scouring action of water in a channel. It is also a means of rapidly draining a small part of a field and efficiently transporting sheet eroded sediment from the rill's catchment. A broadly accepted distinction between rills and gullies, often applied in soil conservation, is that the former can be eliminated using normal agronomic practices (such as ploughing), whereas gullies require specific large interventions such as bulldozers, concrete lining or gabions (rock-filled bolsters placed in gully to accumulate sediment). Rills tend to occur on slopes, while gullies occur along drainage lines.

Where do they occur? Rills will occur on a sloping surface where runoff is prevalent because of land use and lack of vegetation. Typically, rills occur where soil has been disturbed but the surface is left relatively

Figure 4.1a: Rills, Lesotho

smooth and unvegetated (e.g. after tillage, after building construction and on the sides of earth dams and road embankments). Rills are also likely to form in any slight depression in the soil, so paths, roadways, culverts and tracks made by tillage equipment are at risk of developing into rills.

How can they be measured? The commonest assessment of rills is the volume of soil that has been directly eroded to create the rill: i.e. the space volume and the associated mass of soil now missing because of the rill. This calculation does not include any estimate of the amount of erosion that occurs between rills, i.e. inter-rill erosion, which can be measured using other techniques such as pedestals. The measurement of soil loss from rills assumes that the depression forms a regular geometric shape. Triangular (see Figure 4.1b), semi-circular and rectangular cross-sections are most common.

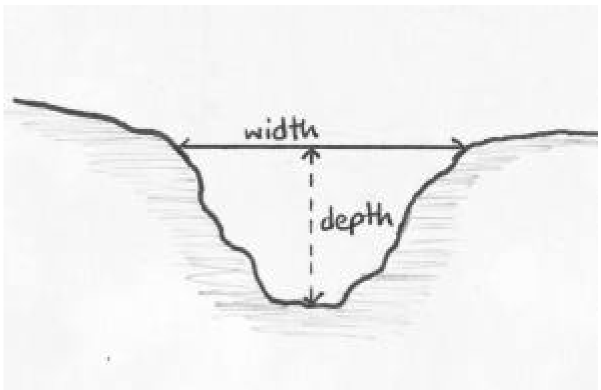


Figure 4.1b: Sketch Showing Cross-Section of a Triangular shaped Rill

In order to calculate the quantity of soil lost it is necessary to measure the depth, width and length of the rill. A number of measurements of both the width and depth of a rill are suggested in order to get an average cross-sectional area. This averaging is appropriate as a rill will not be a constant width or depth throughout its length. These measurements of average cross-sectional area and length are used to calculate the volume of soil displaced from the rill. If it is known how long it has taken for the rill to form (if, for example the land was last tilled two months or two years ago), then an annualised rate of soil loss can be estimated.

Single rills are rarely found. They usually occur together in the same part of the landscape. Each rill has a contributing area where water will runoff and pass into the rill, and sediment will be derived that is similarly passed along the rill. The most useful measure of the degree of importance of rill erosion is to calculate the volume or mass of soil per square metre of catchment (see Figure 4.1c)

This can be converted to tonnes per hectare to make the measurement comparable to other estimates of soil erosion.

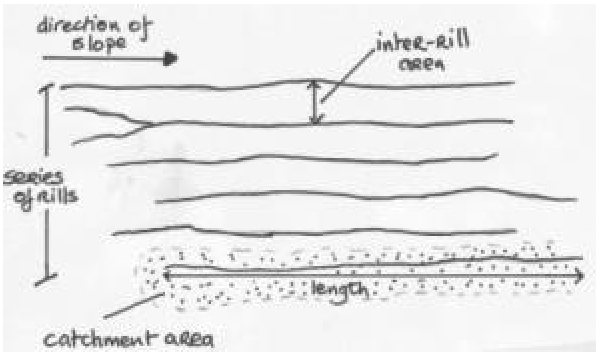


Figure 4.1c: Sketch – Series of Parallel Rills

Potential for Error:

1) Where rill erosion is evident, this is not the only form of erosion occurring. Rills are merely a visible symptom of sheet erosion. Therefore, it is important that any measurement of soil loss from a rill should not be treated as the total amount of soil lost from a particular area. The rill is indicative of the poor state of the immediate catchment of the rill, and wherever feasible, field assessments of sheet soil loss should be made. Experience indicates that the soil removed to form the rill is usually only a small fraction of the total soil loss from the catchment of the rill. This may not be the case if there is a dense network of rills.
2) Averaging cross-sections down the length of the rill, and then multiplying by the length of the rill, will give only an approximation of total volume, The more measured cross-sections and the closer the measurements are to the actual shape of the rill, the more accurate will be the rill erosion estimate.
3) As noted, rills occur where pre-existing depressions have become eroded by flowing water. The field assessor needs to estimate the volume of the original depression, and subtract this from the total volume, to calculate the soil removed by the rilling process.
4) Where redeposition of the materials removed from the rills occurs in the same field, to avoid overstating the level of soil lost an estimate of the amount of soil redeposited must be subtracted from the calculated soil loss from rills.
5) Rills are ephemeral features, easily obliterated by farming practice such as weeding. The evidence of erosion can, therefore, also disappear unless rapid and timely assessments are made. The early growing season in arable crops is especially conducive to rilling.
6) Estimation of the contributing catchment area to a rill must be made only after careful site inspection. Examine evidence of flow lines of water to determine the shape and size of the boundary of the contributing area. Look for the watershed between two rills as the boundary lines between contributing areas. In a levelled field between terraces or field edges, this is not usually difficult. The contributing area may be of the order of 10 to 100m^2.
7) Rills may be caused (at least in part) by runon from areas upslope. This should be taken into account when surveying for contributing area.

Worked example

EXAMPLE
FIELD FORM: RILL

Site:

Date:

Measurement	*Width* *Cm*	*Depth* *cm*
1	10	5
2	15	7
3	12	5
4	11	6
5	11	6
6	12	4
7	14	3
8	10	2
9	13	3
10	13	2
11	11	4
12	11	5
13	10	6
14	15	5
15	14	5
16	13	3
17	10	4
18	11	4
19	12	3
20	12	2
Sum of all measurements	240.0	84.0
Average*	WIDTH = 12.0	DEPTH = 4.2
Length of rill: (m) 2.50		
Contributing (catchment) area to rill: (m^2) 12.0		

Rem.: to get average divide the sum of all the measurements by the number of measurements made.

Calculations:

(1) Convert the average width and depth of the rill to metres (by multiplying by 0.01). Thus, an average horizontal width of 12cm is equal to 0.12m and an average depth of 4.2cm is equivalent to 0.042m.

(2) Calculate the average cross-sectional area of the rill, using the formula for the appropriate cross-section: the formula for the area of a triangle (i.e. ½ horizontal width x depth); semi-circle (1.57 x width x depth); and rectangle (width x depth). Thus, assuming a triangular cross-section it is:

[½] x WIDTH (m) [0.12] x DEPTH (m) [0.042] = CROSS-SEC AREA [0.00252 m^2]

(3) Calculate the volume of soil lost from the rill assuming that the measurements above were taken from a rill measuring 2.5 metres in length.

CROSS-SEC AREA (m^2) [0.00252] x LENGTH (m) [2.5] = VOLUME LOST [0.0063 m^3]

(4) Convert the total volume lost to a volume per square metre of catchment.

VOLUME LOST (m^3) [0.0063] ÷ CATCHMENT AREA (m^2) [12] = SOIL LOSS (m^3/m^2) [0.000525]

(5) Convert the volume per square metre to tonnes per hectare.

SOIL LOSS (m^3/m^2) [0.000525] x BULK DENSITY (t/m^3) [1.3] x [10,000] = SOIL LOSS (t/ha) [6.9]

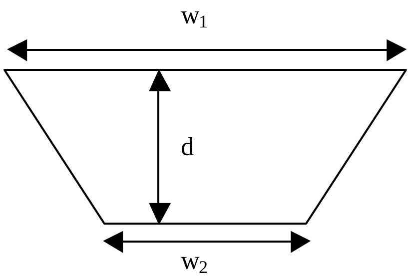
4.2 Gully

What is it? A gully is a deep depression, channel or ravine in a landscape, looking like a recent and very active extension to natural drainage channels. Gullies may be continuous or discontinuous; the latter occurs where the bed of the gully is at a lower angle slope than the overall land slope. Discontinuous gullies erode at the upslope head, but sediment themselves at the end of the discontinuity. Hence, several discontinuous gullies may occupy the same landscape depression, their shapes progressively moving upslope. Gullies are obvious features in a landscape, and may be very large (metres wide and deep) causing the undermining of buildings, roads and trees.

How does it occur? A gully is caused by the action of water. Runoff is channelled into grooves which deepen over time to form a distinct head with steep sides. Gullies extend and deepen in an up-valley direction by waterfall erosion and progressive collapse of their upslope parts; gully sides may collapse by water seepage or undermining by water flow within the gully.

Where do they occur? Several conditions are conducive to gully development. They tend to form where land slopes are long and land use has resulted in loss of vegetation and exposure of the soil surface over a large area so that the land now produces more runoff. They are particularly prevalent in deep loamy to clayey materials, in unstable clays (e.g. sodic soils), on pediments immediately downslope of bare rock surfaces and on very steep slopes subject to seepage of water and to landslides.

How can they be measured? The measurement of soil loss from gullies is essentially the same as that for rills, except on a larger scale and with a different cross-sectional shape. Gullies usually have a flat floor and sloping sides, and account must be taken of these. In measuring gullies, the estimate being made is of the amount of soil displaced from the area now occupied by the gully furrows. This calculation does not include any estimate of the amount of sheet erosion occurring on the land adjacent to the gully.



X-section = (w1 + w2)/2 * d

Figure 4.2a: Cross-sectional Area of a Trapezium-shaped Gully

In order to calculate the quantity of soil lost it is necessary to measure the depth, width at lip and base and length of the gully. Large gullies could be measured by standard field survey equipment such as a dumpy level, although often a 30-100 m tape and clinometer is sufficient. Measurements of width and depth should be made at a number of points along the gully. If there are big variations in the width and/or depth of the gully, it is best to break the gully into similar sections and calculate the amount of soil lost for each part. These can be summed to give the total amount of soil lost from the gully.

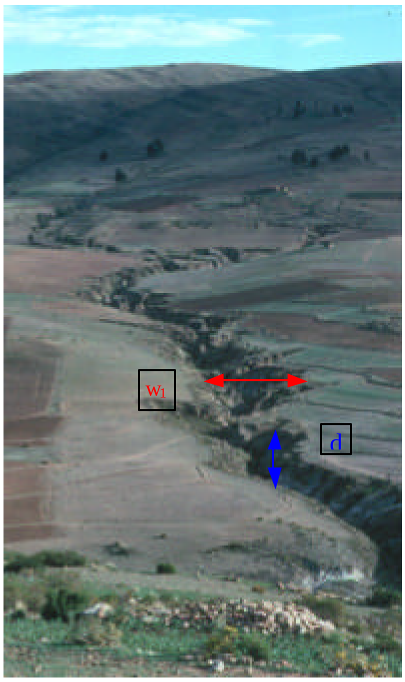


Figure 4.2b: Gully, Bolivia

Gullies, as more or less permanent features of the landscape, present a good opportunity to keep a time series record of their extension (or sedimentation). Repeated visits and simple measurements, plus aerial photographic and historic evidence, enable monitoring of catchment land degradation condition over time-spans of more than 50 years. Techniques that have been used include:

- time-series aerial photography; gully progression can be directly measured;
- interviews with older members of the community and transect walks to indicate where the gully stood at significant dates in the past;
- use of permanent monitoring stakes and repeated survey measurements after major storms.

An annual rate of soil loss may not be meaningful, even if the number of years that the gully has been in existence can be established, because different rates of soil loss will occur as the gully deepens and encounters different layers of soil. The headward extension of a gully is very dependent on the condition of the catchment, sheet erosion sediment production and rates of runoff. As a gully grows much of the soil loss may come from the sides of the gully and not sheetwash. If catchments are conserved or planted to forest, gullies may stabilise and heal.

The volume of soil lost from a gully can be converted into an equivalent tonnes/hectare measurement, but the usefulness of this measure is limited. First, the actual volume of the gully is only a small fraction of total sediment loss from the catchment. Secondly, the gully is more a symptom of a degraded catchment rather than the degradation itself.

<u>Potential for Error:</u>

1) Gullies very often visually dominate the landscape. Many conservation schemes erroneously focus on the gully, rather than the reason for the gully, which lies in the catchment. It is easy to forget that sheet erosion is likely to be ongoing and probably far greater in total sediment production.
2) Care needs to be exercised in measuring the catchment for gullies in order to make assessments of soil loss per hectare. In particular, the contributing area providing runoff decreases as the gully head extends up valley. Large gullies can be assessed from aerial photography or even maps.

Worked example

EXAMPLE
FIELD FORM: GULLY

Site:

Date:

Measurement	*Width at lip(w_1)* *m*	*Width at base (w_2)* *M*	*Depth* *m*
1	10.0	4.0	2.1
2	12.0	5.0	2.1
3	11.0	4.0	1.9
4	12.0	6.0	1.8
5	9.0	6.0	2.1
6	9.0	3.0	2.2
7	11.0	5.0	2.0
8	9.0	5.0	2.3
9	10.0	4.0	2.4
10	12.0	5.0	2.2
11	14.0	6.0	2.3
12	9.0	6.0	1.8
13	9.0	4.0	1.9
14	11.0	5.0	1.8
15	10.0	4.0	1.7
16	9.0	5.0	2.0
17	8.0	3.0	2.0
18	10.0	5.0	1.7
19	11.0	6.0	1.9
20	8.0	5.0	1.8
Sum of all measurements	204.0	96.0	40.0
Average*	WIDTH w_1 = 10.2	WIDTH w_2 = 4.8	DEPTH (d)= 2.0

* Rem.: to get average divide the sum of all the measurements by the number of measurements made.

Calculations:

(1) Calculate the average cross-sectional area of the gully, using the formula (w1 + w2)÷2 x d.

½ (AV WIDTH w_1 +AV WIDTH w_2)	½(10.2+4.8)	x	DEPTH (m)	2.0	=	CROSS-SEC AREA		15 m^2

(2) Calculate the volume of soil lost from the gully assuming that the measurements above were taken from a gully measuring 200 metres in length.

CROSS-SEC AREA	15	*	LENGTH (m)	200	=	VOLUME LOST	3,000 m^3

(3) Convert the volume lost to a per metre equivalent, assuming a catchment area of 1 km^2, or 1,000,000 m^2.

VOLUME LOST	3,000	÷	CATCHMENT AREA (m^2)	1,000,000	=	SOIL LOSS (m^3/m^2)	0.003

(4) Convert the volume lost to tonnes per hectare over the whole catchment area.

SOIL LOSS (m^3/m^2)	0.003	*	BULK DENSITY (t/m^3)	1.3	x	10,000	=	SOIL LOSS	39 t/ha

4.3 Pedestals

What are they? 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 and give a pedestal-like feature – but note warning 2 below. Pedestals are useful as an indicator of high sheet erosion rates of the order of 50 or more tonnes/hectare/year.

How do they occur? Pedestals are caused by differential rainsplash erosion, which dislodges soil particles surrounding the pedestal but not under the resistant capping material. The soil particles in the pedestal itself are unaffected because they are protected by a material that harmlessly absorbs the power of raindrops. (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, especially on surfaces where erosion rates are very large due to high intensity rainfall.)

Where do they occur? Pedestals occur on easily eroded soils, where random protection from erosion is afforded by stones or tree roots. Pedestals are often formed under trees or crops because the intercepted rainfall falls to the ground as larger drops with greater energy to displace soil particles. The presence of gravel, pebbles or very coarse sand particles is needed – but not in excessive amounts (see 'armour layer') as this obliterates the differential effect – or other capping materials.

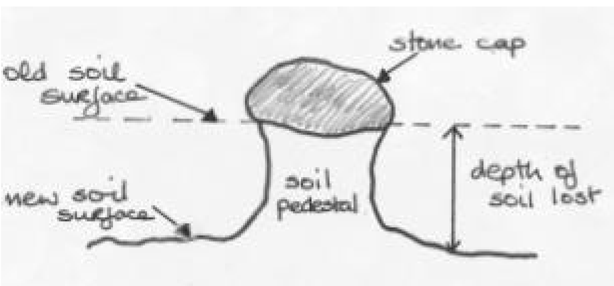


Figure 4.3a: Sketch of Soil Pedestal Capped by a Stone

How can they be measured? The height of pedestals can be measured using a ruler.

Figure 4.3b: Pedestals with Carrot Seedlings, Sri Lanka

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 surface around. The difference between the height of the pedestal and the surrounding soil surface represents the soil loss since the soil was last disturbed by tilling or other agricultural practice. Therefore, by knowing the timing of the disturbance, it is possible to estimate a rate of soil loss.

Where possible a number of measurements should be obtained from different parts of the field. A single pedestal, or a concentration of pedestals in a particular area, are not necessarily indicative of the occurrence of sheet erosion. It is usual to take a large number of pedestal heights and express overall erosion or lowering of the ground surface as an average of these heights. It is recommended to divide the field into a number of small areas or localities of about 1 m^2, and take the maximum pedestal height in each locality – see warning 3 below.

Potential for Error:

1) As noted above, 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.
2) Pedestals can be confused with clumps of sediment trapped by vegetation. In this

instance deposition, rather than erosion, is the feature demonstrated by soil accumulations.

3) Capping stones that were originally buried in the soil may become exhumed by erosion and subsequently form a pedestal. Therefore, the height of the pedestal in such cases will underestimate erosion. It is therefore recommended that only the highest pedestals (where it may be assumed the capping material was on the surface) are taken for assessment in any small locality.

4) Material removed from around pedestals may be redeposited elsewhere in the field. Should this occur an estimate of the quantity of soil redeposited must be subtracted from the calculated soil loss to arrive at the net soil loss.

Worked example

EXAMPLE
FIELD FORM: PEDESTALS

Site:

Date:

Measurement Locality	*Maximum Height of Pedestal in Locality (mm)*
1	10
2	12
3	10
4	15
5	10
6	14
7	14
8	13
9	14
10	11
11	12
12	10
13	10
14	8
15	12
16	13
17	11
18	15
19	17
20	10
Sum of all measurements	241
Average*	AV PED HEIGHT = 12.05

* Rem.: to get average divide the sum of all the measurements by the number of measurements made.

Calculations:

(1) Calculate t/ha equivalent of the net soil loss (represented by the average pedestal height). Using an average bulk density of 1.3g/cm^3, a 1 mm loss of soil is equivalent to 13 t/ha.

AV PED HEIGHT (mm) [12.05] x BULK DENSITY (t/ha) [13] = [157 t/ha]

4.4 Armour Layer

What is it? An armour layer is the concentration, at the soil surface, of coarser soil particles that would ordinarily be randomly distributed throughout the topsoil. Such a concentration of coarse material usually indicates that finer soil particles have been selectively removed by erosion.

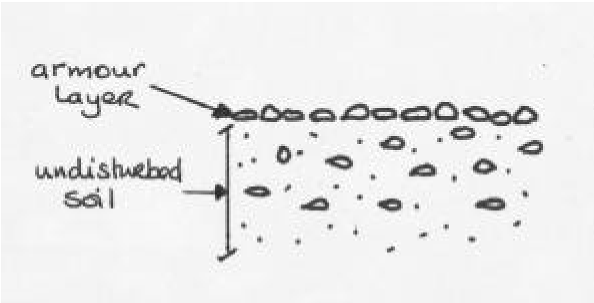


Figure 4.4a: Sketch of Armour Layer

Figure 4.4b: Measuring Armour Layer Using a Ruler, Sri Lanka

How does it occur? Raindrops or the power of the wind detach the finer and more easily eroded soil particles. Then water or wind carries them away from the topsoil surface, leaving behind the coarser particles.

Where does it occur? An armour layer is most likely to form on soils which have both a stony/coarse fraction as well as fine clays, silts and organic matter, following rainfall/severe winds.

How can it be measured? Dig a small hole that shows the undisturbed armour layer. Using a ruler, measure the depth of the coarse top layer. Where the depth of the armour layer is less than one millimetre, it is best to scrape the stones from a small area of about three times the size and then measure this depth, and dividing by three. This helps to reduce the inaccuracies in trying to measure very small depths of stones. 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.

These calculations tell us the amount of fine particles that have been lost since the soil was last disturbed – for example, since it was tilled or weeded.

Potential for Error:

(1) Stones on the surface may arise for other reasons, such as the exhumation of a concentration of stones in the subsurface soil.
(2) The depth of the armour layer will most likely be measured to the nearest millimetre. For every millimetre the equivalent soil loss is 13 t/ha (assuming an average bulk density of 1.3g/cm^3). Therefore, the accuracy of the measurements will be important in arriving at the soil loss.
(3) The calculations also rely on a subjective assessment of the proportion of coarse

material occurring in the topsoil. It is useful to check percentage estimates with colleagues in the field to see if there is any appreciable difference.

(4) As well as the erosion process itself, repeated shallow tilling of the soil, especially in weeding operations, may concentrate more stones near the surface. Where this happens, the erosion rate will be exaggerated, if the percentage concentration of stones in the original soil is based on an estimate well below the topsoil. Closer inspection of stone concentration can help with correcting for this.

Worked example

EXAMPLE
FIELD FORM: ARMOUR LAYER

Site:

Date:

Measurement	*Depth of Armour Layer (in mm)*	*Proportion of Coarse Material in Topsoil*
1	0.9	20%
2	1.1	25%
3	1.0	15%
4	1.1	22%
5	0.9	20%
6	1.2	20%
7	0.8	22%
8	0.9	19%
9	1.1	20%
10	1.1	20%
11	1.2	18%
12	1.0	20%
13	0.8	18%
14	0.9	22%
15	0.7	22%
16	1.0	20%
17	1.1	18%
18	1.2	20%
19	1.1	20%
20	0.9	19%
Sum of all measurements	20.0	400%
Average*	AL DEPTH (mm)= 1.0	COARSE % = 20%

* Rem.: to get average divide the sum of all the measurements by the number of measurements made.

Calculations:

(1) First, convert the measured soil loss to its equivalent in metres. In this instance, because the measurements are in millimetres it is necessary to multiply by 0.001.

AL DEPTH (mm) [1.0] x [0.001] = AL DEPTH (m) [0.001]

(2) Calculate the depth of soil required to generate AL DEPTH (m)– this average measured depth of coarse material is 0.001m according to the measurements noted above. The measurements give an estimate of 20% (or $^{1}/_{5}{}^{th}$) for coarse material in the topsoil.

AL DEPTH (m) [0.001] x COARSE % [20% or $^{1}/_{5}{}^{th}$] = TOTAL SOIL(m) [0.005]

(3) Calculate the soil lost

TOTAL SOIL (m)	0.005	-	AL DEPTH (m)	0.001	=	NET SOIL LOSS (m)	0.004

(4) Calculate t/ha equivalent of net soil loss – using an average bulk density of 1.3g cm^3. At this bulk density 1mm of soil loss is equivalent to 13 t/ha, so 1m of soil loss would be equivalent to 13,000 t/ha.

NET SOIL LOSS (m)	0.004	x	EQUIV VOLUME PER HECTARE (t/ha)	13,000	=	52 t/ha

4.5 Plant/Tree Root Exposure

What is it? Plant or tree root exposure describes a situation where the base of the tree trunk or lateral roots are partially exposed above the present soil surface. Often a mark can be located on the trunk of a tree or stem of the plant to indicate where the original soil surface was when the plant started to grow.

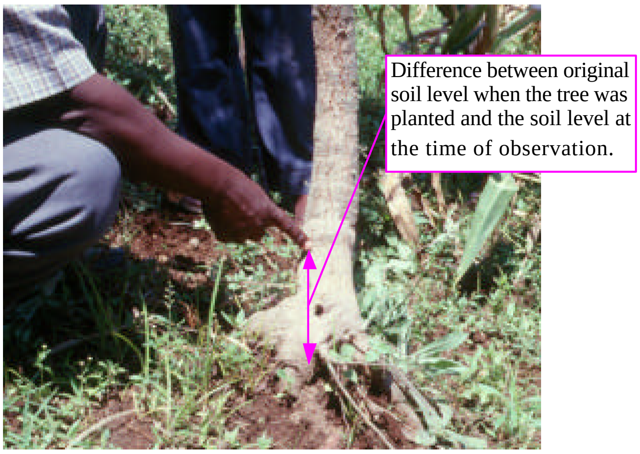


Figure 4.5a: Tree Root Exposure, Vietnam

How does it occur? Root exposure may occur where soil particles are removed by water or wind, lowering the overall soil level. Stem flow may be particularly relevant, especially where water is funnelled between exposed roots. Away from the stem, roots can act as a cap and protect against rainsplash erosion in the manner of a pedestal (see technique 4.3).

Where does it occur? Root exposure occurs where crops or trees are growing in areas subject to erosion.

How can it be measured? Using a ruler, measure the distance from the soil surface to the point on the plant stem/tree trunk which would have originally been at ground level. For lateral roots away from the stem, the upper surface of the most exposed roots is usually taken as the former soil surface. Because the measurements depend on the standing plants/trees in a particular field, it may not be possible to repeat the measurements at different points throughout the field. However, if root exposure is evident at different places in the field a number of measurements should be taken to assess the average soil loss. Differences in root exposure may reflect different erosion processes (for example, stemflow and rainspash) occurring in the same field.

The measurement gives an estimate of the soil lost since the plant/tree was planted (but see potential for error, below). In the case of a crop, this may be a single growing season, whereas in the case of a tree it will depend on the age of the tree. The age of a tree is best determined by enquiry from the farmer, verified by direct observation. Independent verification of the age of many trees can be obtained by counting tree rings (known as dendrochronology). However, tree rings are not always made annually, especially in the tropics and subtropics (see Box 4.3), so it is important to know the growth patterns of any tree species used to age an erosion feature. Mature trees are sampled for their rings using a tree corer. Opportunity may also be taken if trees have been cut for fuelwood or other purposes where it may be possible to examine a complete transverse section of the stump. The annual soil loss is calculated by dividing the measured difference between the actual soil level and that which existed when the plant/tree started to grow.

Box 4.3: Choosing Suitable Trees

Both the techniques of using tree mounds and those of examining tree root exposure (#4.5) demand certain characteristics of the indicator tree species. First, the tree must not in its growth cycle do anything unusual, such as heave itself out of the ground as the roots enlarge. Another unusual phenomenon noted with gum (*Eucalyptus* spp.) trees in parts of Africa is piping and underground erosion, to the extent that the tree itself may subside into the hole so created. Secondly, the tree should be capable of being dated. In farmers' fields, trees may well have been planted and dates are easy to determine from the land user. But elsewhere the assessor has to rely on dendrochronology or counting tree rings. Only some 10 to 30 % of tropical trees have clearly defined growth rings.

A full listing cannot be given here (see Humphries and Macris reference in Bibliography) but trees that have been used successfully in various parts of the world to assess land degradation include:

- *Acacia drepanalobium* – the ant-gall acacia, a slow-growing thorny shrub
- *Acacia albida* – throughout Africa planted in fields because of its beneficial shade and leaf fall.
- *Tectona grandis* – teak, very tall with large leaves, planted on a 40+ year cycle. Erosion is often high underneath the canopy and roots become exposed easily
- *Tamarindus indica* – the tamarind, planted as a long-lasting fruit tree throughout the tropics. Its roots easily become exposed.
- *Parinari curatellifolia* – a fruit tree (the fruit used for wine) that grows on problematic sodic soils in Africa. Farmers usually always retain these magnificent trees in their fields and their age will be known by oral tradition.

Trees with buttresses, common in rainforest environments, are not suitable for tree root exposure technique. The buttress does not imply that the original soil level has lowered.

Potential for Error:

1) While obstacles in a field may provide indications of soil loss, these may not be representative of the soil loss in the field as a whole. The obstacle may cause channelling of erosive water flows, thus increasing the soil loss around the obstacle, or it may slow down the surface flow, allowing deposition to occur. Therefore, extrapolated soil losses, calculated solely by reference to plant/tree root exposure, may be either overstated or understated.

Figure: 4.5b: Aerial Roots of Maize, Brazil

This is why it is useful to include erosion estimates from lateral roots located away from the trunk.

2) Also, possible errors introduced where plants tend to heave 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. The air roots of maize plants (see Figure 4.5b) can also be deceptive.
3) Related to the above error is the expansion of root diameter as the tree grows. Roots running parallel to the surface may rise to/above soil level. This gives the appearance that there has been more erosion than there has been.

Worked example

EXAMPLE
FIELD FORM: PLANT/TREE ROOT EXPOSURE

Site:

Date:

Measurement *A*	*Measured Difference in Soil Level* *mm* *B*	*Converted to Tonnes/Hectare* *B x 13** *t/ha* *C*	*Age of Plant/Tree* *years* *D*	*Annual Change in Level* *t/ha/yr.*
1	7	91	5	18.2
2	6	78	5	15.6
3	7	91	5	18.2
4	8	104	5	20.8
5	8	104	5	20.8
6	6	78	4	19.5
7	3	39	2	19.5
8	2	26	2	13.0
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
Sum of all measurements	-		-	145.6
Average**	-		-	ANNUAL SL = 18

* Rem.: 1mm of soil loss is equivalent to 13 t/ha, where the bulk density is $1.3 g/cm^3$.

** Rem.: to get average divide the sum of all the measurements by the number of measurements made. In this case only 8 measurements were possible so the divisor is 8.

In this case it has been assumed that plants of different ages in the same plot have demonstrated root exposure.

4.6 Exposure of Below Ground Portions of Fence Posts and Other Structures

What is it? Sheet erosion, resulting in a reduction in the general ground level, can be identified where the below ground portions or foundations of man-made structures, such as fences posts, other poles, old tracks and roads, bridges and buildings, are exposed. (Soil accumulations are also possible around these kinds of structures. Where this occurs, the technique described to quantify soil loss evidenced by build up against barriers can be used to estimate erosion rates.)

How does it occur? The action of wind or water detaches soil particles from the soil surface and transports them to be deposited elsewhere. Over time, assuming that removal exceeds deposition, this will lead to a reduction in the level of the soil surface. Structures with known foundations/depths below surface can be used to measure the general lowering of the soil surface.

Where does it occur? Measurements of soil loss using man-made structures can only be made where it is clear that factors other than erosion (for example, construction) have not been the cause of soil loss. Fence posts and other poles are particularly useful since the insertion into the ground involves minimal disturbance. Track, road and bridge construction often involves a greater degree of initial disturbance, but this can be compensated for by allowing an initial settling-down period. In particular bridges and tracks/roads often become useful markers if abandoned or no longer maintained. Buildings are a more complicated item to deal with and a great deal of care is required.

This type of investigation encompasses archaeology and an investigator should be aware of rights and legal obligations that apply in the local area.

How can they be measured? The measurement strategy clearly 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 the area (see Box 4.4). 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 measured. (Excavation is required where the post is expected to be completely buried as a result of deposition of soil particles.)

The same procedure applies to buildings and other structures though because they are point locations they cannot provide the spatial record that fence lines can. In the case of paved paths and roads it is common for the pavement to seemingly disappear over time. This may occur by burial during sedimentation or, in areas of active erosion, especially on steep slopes, the pavement may be undermined and the path breaks-up. (Such break-up can also be due to the removal of soil from beneath the pavement by various animals such as ants, earthworms and termites.) An absence of path destruction can indicate reasonable stability and low erosion rates (Fig 4.6).

Box 4.4: Example of Use of Fence posts to Determine Soil Loss – Degraded Rangelands, Australia.

In an Australian study the straight fence lines crossed hilly terrain and floodplains to enclose grazing areas. The posts were of uniform length and each contained three uniformly positioned drill holes for fence wire. In this case the height of the lower hole was positioned at a set height above the ground surface. This configuration provided a good basis for establishing the position of the original ground surface. Erosion was indicated by an increased distance between the present day ground level and the height of the lower hole, which was measured by a ruler to the nearest 0.5 cm. The study was able to use a number of fence lines to show a distinct spatial pattern to erosion and sedimentation and delimit areas where degradation of this type was not evident.

Source: Geoff Humpreys, Macquarie University, personal correspondence.

Figure 4.6: The Old Silk Road, Gaolingong Mts, Southern China

Potential for Error:

1) The use of fence post, poles and similar structures is only possible where the age of the structure is known and where it is possible to determine the level of the original ground surface. Not being able to satisfy either parameter means that the technique is unsuitable.
2) Fences and other structures may actively promote erosion or sedimentation. Hence, fences with a railing or other barrier at or close to the ground level are better treated as an example of Technique 4.10 "Build up against Barriers" especially when aligned across the slope. The best fences are those without a barrier near ground level and aligned perpendicular to slope. Local scouring around a post can usually be detected since it creates a depression, often semi-circular, below the existing surface. This extra depth can be excluded from any calculation.

Worked example

EXAMPLE
FIELD FORM: FENCE POST EXPOSURE

Site:

Date:

Measurement *A*	*Depth of erosion* *mm* *B*	*Converted to Tonnes/Hectare B x 13** *t/ha* *C*	*Time Elapsed Since Structure Installed* *Years* *D*	*Annual Change in Level* *t/ha/yr.*
1	20	260	45	5.8
2	55	715	45	15.9
3	40	520	45	11.6
4	105	1365	45	30.3
5	60	780	45	17.3
6	55	715	45	15.9
7	80	1040	45	23.3
8	35	455	45	10.1
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
Sum of all measurements	-		-	130.2
Average**	-		-	ANNUAL SL = 16 t/ha

* Rem.: 1mm of soil loss is equivalent to 13 t/ha, where the bulk density is 1.3g/cm^3.

** Rem.: to get average divide the sum of all the measurements by the number of measurements made. In this case only 8 measurements were possible so the divisor is 8.

4.7 Rock Exposure

What is it? Rock exposure describes the situation where underlying rock has, because of erosion, been exposed at the ground surface.

How does it occur? Rock exposure occurs where the soil particles that had previously overlain the rock have been removed by the action of wind or water. The bare rock surface is exhumed: i.e. its relative position with respect to the soil surface has changed.

Where does it occur? Rock exposure occurs where there are shallow soils covering rocky but massive parent material. Well-weathered parent rock is not suitable because it is also erodible and fails to give a clear marker against which to measure soil removal.

How can it be measured? It is necessary to assess where the bare rock was when accelerated erosion started to happen. This can be difficult, but two practical field situations can be considered. First, the rock was only partially buried. In this case, the old surface soil usually stains the rock and the previously-buried part of the rock can be clearly seen. In other situations the older exposed rock is covered in lichens whereas the recently exposed rock is not. Even when the lichens have been removed, evidence of their presence remains in the form of etching patterns on the rock surface. Measurement, then, is straightforward: take the depth of soil removed by measuring vertically from the current soil surface up to the boundary of the stained part of the rock. Secondly, the rock may have been completely buried. This will have happened when there are no clear staining marks to differentiate from unstained areas. In this case, the conservative assumption is that the rock will have been just below the old surface of the soil. Under this assumption the removal of soil by erosion amounts to a depth equivalent to the whole height of the rock exposure. It will be clear that this will give a minimum estimate of long-term soil loss. At least there will be no danger of spurious exaggeration! It is recommended that a large number of such measures be undertaken in order to reduce individual sampling errors. If periodic measurements are planned, markers could be left to show the current level of soil. Masonry nails provide a useful marker in harder rocks. Future measurements could then be made by reference to these markers. However, this is unlikely to yield measurable results in less than several years of erosion – in other words, after enough erosion to cause a lowering of at least 10 mm.

Potential for Error:

1) The main source of error is identifying where the rock sat in relation to the ground surface before significant erosion started. The best situations are on dark-coloured rocks which weather to rich-brown clays or lighter rocks that weather to reddish clays – in these cases, the staining is easily visible and may last for many decades. The best check is to look at a number of rock exposures and gain an overall consistent set of measures of soil removal – then greater confidence can be gained in the accuracy of the estimates.
2) The baseline of the level of the current soil surface can be problematic. The rock exposure itself alters the local hydrology and may partially protect the soil on the upslope side. On the downslope side, eddies in the water flow may cause greater scouring, thereby lowering the current soil surface more than if the rock had not been there. Only careful site inspection can confirm these sources of error. But once detected, they can be compensated for.
3) The time over which rock exposure has occurred can be difficult to estimate. Normally, it is sufficient to enquire when the land was first opened up for agriculture, and use this date to calculate the length of time over which erosion has occurred. However, the land degradation hazard may not have been evenly distributed over that time. So, results should be presented as long-term mean estimates.
4) Falling trees (or windthrow) often result in the occurrence of stones and bedrock fragments on or near the surface. Thus, especially where there is evidence of forest clearance or recently fallen trees, stones at or near the surface may not be indicative of erosion processes.

Worked Example:

See 'solution notches'.

4.8 Solution Notches

What are they? This is a particular but very useful case of the previous indicator – rock exposure. Solution notches are indentations found on rocks that indicate the historic soil level.

How do they occur? Solution notches arise because of chemical reactions between the soil, air and the rock. Topsoils have greater chemical reaction with rock because of humic acids released by organic matter as it decomposes and the greater abundance of soil flora and fauna. Therefore, in the zone of the former topsoil, especially at the interface between topsoil and atmosphere, there is greater weathering of adjacent bare rock. This weathering leaves a horizontal solution mark or notch, which is often smoother than the exposed rock. Where the soil is subsequently removed (by erosion or other means) these notches become visible as permanent markers of where the soil was.

Where do they occur? Solution notches are most likely to occur on limestone and calcareous rocks. These are the rocks most susceptible to solution by acid organic chemicals, but the same effect can occur on other rocks.

How can they be measured? Measurement is broadly similar to rock exposures. The distance from the solution notch to the current soil level gives an indication of how much soil has been eroded. This distance can be measured using a ruler, and then converted into a soil loss per hectare equivalent. A problem in using solution notches to determine a rate of soil loss is finding another indicator for calibration, so that the period over which the soil loss has occurred can be estimated. Other indicators might include tree root exposure on nearby trees or marks of soil level on houses built a known number of years previously. Alternatively, it may be possible to date the 'exposed' surface by reference to solution pitting, but since this occurs at a rate of 2-5 mm/1,000 years the surface must have been exposed for at least a few hundred years.

Potential for Error:

1) Marks on rocks may not be solution notches. They may indicate other forms of damage, for example scraping by machinery. However, this type of damage initially produces rough, broken surfaces with sharp edges in contrast to the smooth form of natural notches.
2) The amount of soil loss around the base of a rock may be less, or greater, than that which occurs nearby. Deposition of soil particles may occur against the rock (as in build-up against barriers) or channels may form around the base of the rock, increasing the amount of soil loss.
3) It can be difficult to determine an appropriate time-span over which the erosion occurred.

Worked Example:

This example applies to both rock exposures and solution notches. A large number of individual measurements should be carried out in the locality, and results compared to gain a view of how consistent is the evidence. Other techniques such as root exposure and tree mounds should be undertaken to corroborate the results from exposed rocks.

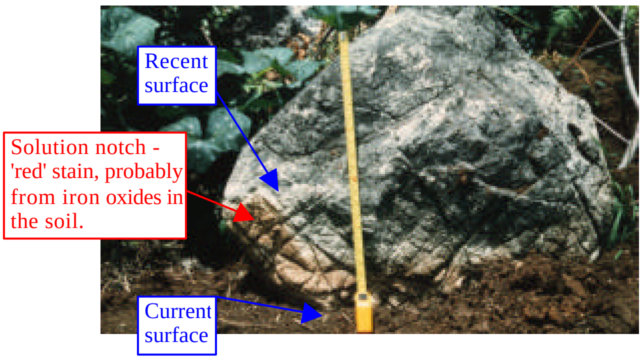


Figure 4.8 Solution Notch

Note that the 'red' surface is smoother than on the 'grey' part of this limestone rock.

Assume that the solution notches (or staining evidence on the rock) are at a distance (h) of 22cm from the current soil surface – see photo. It is estimated that this soil loss has occurred since the land was deforested and agriculture commenced 20 years previously.

Annual soil loss = 22/20 = 11 mm/yr

Convert to Tonnes/Hectare = 11x 1.3 x 10 = 143 t/ha/yr

4.9 Tree Mound

What is it? A tree mound describes the situation where the soil under a tree canopy is at a higher level than the soil in the surrounding area. A tree mound has approximately the same diameter and shape as the overhanging tree canopy.

Figure 4.9a: Tree Mounds

How does it occur? The presence of tree mounds indicates that there has been more erosion away from the tree than near it, since the surface of the mound represents an earlier soil level. Hence, it can be concluded that the erosive impact of the raindrops is absorbed by the tree canopy. This reduces the eroding power of raindrops reaching the ground surface, and therefore the amount of soil dislodged. In contrast, soil unprotected by a tree canopy is subject to the full force of the raindrops, so that soil particles are dislodged and are transported downslope in runoff. Other factors contributing to the creation of a tree mound include the binding effect of the tree roots, the greater incorporation of organic matter into the soil beneath the tree, the displacement of soil during tree growth and the construction of nests by ants and termites. In addition, some have claimed also that livestock sit under trees during the day for shade, thereby providing greater inputs of manure. Thereby, a local difference in level of soil surface is constructed, enabling field assessment of historical erosion rate in the general area as compared to the baseline level of minor erosion under the tree.

Where does it occur? Tree mounds occur where there is a tree providing good, continuous, protection to the ground surface. The best sites for assessment are on extensive low-angle plains of semi-arid zones, where occasional trees dot the landscape. The original area where this technique was developed was in East Africa with the ant-gall acacia, *A. drepanalobium*.

How can it be measured? The level of the soil surface under the tree and in the open is compared. The difference in height between the soil surface under the tree and in the surrounding area gives an approximation of the soil loss that has occurred during the life of the tree.

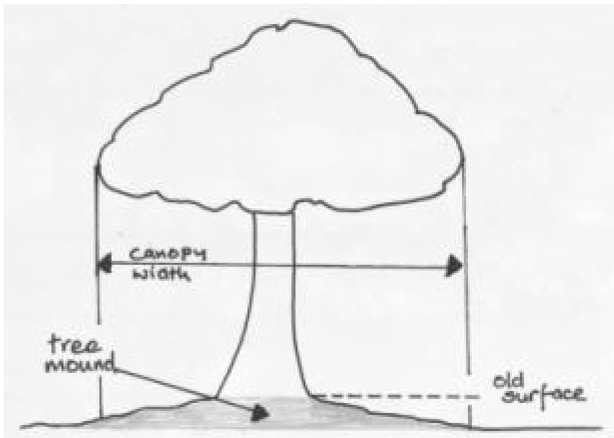


Figure 4.9b: Sketch of Tree Mound

The life of the tree can be assessed by asking local people, or by dendrochronology (the counting of tree rings). The non-destructive approach is to be preferred. However, in the original area where this technique was developed, a selected number of ant-gall acacias were felled, their age assessed from rings in the trunk, and their circumference measured. Regression graphs were then constructed of tree age versus circumference. These calibration graphs then enabled age assessment to be undertaken non-destructively for all further sites in the local area.

A large number of measurements should be taken. First, the height difference between maximum elevation of the mound and general level of soil surface should be measured. A spirit level is useful here to extrapolate from the top of the mound horizontally away from the tree to the general soil surface. The difference in soil level close to the edge of the tree canopy can be easily measured using a ruler.

Secondly, the historical erosion rate should be calculated and the time period noted over which this historical rate applies. Thirdly, the measurements are repeated for trees of different sizes and ages. It is recommended that erosion rates be grouped according to bands of progressively older time periods to see if there is any difference in calculated average erosion rate. Typically, in the East African case, the longer the time period, the lower was the average erosion. This indicated that erosion rates have been getting greater in recent historical times as grazing pressures have increased.

Potential for Error:

1) Mounds around the base of trees, shrubs and other plants may have been caused by factors other than erosion. For example, termite mounds are commonly found around trees and shrubs. In addition, the trunks of trees may act as a barrier to the transport of sediment resulting in deposition. Organic matter may build up under trees, especially where leaf litter accumulates or livestock shelter.
2) 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 may actually exist[1].
3) Because the tree canopy size changes as the tree grows, 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.
4) Wind-borne sediment can be slowed or trapped by trees and shrubs, falling to the ground surface underneath the leaf canopy. Such material increases the difference between the surface beneath the tree and beyond but it bears no relation to the original soil level and may have been transported from far off.
5) Counting tree rings as an estimate of age of tree is problematic in many tropical species. Rings may occur seasonally, where there are two rainy seasons per year as in East Africa. They may merely indicate longer cycle climatic conditions such as runs of wet and dry years. Careful checking is needed, and local advice and information from farmers is invaluable. On cropland, trees will usually have been planted and the land user will be able to give direct information.
6) Sometimes farmers deposit organic refuse around the base of trees when weeding garden plots. This is particularly common in humid areas, such as the highlands of New Guinea. Alternatively, farmers may remove the tree mound, especially if it contains organic matter, to distribute to their fields.

[1] This effect can be allowed for when the volume of the tree mound (V_M) exceeds the volume of the lifted soil which can be assumed to be the volume of the root bole (V_B) which is approximately given as the product of the basal tree area and its diameter. When $V_B = V_M$ the original soil height (H_o) is assumed to be the height at the edge of the existing mound. Otherwise when $V_M > V_B$, $H_o = (V_M - V_B) / 0.33 ? r_M^2$ where $V_M = 0.33 ? r_M^2 h$ and $V_B = ? r_M^2 d$, and where h is the height of the tree mound and d is the basal diameter of the tree.

Worked example

EXAMPLE
FIELD FORM: TREE MOUND

Site:

Date:

Measurement *A*	*Measured Difference in Soil Level* *mm* *B*	*Converted to Tonnes/Hectare* *B x 13** *t/ha* *C*	*Age of Plant/Tree* *years* *D*	*Annual Change in Level* *t/ha/yr.*
1	35.0	455.0	25	18.20
2	28.0	364.0	20	18.20
3	22.5	292.5	18	16.25
4	18.0	234.0	10	23.40
5	21.0	273.0	15	18.20
6	24.0	312.0	15	20.80
7	21.0	273.0	15	18.20
8	22.5	292.5	18	16.25
9	27.5	357.5	22	16.25
10	27.5	357.5	22	16.25
11	29.0	377.0	20	18.85
12	27.0	351.0	20	17.55
13	22.5	292.5	15	19.50
14	22.5	292.5	18	16.25
15				
16				
17				
18				
19				
20				
Sum of all measurements	-		-	254.15
Average**	-		-	ANNUAL SL = 18 t/ha/yr

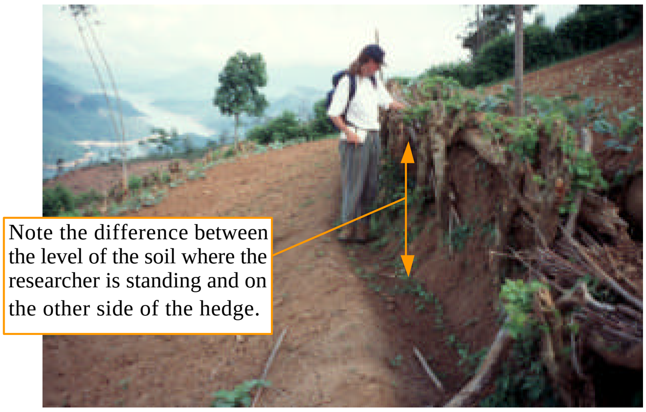
* Rem.: 1mm of soil loss is equivalent to 13 t/ha, where the bulk density is $1.3 g/cm^3$.

** Rem.: to get average divide the sum of all the measurements by the number of measurements made. In this case only 14 measurements were possible so the divisor is 14.

In this case it has been assumed that trees of different ages in the same plot have demonstrated tree mounds.

4.10 Build up against Barriers

<u>What is it?</u> Where the transport of eroded material is halted by an obstruction, the particles suspended in the runoff may be deposited against the obstruction as the water slows. This results in a build up of sediment against the barrier. This indicator measures movement of soil across the field rather than loss from the field.

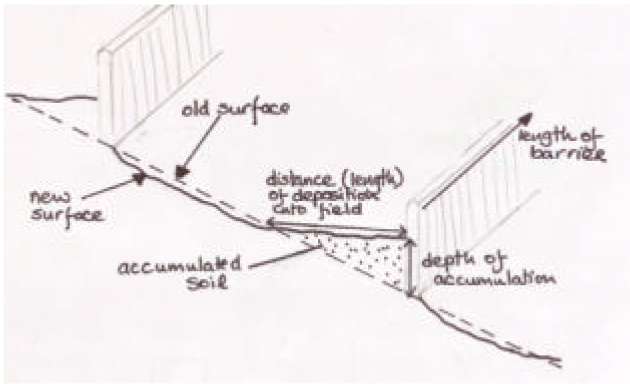


<u>Figure 4.10a: Build up of Soil Behind a Gliricidia Hedge, Sri Lanka</u>

<u>How does it occur?</u> Fine soil particles are transported in water. If the runoff meets a barrier, its speed is reduced and soil particles settle out of suspension, thereby creating a small sedimentary layer. On steeper slopes, and especially when the soil is dry, clods of soil may roll downslope with the slightest disturbance. Over time such deposited matter will alter the slope surface. This build up is often accelerated by plough erosion – see error 3.

<u>Where does it occur?</u> Build up against barriers will occur where an obstruction exists to bar the transport of fine soil particles. Typical obstructions are field boundaries, logs on the surface, stone bunds and fence lines.

<u>How can it be measured?</u> The volume of soil trapped behind the barrier is 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.



<u>Figure 4.10b: Sketch of Build-up of Eroded Material Against a Barrier</u>

A visual examination of the area close to the barrier will indicate how far the deposition extends into the field. This distance (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. (There is a danger that because of soil erosion on the lower field the soil level next to the barrier will have been lowered.) As illustrated in Figure 4.8a, the depth of the accumulation of soil is not constant. In order to calculate the amount of soil accumulated a linear slope is assumed.

The amount of soil accumulated behind a barrier represents a build-up over time. The annual rate of soil loss from a hillside is arrived at by dividing the quantity of accumulated soil by the number of years that a barrier has been in existence. Older barriers can be treated as archaeological sites and careful excavation can lead to the recovery of dateable materials such as charcoal and artefacts.

<u>Potential for Error</u>

(1) 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.

(2) 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.

(3) Tillage techniques may increase the soil depth behind barriers, particularly where conservation techniques such as terracing have been introduced to lessen the effect of slope. This tillage erosion is also called 'plough' erosion, because farmers often scrape soil downhill when they cultivate.

(4) If the slope was convex before the barrier was constructed, the estimate of soil loss will be understated as it assumes a linear slope.

Worked example

EXAMPLE
FIELD FORM: BUILD-UP AGAINST BARRIER

Site:

Date:

Measurement	*Measured Depth cm*	*Measured Length cm*
1	18	100
2	12	110
3	14	120
4	19	70
5	18	80
6	18	60
7	17	90
8	13	90
9	14	100
10	15	120
11	15	110
12	12	120
13	19	100
14	19	80
15	14	70
16	16	90
17	15	70
18	17	100
19	17	110
20	18	100
Total	320	1890
Average	16	94.5
Length of barrier:	(m) 7.00	
Contributing (catchment) area to barrier:	(m^2) 70.0	

* Rem.: to get average divide the sum of all the measurements by the number of measurements made.

Calculations:

(1) Convert the average depth and length of the accumulation against the barrier to metres (by multiplying by 0.01). Thus, an average depth of 16cm is equal to 0.16m and an average length from the barrier into the field of 94.5cm is equivalent to 0.945m.

(2) Calculate the average cross-sectional area of the accumulation, using the formula for the area of a triangle (i.e. ½ horizontal width x depth).

[½] x DEPTH (m) [0.16] x LENGTH (m) [0.945] = CROSS-SEC AREA [0.07560 m^2]

(3) Calculate the volume of soil accumulated behind the barrier assuming that the barrier measures 7 metres in length.

CROSS-SEC AREA (m^2)	0.07560	x	BARRIER (m)	7	=	VOLUME ACCUMULATED	0.5292 m^3

(4) Convert the total volume accumulated to a volume per square metre of contributing area, of 70 m^2.

VOLUME ACCUMULATED (m^3)	0.5292	÷	CONTRIBUTING AREA (m^2)	70	=	SOIL LOSS (m^3/m^2)	0.00756

(5) Convert the volume per square metre to tonnes per hectare.

SOIL LOSS (m^3/m^2)	0.00756	x	BULK DENSITY (t/m^3)	1.3	x	10,000	=	SOIL LOSS (t/ha)	98.3

(6) Convert the total soil loss as represented by the soil accumulated behind the barrier into an annual equivalent, assuming that the barrier was constructed 3 years before the measurements were recorded.

SOIL LOSS (t/ha)	98.3	÷	TIME (yr)	3	=	ANNUAL SOIL LOSS	33 t/ha/yr

4.11 Sediment in Drains

What is it? On agricultural land, runoff from a hillside is often channelled off the slope via drains running across the slope that are designed to protect the land from excess runoff. Sediment being carried in the runoff may be deposited as the water passes along the drains.

Figure 4.11: Sediment in Furrow, Venezuela

How does it occur? As runoff slows down on entering the across-slope drain, the eroded materials being carried are deposited within the drain. The process is exactly the same as sedimentation in a riverbed where the velocity of the flow ceases to be sufficient to carry particles in suspension. The deposited sediment indicates the amount and type of material that has been eroded from the land above the drain.

Where does it occur? Sediment deposition occurs in most places were erosion occurs, as particles of soil dislodged are inevitably re-deposited elsewhere downslope – in this case in drains which act as sediment traps.

How can it be measured? The difference between the surface level of the drain before and after deposition represents the quantity of eroded material deposited from the drain's catchment area. The sediment in the drain can be measured by calculating the depth of the sediment, the width and length of the drain. By multiplying these three figures together the volume of soil deposited in the drain can be estimated. A number of measurements, at different points along the drain should be taken to obtain an average depth of sediment deposited and an average width of the drain.

Potential for Error:

1) Run-on to an area carries sediment. If deposited, this sediment is measured as if it had come from the drain's catchment area, thus resulting in a possible overstatement of the amount of soil loss.
2) Eroded material that is very fine (such as organic matter, clays and silts) may not be

deposited in the drain but be deposited further downstream. This eroded material is completely missed by these calculations. This means that the amount of erosion from a plot may be understated, particularly if the greatest soil loss occurs after a small number of large rainfall events/storms, rather than continuously throughout a season.

3) The type of eroded material is also unrepresentative of total soil loss – but see 'enrichment ratios' in section 4.12.

4) Eroded material in a drain can itself be picked up by runoff in the drain and carried further downstream. Thus measurements taken after a storm event might suggest less soil loss than measurements taken in the same place before the storm.

5) In-field erosion and deposition is disregarded. Therefore, provided the eroded material does not leave the plot and get deposited in the drain, it will not be included in this measurement of erosion.

Worked Example:

Because of the potentials for error noted above, sediment in drains will tend to give a very conservative estimate of soil loss from fields. Actual values of soil loss can be estimated by multiplying by an assumed enrichment ratio – but this is not shown in the example below.

EXAMPLE
FIELD FORM: SEDIMENT IN DRAIN

Site:

Date:

Measurement	*Depth of Sediment cm*	*Width of Drain cm*
1	2.6	30
2	2.9	28
3	2.6	30
4	2.7	30
5	3.0	28
6	2.7	27
7	3.2	30
8	3.0	28
9	2.8	30
10	2.8	30
11	2.8	30
12	3.0	29
13	3.0	28
14	2.5	27
15	2.9	28
16	2.7	29
17	2.7	29
18	3.2	30
19	3.6	30
20	3.3	29
Sum of all measurements	58.0	580.0
Average*	DEPTH = 2.9	WIDTH = 29.0
Length of drain: (m) 10		
Contributing (catchment) area to drain: (m^2) 50		

* Rem.: to get average divide the sum of all the measurements by the number of measurements made.

Calculations:

(1) Convert the average depth and width of the sediment in the drain to metres (by multiplying by 0.01). Thus, an average depth of 2.9cm is equal to 0.029m and an average horizontal width of 29cm is equivalent to 0.29m.

(2) Calculate the average cross-sectional area of the sediment in the drain.

WIDTH (m)	0.29	x	DEPTH (m)	0.029	= CROSS-SEC AREA	0.00841 m^2

(3) Calculate the volume of soil deposited in the drain, where the drain is 10 metres long.

CROSS-SEC AREA (m^2)	0.00841	x	LENGTH (m)	10.0	= VOLUME DEPOSITED	0.0841 m^3

(3) Convert the total volume to a volume per square metre of catchment.

VOLUME DEPOSITED (m^3)	0.0841	÷	CONTRIBUTING AREA (m^2)	50	= SOIL LOSS (m^3/m^2)	0.001682

(4) Convert the volume per square metre to tonnes per hectare.

SOIL LOSS (m^3/m^2)	0.001682	x	BULK DENSITY (t/m^3)	1.3	x	10,000	= SOIL LOSS (t/ha)	22

4.12 Enrichment Ratio

What is it? Enrichment is the process whereby soil erosion by water tends selectively to affect the finer, more fertile, fraction of the soil, leaving behind coarser, less fertile fractions in the field. Enrichment effectively means that soil material eroded furthest has the highest quality, while soil remaining in the field deteriorates faster because the remaining soil gets progressively less fertile. The enrichment ratio is, therefore, a measure of the proportional enrichment of eroded (and deposited, for example, in drains) materials when compared to the original soil from which they were eroded. It is normally assessed by measuring the quantity of nutrients found in the eroded sediment, compared to the quantity in the topsoil from the field which is being eroded. . However, for the purposes of 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.

The enrichment ratio is, therefore, unlike any of the previous measures of land degradation in that it does not give an absolute figure of soil loss. Instead, it assesses the potential seriousness of erosion in accelerating deterioration in soil quality – the higher the enrichment, the more fertility is being lost per unit quantity of erosion. In practice, the enrichment ratio may be used to convert previous field measures such as sediment in drains into absolute total losses of soil.

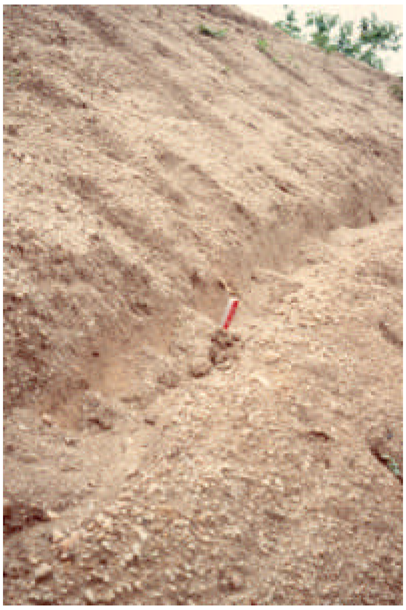


Figure 4.12: Sediment Fan, Sri Lanka

How does it occur? Wind and water erosion selectively remove the finer soil particles and lighter organic matter, both of which contain relatively higher levels of nutrients than mineral soils. Thus, when these soil particles are finally deposited lower down in the field, in drains, local reservoirs or eventually the sea, they enrich the location in which they settle. The removal of fines in this way is a natural process, apparent under natural vegetation.

Where does it occur? Enrichment of sediment occurs almost everywhere. The exact level of enrichment ratio varies from storm to storm, crop to crop, and according to prior history of erosion. Ratios tend to be highest on poorer soils and those with low clay contents. They are also highest at the beginning of the season and immediately after soil disturbance when there is abundance of fine particles at the surface.

How can it be measured? Measurement of the enrichment ratio requires comparison of the soil that has been enriched as a result of deposition with the soil from which the deposited material has been eroded. Equal quantities of soil should be taken from the eroded and the depositional locations. By visual observation in the palm of the hand, the proportion of coarse material to fine materials in each sample should be estimated. This should be repeated a number of times. 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. For example, a single intense storm on a newly-tilled soil can give an ER of 10:1, which is also simply described as 10.

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.
6) 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.

Worked example

EXAMPLE
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%

* Rem.: to get 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]

4.13 Soil Texture and Colour

What are they? Soil texture is the 'feel' of a soil, constituted by the relative proportions of different types and sizes of particle making up the soil. Soil colour is directly the 'look' of a soil, constituted by the overall hue (based on primary colours), chroma (the strength of the colour) and the degree of greyness (from black to white) of the soil. When soil degradation takes place, both the texture and colour change. These changes can provide opportunities for field assessment of the occurrence and degree of land degradation. Colour changes, especially in recently cultivated land, are often one of the first obvious indicators of land degradation.

How do they occur? Soil texture and colour are intrinsically functions of the parent material of the soil, as modified by organic material. Dark soils, rich in clays, come from basic rocks such as basalt. Light soils, poor in clays, come from acid rocks such as sandstone. Texture is dependent on the size and shape of particles and, therefore, on the mix of sand, silt and clay making up the soil. Soil texture is important for two reasons. First, particle size and shape influence the likelihood of loss through wind or water erosion. For example, the creation of an armour layer (see technique 4.4) results when wind or water action has removed the finer soil particles. Soil texture also affects the infiltration rate of water, which in turn influences the amount of surface runoff and the potential for removal of soil particles. In general, the larger the size of particles, the greater the spaces between them and so infiltration occurs more quickly, unless interrupted by other factors. Water stress is a common production constraint, especially in arid and semi-arid areas. Where the moisture holding capacity of the soil is reduced, or degraded, the incidence of moisture stress may be more frequent, or occur after lesser periods of dry weather.

How can soil texture be measured? The generally accepted dimensions of soil particles are set out below.

Description	*Size*	*Visibility (to naked eye)*
Sand	0.050-2.000 mm	Particles are visible
Silt	0.002-0.050 mm	Particles are barely visible
Clay	< 0.002 mm	Particles are not visible

There are standard field techniques for assessing texture, involving feeling the soil in the hand when moist – see any field manual such as that published by FAO. For land degradation assessment, it will usually be sufficient to categorise texture into:

- Sandy – sand size particles predominate; low intrinsic fertility; easy to degrade (sensitive); fine and medium sands susceptible to wind erosion
- Loamy – balanced proportions of sand, silt and clay, plus usually abundant organic matter; fertile; no major use limitations; difficult to degrade (insensitive)
- Clayey – dominated by clays (either active clays or highly weathered stable clays); susceptible to several degradation processes such as waterlogging; high intrinsic fertility; variable susceptibility to degradation.

Texture assessment should be accompanied by the implications for degradation as noted above but supplemented by field observations and the specific nature of the soil.

For land degradation assessment through texture, it is important to select the least degraded soil (from, say, a hedgerow, local forest, graveyard) and compare it with a degraded field soil. If water erosion has been prevalent, the loss of organic matter and selective removal of silt and clay will influence texture. Stones, varying from fragments of quartz to large pebbles, are also aspects of texture affected by degradation – see 'armour layer' and 'pedestals' for assessing these.

How can soil colour be measured? Munsell soil colour charts give a full description and code for soil colours. It is necessary to standardise the moisture level of the soil for the colour determination. In dry conditions the colour is best examined from naturally dry soil, but in humid conditions moist soil is far more practical. Where soils may be observed in either dry or moist form it is best to record both colours.

For land degradation assessment, it is again necessary to compare colours between undegraded and degraded conditions. Holding samples of the soil from the two conditions is an immediate indicator of soil degradation. The Munsell colour values give a semi-quantitative measure.

At a larger scale in-field, the occurrence of lighter patches in a field is often the result of topsoil loss and exhumation of subsurface, which is naturally sandier and lighter in colour. On terraces, lighter soil usually occurs on the upslope portion where soil has been removed and transported to the lower part of the terrace. On fields with no barriers, patches are more common, especially on slight rises, spur crests and upper slopes. Examination of large-scale air photos can supplement the field observations of these lighter patches.

Potential for Error:

(1) Precise assessments of soil texture can only be accomplished after laboratory analysis. If laboratory services are available, samples should be carefully collected. The results will then be useful not only to calculate selective loss of clays and organic matter, but also in determining enrichment ratio. Field assessments must be kept very broad, because it takes considerable experience to be able to assess, say, sand percentage to nearer than +/-10%.

(2) For both soil texture and soil colour, the baseline soil for comparison is crucial. Relatively undisturbed soil is to be preferred, but it is also useful to compare soils from adjacent fields with different histories of land use. Care needs to be taken that the soils are truly of the same intrinsic type: i.e. that they would have looked and felt exactly the same if land use had not occurred.

(3) Soil colour varies greatly with soil depth. Care needs to be exercised that only surface soil is used, so that differences in colour can then be ascribed to soil erosion.

4.14 Soil and Plant Rooting Depth

What is it? Soil depth is simply the vertical depth of soil from the surface down to weathered rock, or other impermeable barrier such as a stone-line or hardpan. Rooting depth describes the depth available to plant roots – for all practical purposes, it is the same as soil depth.

How does it occur? The depth of soil material above weathered rock is a product of climate, which determines the rate of chemical breakdown of rocks, and the type of rock. Some rocks break down more quickly than others. The specific depth at any one site is determined by the balance between natural forces of removal of topsoil (sometimes called geological erosion – occurs at a rate of less than 1 tonne/ha/year) and the formation of new soil in the subsurface. The faster the rate of weathering and the more susceptible the rocks are to breakdown, the deeper is the soil. Deep soils are not necessarily more fertile, because they may contain layers of highly weathered and nutrient-deficient clays.

Figure 4.14a: Plough Pan, Brazil

An impermeable layer induced by land use or agricultural practices is the other main way that soil depths and plant rooting depths may be reduced. It may be a result of ploughing when the soil is too wet, which results in a compacted layer below the plough blade, or it may form because of chemical compaction in and around stonelines. Formation of an impermeable layer is a direct land degradation process.

The rooting zone is the main supplier of nutrients and water for plants. If the rooting depth available to a plant is insufficient to allow that plant to put down sufficient roots the plant will exhibit less vigorous growth and crop yields are likely to be depressed. The depth of soil required by different plants varies, as does their ability to put down roots. For example, cotton roots cannot penetrate soil with a bulk density greater than 1.8 g/cm^3. Wheat requires 75 cm of soil depth, or else yields will fall.

Soil and plant rooting depth are, therefore, important indicators of erosion because they may directly affect production output, if depth is limiting. They are variables most often mentioned by farmers. Hence, they are important to assess, and then to relate to observations of plant growth – see Chapter 5.

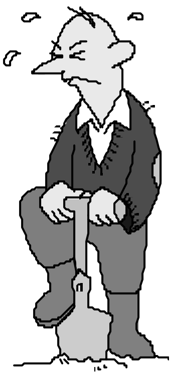
How can it be measured?

The rooting depth can be easily measured in a number of ways:

(1) Using a soil auger: taking a sample of the soil using an auger shows the different horizons that occur in a soil profile. It may be possible to identify any impediment to the rooting depth from a visual inspection of the soil core from an auger.

Figure 4.14b: Using a Soil Auger

(2) Digging a hole: By digging a hole in a farmer's field the whole soil profile can be identified. The depth of topsoil can then be measured down to a clear indicator of a condition that limits root penetration, such as a line of stones, a change in soil colour or a marked increase in clay content. The distribution of plant roots is also indicative of impermeable layers and the effective plant rooting depth. This method is disruptive, and not really appropriate in a field with growing crops. An alternative, or supplementary, approach is to use road or track cuttings. These often reveal the presence of barriers for roots.



(3) Using a stick or steel rod: By applying pressure to a stick/rod it will pass through layers of soil until it meets resistance that prevents the stick being pushed any further into the ground. This approach will not give an accurate measure of the topsoil depth as the pressure exerted each time the stick is pressed into the soil may not be the same, either as a person gets tired, or if different people undertake the exercise. However, the advantage of this method is that a large number of measurements can be taken, and conclusions reached about relative depths of topsoil in a field.

Box 4.5: Evidence of Hoe Pan in Malawi

A study in Malawi in 1999 identified the existence of hoe pan as an impediment to root development where crops are planted on ridges. Where these ridges are split and reformed each year the repeated impact and scraping of the hoe results in a compacted layer. The effects of people walking in the furrows between the ridges, for example during weeding, may exacerbate this compaction.

Evidence of this kind of problem can be obtained from examining plant roots. If roots are stunted and are forced to grow horizontally rather than vertically then further investigation may reveal the existence of a compacted layer beyond which roots cannot penetrate.

Figure 4.14c: Evidence of Stunted and Horizontal Root Growth in Acacia Mangium

In the case of crops planted on ridges in Malawi root depth was restricted to 15cm, being the depth of the ridge.

Source: Malcolm Douglas, Consultant, personal correspondence.

Potential for Error:

(1) Although shallow topsoil depth may imply that land degradation has taken place, unless the measured depths can be compared to previous measures on the same plot (or some other indicator of the topsoil depth – for example if a house with foundations was constructed, or someone buried or a well dug) or to similar plots that have been managed in a different way, it will be difficult to say with certainty how the shallowness can be explained. Some soils are shallower than others even before land degradation and in some cases barriers to the rooting depth occur naturally and not as a result of any degrading process.

(2) The effective plant rooting depth may be controlled by other factors, such as groundwater or very sandy layers with no nutrients. Therefore, visual inspection of depth should include observation of root distribution and possible reasons for lack of roots in any layer.