DESIRE REPORT series

Field measuring and monitoring methods for on-site effects of Soil and Water Conservations measures.

Draft version 1.0

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Foreword

This report is deliverable 4.2.1 of the EU integrated project DESIRE (contract 037046), under the 6th framework programme, sub-priority 1.1.6.3 - global change and ecosystems. DESIRE stands for "Desertification mitigation and remediation of land". In this project a series of Soil an Water conservation measures selected by stakeholders are tested and put in a context of desertification at 18 study sites around the world. One of the documents in the project is this report on monitoring and measurement strategies to give the project partners and stakeholders an overview of the many measurement methodologies that are available.

Note that this document has two phases. Phase one is a preliminary compilation of methods from literature and experience of the authors, which is this document. Phase 2 is an extension of this report by experiences gathered during the project planned over the next 2 years, whereby all partners are invited to comment, extend and criticize the contents. Since there are 26 institutes involved in DESIRE, a substantial improvement is expected. Moreover the document will be part of a Harmonized Information System, which means that its contents will be made available electronically, with various entry keys. The exact format is not known at this point.

Prof. Dr. Victor Jetten
ITC, The Netherlands
23 April 2008

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1 Introduction to DESIRE Work block 4

Stocking & Murnaghan (2002) state: "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."

The main objective of this work block is to test the effectiveness of the conservation and mitigation measures selected by the stakeholders in WB3. The effectiveness is to be tested against two goals: i) the expected results of the landowners, in general farmers, that have to implement the soil and water conservation measures, and ii) the effects on the environment and mitigation of desertification processes. These are not necessarily in line: stakeholders may first want to improve their situation and livelihood, for instance have a larger yield or yield security. They may be less concerned with long term soil erosion, or not even perceive that as a problem, and their investment in implementation of SWC should result in some tangible benefit. However, SWC measures can also work in synergy, for instance water harvesting techniques often work as obstruction against runoff and erosion, terracing provides more available area for agriculture.

Since most sites are covering a large area and are complex in terms of topographic relief, land use and soils, it will not be possible to monitor all combinations of Soil and Water Conservation measures, land use types and environmental setting. The feasibility depends on a combination of what the site coordinator can establish and the priority that is seen by the stakeholders. The strategy to test the effectiveness adopted in DESIRE is to compare in each site on a very detailed level location where SWC have been implemented with adjacent locations where they have not been implemented. This is a straightforward approach that can be adopted by almost all sites (one exception is discussed below). The advantages are that the results are on a scale and level that can be shown and explained directly to the stakeholders, the disadvantage is that the monitoring period is 3 growing seasons for most sites, which may be short in view of the erratic climatic circumstances that are normal in semi-arid areas. For instance if the monitoring years are very wet the SWC may seem to work because of a good harvest, while in fact the rainfall was imply sufficient. On the other hand if the years are very dry, they may not wok and may not be adopted by farmers. This implies that good meteorological records must be acquired or measured on every site, so that the DESIRE monitoring period can be put in a context of climate variation of each site. Based on the WB3 analysis, one or two conservation strategies will finally be chosen by the stakeholders, tested on 2 to 3 locations for the most important crops. The extent of the monitoring exercise depends also on practical considerations. Nevertheless we want to give an estimate of the consequences for the entire location, both as part of the final analysis in WB4, and in the upscaling of WB5. This extrapolation of results will be done using the results of the indictor analysis of WB2, in particular the land unit map that is created as a basis for the indicator method. Also the result of WB1, the WOCAT based expert assessment of the actual desertification situation will provide a good reference for site scale assessment of the SWC measures. The diagram below (figure 1.1) shows how work block 4 is embedded in the project and how it links to the other working blocks.

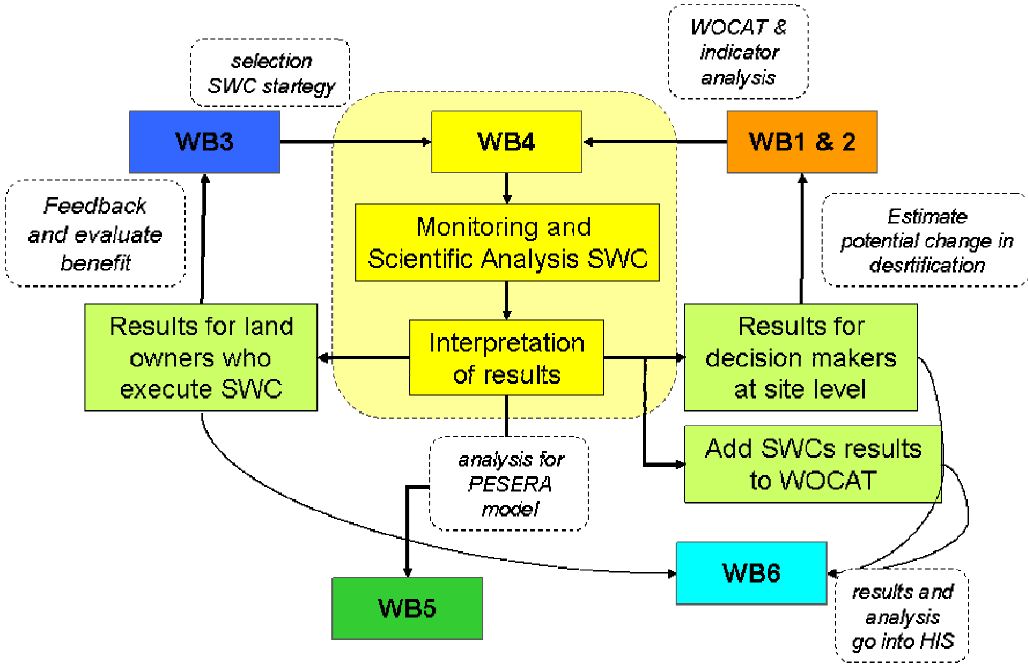


Figure 1.1. Embedding of WB4 and links to other Wbs: WB4 receives input from WB 1 & 2 (desertification analysis); from WB 3 (stakeholder selection of SWC) and the results go back to stakeholders (through WB3 established network); to WB5 (input for PESERA regional model analysis) and all results and analyses are delivered as input to the HIS in WB6.

1.1 Methodology

The strategy to test the effectiveness adopted in DESIRE is to compare in each site on a very detailed level locations where SWC have been implemented, with adjacent locations where they have not been implemented (see figure 1.2). This will be possible for one or two land use types (such as crops) on most sites and on two or three soil types (depending on the situation). It will not be possible to have a statistically significant sample size.

A large number of monitoring and measuring strategies are available, compiled in this document. Since the strategy is to compare plots, the measurements documented here are focused on plot or field scale monitoring.

The best strategy is to try to predict which desertification related processes are being affected by a SWC measure. Is it soil moisture, or sediment dynamics, soil structure, grassland carrying capacity (biomass) etc. This then should lead towards a monitoring or measuring method that is capable of detecting this process and be sensitive enough to record the changes affected by a SWC measure.

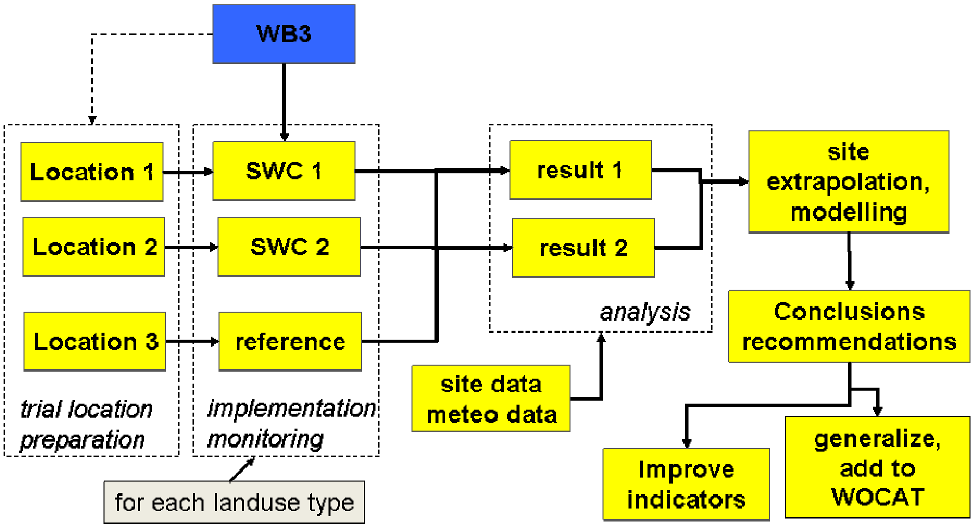


Figure 1.2. Monitoring strategy for each site, comparison of SCW plots with reference plots, analysis and potential implications for site

1.2 WOCAT and desertification processes

The WOCAT system provides a large number of Soil and Water Conservation methodologies, based mostly on farmers experience and standardized into 4 groups. In the table below an attempt is made to indicate which desertification related processes these measures attempt to change (Effect column) and how they can be monitored (Monitoring column). This table then aims to provide the links between the monitoring and measuring methods described in the rest of this report and the WOCAT strategies for soil and water conservation.

There are 3 criteria to assess the success of SWC measures:

1. **economic viability**. Factors to monitor and express the rate of success are crop yield, animal health and yield, monetary returns, labour investment. Investments can be single investments to install an SWC, or returning investments to maintain and renew it e.g. seasonally. Possibly a stakeholder has to invest in new equipment, chemicals, even training. Also other sources of income and opportunities are important, in how far is a stakeholder depending on this particular stretch of land, is it the main source of income? Market economy and subsidies are important.
2. **ecological sustainability.** Factors to monitor are bio-physical processes that are related to desertification, which covers a wide range of processes and variables: weather aspects, vegetation, soil hydrology and chemistry etc. These can be measured with various observation techniques and instruments and form the bulk of this report.
3. **social and cultural acceptance.** This is perhaps the most difficult to quantify or even name, because it often involves a break of old established patterns, and a recognition that to do things better (so called "good agricultural practices") a major change in thinking and activities is required. This also requires understanding and training, and an acceptance that stakeholders may have an influence on desertification both positive and negative. This varies a great deal, some farmers in the project recognize a responsibility and are willing to act (if they for instance receive help), others put all blame for desertification on climate change and world economy, and do not see that they themselves are causing part of the problem (for instance by excessive water use). The only way to monitor this is by interview and group sessions such as done in WB3 of the DESIRE project, which offer some insight in stakeholder perceptions.

It is the intention of this document to offer a large range of monitoring possibilities in these categories. As a result of WB3 the stakeholders in the areas select SWC measures. They rank a series of possible measures relevant to their area, and give their perception on the order of effectiveness and success (table 1.1).

Vegetative and agronomic			
Name	**Activity**	**Effect**	**Monitoring**
Mulching	Leave or apply plant residue/or leave stubble during fallow periods	Improves soil structure, Erosion: promotes infiltration, increases O.M. and soil strength, increases flow resistance Should improve also water content of the soil, decreases evaporation *Organic mulch may not be sufficiently available in semi arid areas and there may competition with fodder needs*	Field trials: Measure infiltration and soil strength at regular intervals, monitor erosion features (such as splash and rills). Monitor evolution of cover fraction by mulch.
Cover crop	Plant extra crop in fallow season	Cover during fallow, crop is ploughed into the soil as extra nutrient supply (and see mulch effects) *Climate may not permit additional growth season*	Field trials: Monitor cover (imagery, photo's, structured observations)
Grass cover	Change land use to grass on strategic places	Runoff prone slopes are covered in grass, prevents runoff and erosion, improves infiltration (but also more evaporation by grass). Straw could be used as fodder or mulch on other parts of the farm *Feasibility: land is taken out of production*	Field trials but has wider implications: farm planning, coordination between stakeholders. Needs (simple) spatial runoff analysis of an area.
Intercropping	Alternate different types of crops perpendicular to slope	Combine dense crops (wheat) with runoff prone crops like Maize (Sorghum), in bands of 10-20 m width, preferably following contour lines. Stop runoff, improve infiltration and resistance, improve strength. *High level of agricultural management needed.*	Field trials, farm plan. Compare with and without. Monitor with documentation (photo's, images). Width between crop types should depend on slope steepness.
Agro-forestry	Combine tree-like crops (perennials) with regular crops	Crops combined with orchards or some tree cover. Maintain cover, prevent fallow periods, splash erosion, improve soil strength and flow resistance, promote infiltration. *feasibility: perceived as water competition problem, which may be true. Different soil layers are used by different plants, nevertheless infiltrating water is first used by the seasonal crop, depending on infiltration characteristics.*	Field trials, monitoring with measurements of soil moisture, compare fields with and without double crops to compare if there is competition for water
Double sowing	Double sowing on strategic places (flow lines, valley floor)	Improve strength and resistance against flow without harvest loss. *Feasibility: simple and promising, decrease in yield in flowline because of sub-optimal plant density*	Field trials, compare with and without. Measure effects with easy flow tests. Needs simple catchment runoff analysis to determine strategic places.

Undergrowth	Orchard with grass	Prevent runoff and splash erosion from trees, improve soil strength and flow resistance, promote infiltration. *Feasibility: seen as competition for water, root system may not compete?*	Monitor soil moisture and runoff/erosion, look at rooting depth, monitor tree crop
Structural			
Name	**Activity**	**Effect**	**Monitoring**
Hedge rows	Plant permanent hedges	Along field border or contour lines as permanent obstacles to catch runoff and prevent erosion. *Feasibility: major investment and undertaking, land taken out of production. Competition for water and nutrients. However, hedges may consist of useful species (fodder, firewood etc)*	Compare with and without, or before and after. Monitor runoff, sedimentation.
Grass strips/grassed waterways	Grassed bands 5-10m wide, permanent	Following contour lines, bounding waterways or in strategic places to interrupt flow. Width and interval depends on slope steepness and position. *Feasibility: land taken out of production, may interrupt tillage practices and need to be well maintained.*	Compare with and without, catchment analysis needed to determine location. Monitor runoff, infiltration, sedimentation.
Trash-lines	Seasonal obstacles of branches/straw etc.	Usually as boundaries of fields or in strategic locations. Not clear what the effect is, may be washed away in large storm. Similar to hedgerows but temporary. *Feasibility: effectiveness?*	Compare with and without, catchment analysis needed to determine location. Monitor runoff, sedimentation
Small ponds (half moon dikes etc)	Small water collection structures around individual plants	Collect water and prevent runoff. Sometimes ponds have amore permanent character when lined with stones	Compare with and without, monitor moisture content, monitor rill activity etc.
V-shaped trenches	Plants wide apart and water collecting area in the middle	Space plant rows wide apart and guide water with shallow "fish bone" structure from middle of bare area to the sides where the plants are. Interrupt runoff and increase water harvesting. *Feasibility: balance between area needed and crop production*	Compare with and without, monitor moisture content, monitor rill activity etc. Flow tests
Car-tires	Line up car-tires filled with soil as barrier	Advantage: use of waste material (car-tyres), place in strategic locations	Needs catchment runoff analysis to determine best location

Table 1.1. A sample of WOCAT conservation measures, their intended effects and monitoring possibilities. Please note that the table is not yet complete in view of the many WOCAT measures.

1.3 Indicators

In the DESIRE project Workblock 2 is an indicator based assessment of the study areas, that is derived form the DIS4ME and MEDALUS systems. Many desertification indicators are similar to the factors described in this document. To repeat the indicator list here is not very helpful, the list is extensively described in the WB2 Indicator document compiled by the University of Athens (partner 9), and further information can be found in the "Manual on key indicators of desertification and mapping environmentally sensitive areas to desertification", MEDALUS project

(Kosmas et al., 1999). Some description out of this report are used. The report offers very practical information on the factors leading to desertification in the Mediterranean area.

There are many links between the indicator system and the monitoring and measuring methods compiled in this report. On the one hand they are sometimes the same, i.e. the variable that is measured is directly an indicator for desertification. Examples are plant cover, soil moisture, stoniness. On the other the indicators are sometimes classified or rated factors, which are given a weight of importance, and are derived from the variables described here.

In other words the indicator system is good to describe the general plot setting (relief, soils, landscape factors, climate etc.), it is sometimes good to monitor differences between plots with and without SWC measures, and sometimes they are not directly suitable for SWC impact monitoring but can be derived from measurements that are done. For instance there are long term climatic indicators that are necessary to describe the climatic setting, but these are not changing as a result of SWC measures (within the timespan of the project) and are therefore not considered for monitoring.

Table 1.2 below shows the indicator list used in WB2. Three levels of indicators are shown. Local indicators (L) can be used for the plot level monitoring in WB4 and means for assessing them are given in the various chapters in this manual. Local indicators on a general level (G) can be used to describe the plot and stakeholder situation and characteristics, but that will not change as a result of SWC measures applied on a plot level. They relate to chapters 2 and 3 in this manual.

	Local monitoring	Local general	Regional
Agriculture			
Farm ownership		G	
Farm size		G	
Land fragmentation		G	
Net farm income		G	
Parallel employment		G	
Cultivation			
Tillage operations	L		
Tillage depth	L		
Tillage direction	L		
Mechanization index	L		
Husbandry			
Grazing control	L		
Grazing intensity	L		
Land management			
Fire protection	L		
Sustainable farming		G	
Reclamation of affected areas		G	
Reclamation of mining areas		G	
Soil erosion control measures		G	
Soil water conservation measures		G	
Terracing (presence of)		G	
Land use			
Land abandonment		G	
Land use intensity		G	
Land use type		G	
Period of existing land use		G	
% urban area			R
Rate of change of urban area			R
Distance from seashore		G	
Water use			
Aquifer over exploitation			
Irrigation percentage of arable land			
Runoff water storage			
Water consumption by sector			
Water scarcity			
Tourism			
Tourism intensity			R
Tourism change			R
EU farm subsidies			R
Protected areas			R
Policy enforcement		G	

Table 1.2. Indicators from WB2 and the level of use in WB4

1.4 Local indigenous indicators

In WB3 the term local indicators is used in a different context: local indicators are those that are recognized by the stakeholders and can be monitored by the stakeholders. They are recognizable features that for the stakeholders represent indications of land dgradation, or alternatively, conservation.

It is extremely important that the good relations with the stakeholders that are built up during the first year of the project are maintained and that their role does not suddenly stop because WB4 is perceived as a "scientific" phase of SWC monitoring. The sense of project ownership that has been created until now must be continued by asking the stakeholder to help in the monitoring of the SWC measure. For that he local indicators of WB3 re a good means. Apart from that the stakeholders should keep rack of the efforts they hve put into the whole exercise and evaluate what they perceive as a success or failure. This is in part related to the socio-economic monitoring in chapter 3 of this manual.

Table 1.3 is a compilation of indictors that were collected during the WB3 workshops. Not all can be monitored at each site. Those that are relevant at each site (already gathered in WB3) should be used. The table here is an overview.

Local indicators selected by stakeholders	
Soils	Multiplication and increase of the rills in the fields
	Loss of colour of the soils and constitution of white spaces at the upper part of the fields
	Lost fertile surface soil in steep slopes
	Soil crusting and compaction
	Low fertility of the soils
	Increased salinization in upper and deeper layers
	Outcropping: increase in visibility of stoniness and parent material (rocks)
	Easiness of soil ploughing
Crops/vegetation	Reduction of the yield of some fields even during rainy years
	Loss in crop quality
	Stability of yield
	Decrease in income
	Drought stress in soils and crops
	Reduced vegetation and biodiversity in grazing land (decrease in the number of observed wild species)
	Increase in demand of fodder
	Insufficient feeding of animals
	Decrease in the number of animals
	Poor vegetation cover
	Incomplete decay of plant residues
	Slow growth of plants
	Early withering of plants
	Poor seed germination
	Halophytic vegetation
	Rapid growth of plants after the first rains
Erosion	Rill erosion

	Gully erosion
	Sediment movement and accumulation
	Observed wind blowing particularly during tillage period, unveiling of grains after heavy wind storms
Hydrology	Reduced discharge of groundwater and sources
	Groundwater overuse: necessity for lowering the pipe in drillhole
	Reduced and irregular rainfall
	High groundwater level
	Fast soil drying
	Pools on the soil surface after irrigation/rainfall
	Increase of overland flow on the soils (measured downstream)
	Flooding through stream

Table 1.3. Indicators from WB3 selected by stakeholders to be used in the monitoring process

2 General plot descriptions

Plot based research has the great advantage that they are good for demonstration purposes. They often have “human” scale to which stakeholders can relate. They are however not very suitable for extrapolation to larger areas. Many desertification processes are not only active at a given location, but there are many influences between upslope-downslope or upstream-downstream. Water, sediment and chemicals are moved in the landscape, and also vegetation dynamics has all kinds of spatial factors. Connectivity between sources and sinks in a landscape is known to be low in semi-arid landscapes, meaning that what happens on a slope is not always seen at the outlet of a catchment. In reverse, what is registered at the outlet or downstream is not a good indicator for the spatial variability of sources and sinks.

Moreover, and even more important, the stakeholders take decisions and are involved in activities based on a much wider framework then a field or a plot, or even a farm. There are economic drivers which are local, national or international, there are social considerations and psychological influences (general feeling of doing the right thing, experience).

2.1 Participatory impact monitoring

How good is the quality of the information obtained? If the budget for monitoring is low, not all methods can be highly accurate. Therefore, the principle of triangulation is used, which combines reliability with participation. This means that all individual perceptions which are obtained through interviews and discussions must be cross-checked with the perceptions of others and, if possible, compared with direct observations.

- Interviews and discussions with local stakeholders are the basis for impact monitoring. The information obtained can be very detailed but will be guided by individual perceptions and the different (often hidden) agendas of the stakeholders. Although all kinds of visible and invisible changes might be discussed, socio-economic aspects may dominate. A cross-check of the information, in particular invisible (e.g. social) changes, can be made through interviews with other stakeholders. Visible improvements or deteriorations can be cross-checked with photo-monitoring and participatory transect walks.
- Photo-monitoring provides an overview of visible changes in the project context, which may be predominantly related to biophysical and economic issues. But photos require interpretation and further investigation of the background. This can be done through interviews and discussions, as well as during participatory transect walks, depending on which aspects need further clarification.
- Observations made and discussed during a participatory transect walk provide a detailed view, especially of biophysical issues, although social and economic issues can also be addressed. A transect walk highlights the spatial interrelations of soil degradation and nutrient, water and energy flows, etc. Discussions often start with visible aspects but can ultimately include links with invisible aspects. A transect walk is an excellent opportunity to identify local impact indicators. The information can be cross-checked with interviews and photo-monitoring.

For more details regarding these three methods: see Herweg & Steiner (2002).

2.2 Description of the plot setting

It is very important that the general setting of the plot/fields are well described. This is the biophysical setting, with a combination of climate (long term), weather (short term), relief, soils, landuse and/or vegetation. The indicator report compiled by the Agricultural University of Athens (WB2 in the DESIRE project) offers a good framework for the description of the plots (see also DIS4ME -Desertification Indicator System for Mediterranean Europe, 2005).

2.3 General monitoring

It is advisable to make regular (2 weekly) photo's of the entire plot from a fixed position, which present a good viewpoint. This gives an impression of changes that take place and serves to document activities. Also if the reference plots can be photographed in a similar fashion, a visual comparison can be made. These photographs can be complemented with any type of comment necessary to understand what is going on (e.g. rainfall that occurred shortly before a photograph, or a tillage activity, crop disease etc.).

2.4 A note on sample size

Many monitoring activities will be execute as taking a number of samples or observations inside the plots/fields. Usually a number like 20 or 30 is mentioned as being statistically relevant. This section is meant to give a statistical background of where the number of 20 - 30 comes from. In practice the number of sample locations is determined by practical considerations: time, effort, laboratory analysis capacity etc. The following description is taken from Cammeraat et al. (2002). The size of a sample should be representative at the relevant process scale. The numbers of samples should suffice to reflect the variability and heterogeneity within each measurement unit. For an unknown population, the number of samples can be calculated using Student's t-distribution for which the standard deviation of the sample population is used to estimate the variance of the population (Ambroise & Viville, 1986):

$$N = \frac{t(a)^2}{\varepsilon^2} CV^2$$

Where N is the total number of samples, t(α) is the value of Student's t at the two-tailed significance level, α, and ε is the relative precision, which is the relative difference between the found mean and the true population mean. Values of Student's t are listed in Table 2.1. For a two-tailed test it is hypothetical whether the true mean is under- or overestimated and the relative precision can be specified as a fraction, e.g. 0.05.

α [-]	0.01	0.05	0.10	0.25
t(α) [-]	2.58	1.96	1.64	1.15

Table 2.1: Student's t for two-tailed significance levels α, infinite number of degrees of freedom

CV is the coefficient of variation, which is the sample standard deviation over the mean. Thus, it can be estimated if the results of a reasonable number of samples are known or literature values can be used (Table 2.2).

Property	CV	Property	CV	Property	CV
Particle density	0.03	Undrained cohesion	0.30	Plasticity index	0.10
Bulk density	0.10	Friction angle		UCS	0.40
Porosity/void ratio	0.25	Sand	0.10	Elasticity	0.30
Permeability	3.00	Clay	Wide variation 0.12 – 0.56		

Table 2.2. Recommended CV for some common soil properties (after Lee et al., 1982)

From the CV, the numbers of required samples can be calculated. It is recommended that during and after sampling, the minimum sample number is updated as more accurate values for the true CV become available. As a guideline, the required minimum number of samples is given for the two-tailed significance level of α= 0.05 at various levels of CV and ε (Table 2.3).

CV	0.05	0.1	0.15	0.25	0.5
0.25	97	25	11	4	1
0.5	385	97	43	16	4
0.75	865	217	97	35	9
1	1537	385	171	62	16
2	6147	1537	683	246	62

Table 2.3. Minimum number of samples at α= 0.05 ((t(α)= 1.96) for different CV values and relative precision ε

Note that still 62 samples are required to establish the mean at a relative precision of only 50% when the variation is large (standard deviation is double the mean). Obviously, this method only provides information on the reliability of the population mean and the standard deviation. For local predictions, spatial interpolation techniques should be used and predictions should be cross-validated with some with-held observations (McBratney & Webster, 1983).

3 Monitoring of socio-economic indicators

3.1 Focus-group discussions on feasibility and acceptability (source: CDE)

Socio-economic monitoring is mainly looking at the **feasibility** and **acceptability** of the applied conservation measure. In focus group discussions, ideally at the end of the implementation period you can discuss these issues with the stakeholders concerned. It will also help you to fill in the WOCAT questionnaires on technologies and approaches, as some of the aspects are covered there as well.

In focus-group discussions you may address the following issues and questions. It is very important that a good protocol is taken from such a discussion. Always ask specific questions, which do concern the respondents life, and not general conceptual questions

Work calendar_

- Has the work calendar changed due to the conservation measure?
- How is the distribution among the family members in relation to gender, age, etc and has it changed?
- Has labour increased or decreased

Social barriers

- How have neighbours reacted to the new measure? How could they react?
- What have they said or what could they say?

Such questions can help to identify the perception of the community, their acceptance and values.

Motivation

- What is the motivation to apply the conservation technology?
- Is it mainly productivity increase, or also social prestige, power, etc?
- Is it more important to get short term benefit, or are long-term benefits also considered? Are they planning for themselves mainly, or also taking into consideration the future land use of their children?

Rist and vulnerability

- Which are possible risks of the conservation technology?
- What is the vulnerability of it (e.g. regarding climatic extremes, variations in market prices, etc.)
- What is more important for the land user: to maximize profit taking into consideration a certain level or risk, or to minimize risks?
- Are there synergies with other activities (either within land use activities or even related to off-farm activities)

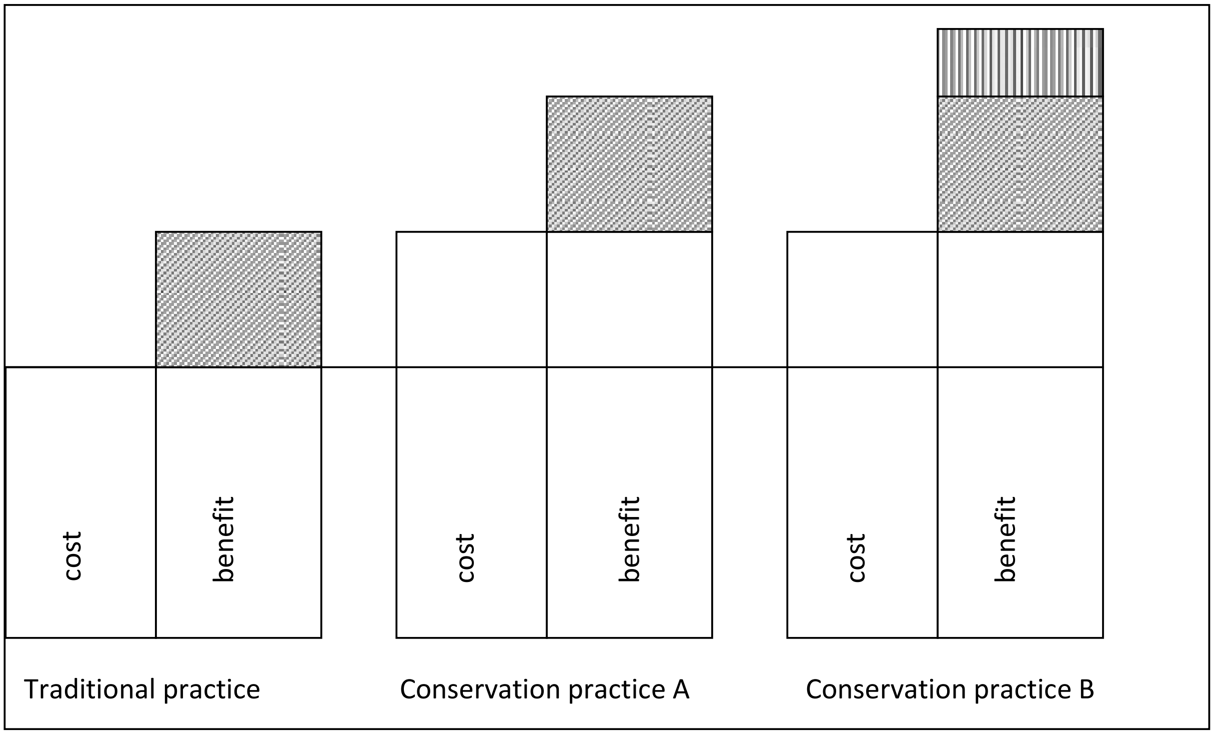
Wealth and other stratification

- Is this conservation measure applicable for poor households?
- For whom / which groups is it not applicable?

Education / level of technical knowledge

- What is the level of education of those applying the technology?
- What level of technical knowledge is required to implement the technology?
- Is any special (technical) knowledge required for the implementation?

Cost-benefit
The following graph can be drawn together with the stakeholders: Draw the cost-benefit ration for the current traditional practice and then for the conservation practice.



Interpretation: only if the net benefit of the conservation practice is really higher than the net benefit of the current practice, the conservation practice has a real added value. In case A above, there is no added value as the difference between costs (inputs) and benefits (output) is the same as with the traditional practice. High outputs are often perceived as higher benefits, although the higher input also needs to be considered. Conservation practice B has an added value, which is symbolized by the shaded box on top.

For further details on possible cost-benefit analyses see also below.

3.2 Production in cropland (source: LADA local assessment manual)

Most important concerns of land users on cropland are tied to some aspect of agricultural production: yields; difficulty in maintaining yields; weeds; stones on the surface making ploughing difficult. The land users' perspective is, therefore, most often articulated through how production is changing and the way in which plants, soil, water supplies and natural vegetation have improved or deteriorated.

Three tools are covered here:
Tool 8.1: Assessing crop yield
Tool 8.2: Assessing crop growth characteristics
Tool 8.3: Nutrient deficiencies as indicators

N.B. An additional tool for conducting an economic evaluation of LD and SLM is provided in **Annex 11 of the LADA manual**

3.2.1 Tool 8.1 Assessing crop yield

Crop yield is dependent, in part, on the underlying productivity of the soil. It is also affected by seed quality, climate, pests, crop diseases and management by the farmer.
Even if yields are increasing, land degradation may also be occurring, but its effects may be masked by the management practices adopted by the farmer, such as increased amounts of fertiliser. Indeed, this masking of land degradation by greater and greater use of inputs is considered by some to be the most serious consequence of land degradation indicating that future yields will crash when farmers are no longer able to afford the inputs

An historic comparison of yields can provide useful information about changes in production. By accessing records of past crop yields from farm records, local co-operatives, marketing boards or official government statistics, a good idea of medium to long term trends can be gained. Then putting those records alongside statistics on fertiliser use, introduction of new varieties and other production-enhancing factors, a qualitative view may be gained of how far land degradation may have impacted production. Often, however, farmers change their production and livelihood practices in response to land degradation. Any one or more of the following explanations and factors should also be considered:

- change in crop type to one more tolerant of degraded conditions: e.g. maize to millet; sorghum to cassava; or annual crops to perennials;
- extensify production onto more marginal hill slopes and poor soils: note that this tends to reduce average yields even faster, and cause further land degradation;
- intensify production on smaller areas by applying manures, irrigation or other inputs: note that this may well reduce overall land degradation;
- land users migrate to towns, or diversify sources of income into non-farm activities such as poaching, brewing; charcoal-making; or village industry: each of these, in turn, may have land degradation implications.

These coping and adaptation practices in response to land degradation are only amenable to descriptive and non-quantitative analysis. The field assessor will want quantitative measures of production constraints. In terms of changed yield, these can be obtained rapidly through participatory techniques directly in the field. Within-field differences in yield are often very significant – the farmer will be well aware of these differences, and the researcher may be able to relate the yield differences to land degradation variables such as soil depth. Root crops, such as carrots, sweet potatoes and beet, are especially amenable to this participatory technique. Farmers are also often happy to draw the size of their individual root crops onto paper. The researcher, then, may purchase an equivalent size of crop from the market, weigh it, and multiply by the number of plants in a fixed area to get accurate yield assessments.

Other practical yield assessment techniques that have been used in the field are listed in table 15 and should be considered for application in appropriate situations. A word of warning, however – information on yield will depend on human recall. The limitations of memory must be recognised – it provides a personal history and interpretation rather than factual evidence. Yet, it is the farmer-perspective that is vital to obtain, rather than absolute quantitative yield figures.

Field-based Yield Assessment	***Relevant situations and warnings***
Relative diameter of growing crops in relation to land degradation indicators, such as depth of topsoil, organic carbon content or slope.	This is useful for vegetables, planted on same date but in different parts of the field. Lettuces or cabbages have significantly different diameters according to soil quality – these measures are a good proxy for yield, especially if the farmer can show what size they are expected to reach at harvest.
Relative height of growing crops (as above).	Height is a good proxy of yield for other crops, such as maize. But note that height is very specific to crop variety, and so relative measures can only be used for the same variety.
Number of tillers on individual cereal plants, such as wheat, barley and oats.	For many cereals, the number of tillers is directly related to yield, because each tiller has a seed head. So, a count of tillers is a useful proxy for yield. Again, the farmer can help by indicating size of expected seed head.
Plant population per square metre.	Where germination is poor due to land degradation, plant population in degraded versus less degraded parts is a useful proxy. This has been used with cereals, especially where soil crusting by raindrop impact has affected germination.
Direct farmer assessments of bags of marketable yield per field from growing crop.	From experience farmers will usually be able to estimate the number of bags of crop yield. Comparison of farmers' estimates between fields is especially useful.

Table 3.1. Techniques for Assessing Yield

3.2.2 Tool 8.2 Assessing crop growth characteristics

Several of the yield assessments use crop growth as a proxy for yield. However, crop growth characteristics by themselves are one of the most common indicators of plant vigour described by farmers.

While it may seem that the cause of differential plant growth is self-evident, it is worthwhile taking some time to map the incidence of the differential growth, and then to plot the possible causation factors. The mapping of the growth is most easily achieved by dividing the field into a grid and recording the relative vigour of the plants in each square. In determining the reasons for differential growth, it is important to eliminate as many explanations as possible. A checklist of questions to help identify the reasons for differential crop growth might include the following:

Crop factors

- Are all the crops in the field the same variety? Very often land users will elect to plant a mix of high yielding (for sale) and lesser yielding (for home consumption and taste preference) varieties that will, nevertheless, produce some yield even if the growing season is particularly dry or wet, or particularly hot or cold.
- Were all the plants in the field sown or introduced at the same time?
- Are the row distances constant throughout the field, or are crops planted more densely in some parts of the field than others?
- Do plants in one part of the field show signs of pest infestation/consumption that are not on plants elsewhere in the field?
- Have animals been grazing along the field boundaries, resulting in reduced crop density and vigour?
- Has one part of the field had a different treatment applied to it?

Land degradation and conservation factors

- Are parts of the field more exposed to wind than the rest?
- Are parts of the field more sloping than others?
- Have conservation or tillage practices introduced in-field differences in soil depth or accumulations of fertile sediment?
- Are there accumulations of soil behind barriers, such as boundary walls and hedges? Has farming practice caused 'plough erosion': i.e. the progressive removal of soil downslope by hand or with the plough?
- Are any parts of the field inherently more fertile than others (e.g. old stream beds)?

Knowledge of the common characteristics of locally planted varieties is extremely useful in determining how a crop that is uniformly productive on a particular plot compares to the same crop planted elsewhere in the locality. Comparisons with fields of the same crop planted nearby may suggest that different management practices have been followed.

3.2.3 Tool 8.3 Nutrient deficiencies as indicators

Different crops require different levels of nutrition. This means that some species may be more susceptible to particular deficiencies than others. Land degradation can, therefore, affect some crops and leave others untouched. So, as with yields and crop growth characteristics, the effect of deficiencies of nutrients, resulting from land degradation, is both crop-specific and soil-specific. This is why local people may respond to nutrient deficiencies by applying fertilisers and manure or changing to a less demanding crop. These responses are themselves also good evidence of nutrient deficiencies, which can be gained from local people and their explanations as to why they have changed practice.

Nutrient deficiencies are caused by more than just removal in the processes of soil degradation. The principal cause (up to 100 kg N or more, in intensive cropping) comes from removal in harvested crops and insufficient replenishment through manures or fertiliser. Excess removal through harvesting, although unrelated to soil erosion, is still a factor of land degradation. Thus, in determining the cause of nutrient deficiencies, the field assessor must make careful judgement, tying field evidence with other aspects of farming practice and local knowledge.

Many commentators argue that visual symptoms are not sufficient indicators on which to base conclusions about nutrient deficiencies or toxicities. The main reasons why visual symptoms alone are insufficient for determining the existence of nutrient deficiencies and their link to land degradation are:

Different plants respond in different ways to nutrient deficiencies. For example, root crops demand over twice the levels of phosphorus than cereals or beans.

1) Deficiencies (or toxicities or other degradation factors) of different nutrients may exhibit the same visual symptom. For example, yellowing of bean leaves can be lack of nitrogen, waterlogging, or even salinity. In maize, the accumulation of purple, red and yellow pigments in the leaves may indicate N deficiency, an insufficient supply of P, low soil temperature or insect damage to the roots.
2) Disease, insect and herbicide damage may induce visual symptoms similar to those caused by micronutrient deficiencies. For example, in alfalfa it is easy to confuse leaf-hopper damage with evidence of Boron deficiency.

Notwithstanding these valid objections to the use of visual observations, their judicious use can provide valuable insights into the constraints in particular cropping systems.

<u>Indicative Conditions for Nutrient Deficiencies:</u> Certain soil types, or soil uses, may be more likely to display nutrient deficiencies than others. The combination of particular soil conditions with visual indicators of nutrient deficiencies makes the conclusions drawn from the latter more robust. In the following table some of the conditions that can lead to nutrient deficiencies and toxicities are noted. These are not the only situations in which deficiencies or toxicities may occur. Land management practices also have a significant impact on the potential for nutrient deficiencies/ abnormalities.

Some general and crop specific nutrient deficiency symptoms are given in two tables in Annex 10 of the LADA manual Experience is required for the reliable identification of nutrient deficiency symptoms in the field.

3.3 Household level livelihoods analysis (source: LADA local assessment manual)

3.3.1 Background

Socio-economic data collection exercises risk being very open-ended, unstructured or unfocussed - these problems can be avoided by establishing this clear focus at the beginning of the assessment: what are the questions we would like answered and/or what behaviour would we like explained?

Some examples of the broad questions that are likely to be relevant in most of the DESIRE study sites are given below.

- Who is practising/benefiting from sustainable land management (SLM) and who isn't (wealthy/poor, men/women?) and why? **N.B.** it is common to find a very patchy engagement with SWC in communities and one objective of this part of the assessment is to find out why this is.
- How does LD/engagement in SLM (prevention and restoration) relate to specific livelihood features and strategies (risk aversion, market orientation, diversification, etc.)
- What are the important socio-economic and institutional and policy drivers for LD, SLM and dryland development (e.g. population pressure, tenure security, effectiveness and fairness of local governance, markets/market access, infrastructure, national/regional policy).
- How does policy affect land degradation and facilitate or hinder engagement in LD control/ SLM?
- What roles do social, financial and other forms of capital play at the local level in influencing perspectives on land and its management..
- What are the important trade-offs land-users make between the different assets to which they have access and how do these affect land management?
- What is the history of the area, have there been any major changes that have affected land degradation (e.g. a major population change (migration in or out), change of enterprise such as from cattle to sheep production with impact on grazing lands).

The aim is not to pose these questions directly to the land-user but attempt to answer them with the livelihoods analysis. There may be additional questions to add to this list in specific contexts.

N.B. It is vital to give these questions some thought before embarking on the assessment as they will provide a structure for the analysis and presentation of the livelihoods results. If we are unclear on the questions we really expect the livelihoods tool to answer then the data collection analysis and reporting will suffer.

3.3.2 Sample

This analysis should be carried out with the 20+ households responsible for managing the land subjected to the detailed bio-physical assessments.

Tool 9.1: a semi-structured interview guided by a checklist of issues/questions around which there will be discussion. This check-list has been drawn from UEA/FAO materials on livelihoods approaches (e.g. Carloni, 2005, Ellis, 2000) and the interview should aim to provide answers to the broad questions raised in above (section 9.1).

Tool 9.2: The results from the household livelihoods interview (tool 9.1) should be disaggregated as far as possible by wealth using the information on different wealth categories collected during the community focus group discussion (tool 4.1)

3.3.3 Tool 9.1 Household livelihoods interview

Objectives
To capture livelihoods-related information that will improve the understanding of the role socio-economic and institutional factors play in affecting the ways in which people view and manage their land resources.

Expected outputs
For each community the results from the interviews will be included together in a "livelihoods" analysis section. More detail on this is given in the next section but there will be two broad types of data collected in these interviews. The first type is descriptive information on household characteristics, asset ownership & access, relevant institutional influences on land-user livelihoods, activities etc. The second type is more explanatory information (mostly around land resources management and degradation) to be used in answering the key "livelihoods" related questions the DESIRE team feel are relevant in the assessment area (see discussion above in section 9.1). The interviewers must be familiar with these questions when conducting the interviews.

Detail of the expected analytical/written outputs from the livelihoods interviews are given in sections 9.4 and 10.

Participants
Household head on his/her own or with other household members (depending on who is around/available). It would be too demanding to try to conduct separate interviews with different household members.

An experienced facilitator to guide the discussion and a recorder from the DESIRE team

Materials/preparations required
Check list to guide interview, recording materials.

Check-list of questions

Natural capital and land degradation *It will usually be necessary to ask separately about soil, vegetation and water resources as the term "land" is likely to be interpreted by land-users as soil.*

- **Activities:** What is the seasonal calendar of different activities that household members are engaged in? (construct a time line identifying what they do by month associated with rainfall)
- **Water resources:** What are the main water uses (for drinking, livestock, irrigation) and sources (pipe, reservoir, water point, spring, well, borehole, dam)? What are the main constraints and problems linked to water resources (distances, prices, safety)? What changes have occurred in uses, quality and access to over the last 10 years?
- **Land resources:** How many hectares of farm land do they have? Does the household own them? If not then on what basis is it being used? (ownership, rental, share arrangement, open-access). Has this (ownership) situation changed in the last 10 years?
- **Cropping:** What do they grow?
- **Livestock:** How many livestock do the household own (by type: cattle, sheep, goats)? Have livestock numbers increased in the last 10 years?
- **Grazing land:** Does the household own its grazing land(s)? If not then on what basis is it being used? (ownership, rental, share arrangement, open-access). How far is it from the home? Has this (ownership) situation changed in the last 10 years?
- **Vegetation resources:** For what activities does the household use the vegetation and forest resources? Do they use wood for fuel? What are the main constraints and problems with vegetation resources (access, use, quality etc)? Has any of this changed in the last 10 years?
- **General changes in activities and practices:** Has the land-user made changes in his/her cultivation practices over the last 10 years?
- **Land degradation:** Is there degradation on the land (soil loss, gully, diminution of vegetation in the grazing lands, loss of fertility)? Which type?

Financial capital and production (this area may be sensitive)
- **Household income:** How does the household earn cash? (crop and/or livestock sales, remittances, fishing, forest products, off farm activities, business, processing food like honey)?
- How much does the household rely on each one (importance of each)? Have there been significant changes in household income in the last 10 years?
- What is the income used for (main things)?
- Are the yields decreasing, constant or increasing over the last 10 years?
- Has the use of fertilisers changed over the last 10 years?
- Are they using subsidies, micro-credit, cooperative bank or borrowing money from relatives? If yes, why and when? Any changes in the last 10 years?

Vulnerability context
- What crises has the household have faced (drought, food insecurity, crop failure, natural disaster, disease, civil unrest, forced migration, legal problems, indebtedness, etc.) and how have these affected the way they use soil, water, vegetation and forest resources?
- Which months are the most difficult in access to food, grazing, fodder and/or water?
- What have changes in the landscape and living conditions over the last 10 years (trends in livelihoods)?
- In his/her opinion, what are the main problems in the area? What things would they like to change or improve?

Physical capital

- How is access to markets and service infrastructure (health centre, school, farming cooperative, water points) in terms of road networks and distances? Has there been any change in the last 10 years?
- What useful infrastructure do they not have access to and why?
- Does the household have access to vehicles (including farming equipment)? What are the terms of access: ownership, hire, sharing, etc. Have there been any recent changes in this situation?

Policies, institutions and processes

- Who controls or makes decisions about how to use or access communal natural resources (water, grazing lands, forest)? Has there been any change in the last 10 years?
- Are there any laws, rules and regulations (formal and informal) that affect how the household manages its land resources? Has this changed in the last 10 years?

Social capital

- Do any household members belong to a local association, committee, producer association, women's group, NGO, or any social group? Since when?
- What are the benefits of being part of the group(s)?

Human capital and household composition

- What is the educational level of the household head? Has he/she received any training?
- Number of household members? Children? Migrants?
- Age of the household head?

Ask the "why" questions not just the "what" questions. There is a danger sometimes that further questions stop when the person conducting the assessment has discovered what is happening. In good livelihoods research the what question needs to be followed by the why question as this reveals the rationale of the land-user and their perspective on land resources.

It is important that the notes are written up as soon as possible after the interview, the same or the next day if possible.

3.3.4 Tool 9.3 Key informant interviews

Results emerging from the livelihoods interviews, the community discussions and other parts of the assessment should be used by the team to cross-check or discuss further with specific individuals. For example it will be useful at some point to discuss aspects of land resource support and governance with local (community or district level) leaders and officials from land and forestry offices. These individuals may confirm observations or claims made by land-users or perhaps offer plausible explanations for particular observations or behaviour. The team should decide and agree on the local resource persons/informants who should be interviewed through semi-structured interviews during the course of the assessment.

3.3.5 9.4 Analysis of the livelihoods data

This section contains guidance for the analysis and presentation of information from the livelihoods interviews. Where useful it uses material from the TOT in Beja, Tunisia as an illustration.

3.3.6 9.4.1 Using wealth characteristics to disaggregate livelihoods data

Wealth is a major determinant of land-user behaviour with regard to land resources management. Thus the analysis should begin by using the wealth-ranking tool (tool 4.1.B) to disaggregate the household sample by wealth. The value of doing this is two-fold. First it helps identify the often quite marked differences that exist in drivers and impacts for different groups of people (e.g. a particular LD problem might be associated largely with poorer people or with recent immigrants). Second it helps with extrapolation: if at a particular site, LD/SLM is associated with a specific socio-economic group then it is quite likely that this association occurs in other areas and at other scales.

N.B. Question xvii) in the focus group discussion (tool 4.1) should have identified other strong socio-economic attributes such as **ethnic group**, **religion**, **time of settlement** (e.g. recent migrants versus long-established residents), **life-style** (e.g. pastoralists versus those preferring settled arable agriculture), etc. Where these distinctions are strong then it may make more sense to disaggregate the sample by one or more of these other factors rather than, or in addition, to wealth.

A structure for the analysis and presentation of the data from the livelihoods component is suggested here:

i) The first task is to describe the sample and from it infer the characteristics of the community. Summarise assets under the main categories identifying those that appear to be key. The key assets will be a combination of those that define wealth together with those that influence (enable or constrain) the ability of people to do what they want to do. We know some that usually figure in this list (money, land, credit, labour, education, health, access to markets on reasonable terms) but there will be others. Identify the main differences in asset profile between the different wealth groups (or other important social grouping). Consider using asset pentagons (see below) to represent asset profiles for different groups and key differences between groups.

ii) Identify and summarise the key policies, rules, customs etc. that influence land-user's management of land resources. Look for differences between wealth groups.

iii) Summarise the main activities and strategies apparent in the sample. Again there may be differences in both of these according to wealth.

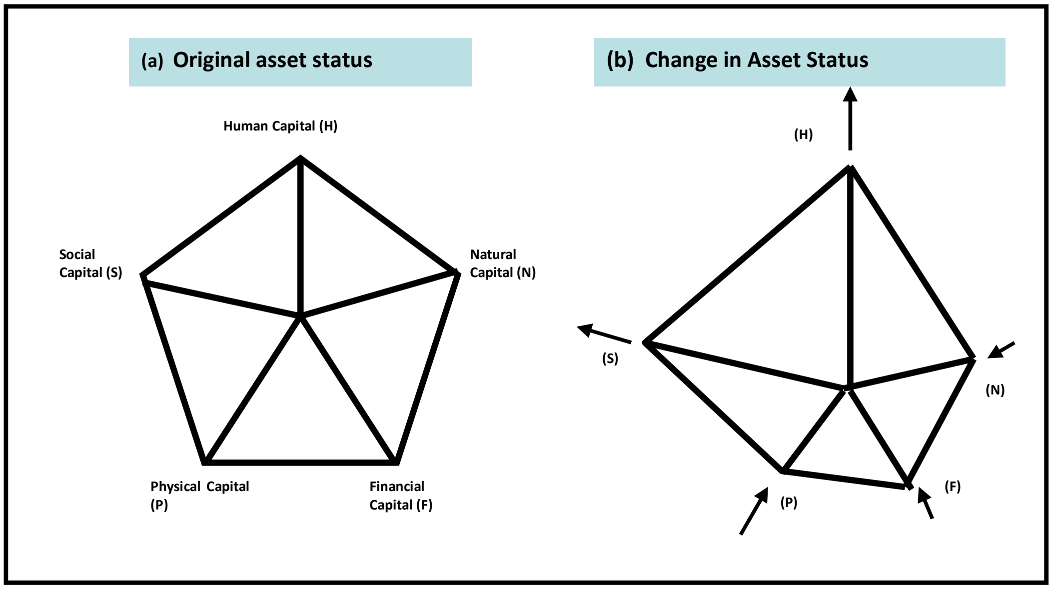
iv) Summarise the information obtained from part II of the livelihoods interview, again looking for patterns in the responses associated with wealth or other significant attributes.

v) Try to identify some of the main trade-offs land-users are making and consider representing these in asset pentagons (see below).

3.3.7 9.4.2 Asset pentagons

Asset pentagons (easily constructed in MS Excel) are a useful way of representing differences in assets between land-users or groups within the same community (or between communities). They can also graphically represent the trade-offs that land-users frequently make in the management of their resources. Figure 22 represents just such a set of trade-offs made by a land-user. This example depicts an individual or a household who has, over a period of time, drawn down his/her natural, physical and financial capital in order to accumulate social (perhaps to pay for a wedding) and human capital (perhaps to send a child to school or pay health-care costs). Looked at in isolation the reduction in natural capital might appear very negatively but the gains in social standing, health or education might more than compensate this and be part of a very logical strategy. Pentagons can be used to display all of the different capital assets as in Fig 22 or just the different assets within a single category (e.g. all the human assets) or just a range of specific key assets. Care is needed, when using and interpreting these pentagons as at best they can only ever be semi-quantitative and typically a number of assumptions and approximations are built into them.

Figure 22. Asset tradeoffs as part of a livelihoods strategy.



Either a descriptive or a semi-quantitative approach can be taken when constructing the pentagons

Descriptive approach
There are 5 axes in the pentagon representing the five asset classes. Assets are ranked, from 0-5 or 0-10 and these rank values are depicted on the pentagon.

Ranking is best carried out by a small group (3-4) of people involved in the field-work, data collection and analysis. Alternatively it could be conducted by one or more key informants from the community.

The group should look at the information on the different asset classes for each socio-economic group and reach consensus on how to consolidate the information into a score for each asset class for each group. These scores are then used to construct the pentagons. An explanation of how the scores were produced should be written down. This will be very important if the information is to be used as a baseline for future monitoring.

This approach is easiest but quite subjective. It is useful for comparing asset profiles between groups or locations etc. as long as the same group is carrying out the ranking in all cases. It is less useful for making valid comparisons at different points in time or between assessment areas where different groups have carried out the rankings.

Semi-quantitative approach
In many cases there will be some quantitative information available on some assets e.g. income, land area, head of cattle, mean number of years schooling etc. and this can be adjusted to fit to a scale (1-10 or 1-100) that can be used to represent assets. It is easiest where there is a single asset within a class accepted as the most important or the most

appropriate indicator. Where there are two or more it is best to select just one of these as an indicator rather than try to combine very different things into a single value (e.g. it is difficult to combine cattle and land to give a single numerical value for natural capital). Social capital is the most difficult class to quantify and may have to be left out or scored as in the descriptive approach above.

As long as the basis of the quantification is clearly recorded this method can be used to compare across different areas and over time as it is less reliant on individual or group judgment.

Concentrating on key assets rather than the five classes
Rather than stick rigidly to the five asset classes in the pentagons it may be more useful in some cases to identify five key quantifiable assets indicative of livelihood success or resilience. These would vary from community to community but would typically include (for a household) some of the following: number of residents, area owned, education level, income, number of cattle. These can be "scaled" in the same way as outlined above and represented in a pentagon.

The information on assets allows us to identify important socio-economic differences between groups and the link between these and land management.

3.4 Farm management

Soil and water conservation measures are implemented by stakeholders. They may be farmers or have a different relation to the land, but there is a sense of ownership or tenancy of the land. There are however many factors to consider, which go beyond a simple cost-benefit analysis. This chapter lists a series of factors to consider and their description. These description are taken directly from Stocking & Murnaghan (2004), "land degradation – guidelines for field assessment". When the analysis of WB1 and WB3 are done and more is known about the stakeholders, a more practical means of monitoring/assessing these factors will be proposed.

Note that the indicator system proposed in WB2 also offers a large set of descriptions to assess farming practices, cultivation practices, animal husbandry etc that are suitable to describe the stakeholder's situation. These are not repeated here but should be consulted.

Land tenure
Security of land tenure affects farmers' willingness to invest resources in land improvement and protection against degradation. Insecurity of land tenure shortens the time-frame used by farmers for decision-making, making it less likely that measures which protect against land degradation will achieve a return in the planning horizon of the land user. Where the occupier of land is unsure of the future, extraction (or 'soil mining') will occur to ensure that these resources are not lost to the individual. A farmer with clear title to the land is more likely to consider investment of money, labour and land in conservation because benefits in production which may only accrue after many years will still be retained by the individual who implemented the measures.

Common property resources are especially vulnerable to land degradation. However, the field assessor needs to distinguish carefully between 'open access' where land users have virtually free rein to use whatever resources they can grab, and 'common pool' resources where access is controlled. Common pool resources are much the more prevalent, and local societies' means of controlling land degrading activities on these resources should be assessed. A good example is the *ngitili* of northern Tanzania, which are dry season grazing reserves held commonly by the local elders on behalf of the village community. All in the village have access to these, but this is carefully controlled to avoid the resource becoming overused, or one individual grabbing an excess share of the limited grazing.
According to the EUROSTAT CODE the utilised agricultural area can be classified as following:
(a) owner – farmed, agricultural land being farmed by the holding which is the property of the holder or farmed by him as usufructuary or inheritable long-term lease holder or under some other equivalent type of tenure;
(b) tenant – farmed, land rented by the holding in return for a fixed rent agreed in advance (in cash, kind or otherwise), and for which there is a (written or oral) tenancy agreement;
(c) shared- farmed, land (which may constitute a complete holding) farmed in partnership by the landlord and the sharecropper under a written or oral share-farming contract. The output (either economic or physical) of the share cropped area is shared between two parties on an agreed basis;
(d) state farm, and
(e) other modes. Other modes of tenure not covered elsewhere. This includes inter alia land over which the holder enjoys rights.

Poverty

Poverty affects how land users manage their land. It reduces the options available, ruling out some conservative practices because they require too much investment of land, labour or capital. Similarly, poverty tends to encourage farmers to focus on immediate needs rather than on those whose benefits may materialise only in the long term. This is not to say that poor farmers are land degraders, while the rich are conservers. Several studies have shown exactly the opposite. In Ethiopia, for instance, some poor farmers have been reported to invest more in their land than the rich, probably because they are almost wholly dependent on their land. The foreclosing of expensive land use options may make the poor develop and apply simple but very effective technologies such as trashlines, earth mounds and ridges, or intercrops. Poverty may also induce rural people to abandon farming and migrate to towns, with a consequent benefit to the land. What the poor cannot do is expend huge effort in digging bench terraces or hiring bulldozers. These measures, available only to the rich, may be effective in controlling land degradation, but they need continual maintenance and commitment by the land user – obligations which the rich may not be prepared to undertake – if they are not to fall into disrepair and induce further land degradation. Poverty is, therefore, a somewhat ambivalent factor, that needs careful analysis and interpretation in its effect on land degradation.

Pressure on the Land

A growing population, for example, puts greater demands on the land. Farms are split into ever-smaller units as land is shared out amongst family members. Land shortage acts as an incentive for land users to push the boundaries of cultivation into more marginal areas, less suited to continuous use. Increasing numbers of people require more food, more water, more fuelwood and more construction materials, all of which must be sourced from the environment. An indirect effect of land pressure is the requirement for more extensive infrastructure. More roads, more transport, more housing and more utilities all have the potential to lead to increased land degradation. However, as with poverty, the evidence for a direct link between increasing populations and degradation is ambivalent. Indeed, several studies have shown how populations may adapt to new circumstances through developing new technologies and adjusting old. In some places, where markets and rural infrastructure have allowed, increased population density appears to have been the spur to sustainable intensification. Extensive land degrading practices such as fuelwood extraction and large herds of livestock have given way to intensive, well-managed small farms, employing manuring, composting, agroforestry and other beneficial practices. So, care is needed before making specific judgements about the effects of population on land degradation – but the issue must still be addressed.

Labour availability

Labour is normally the most limiting constraint of smallholder farmers. Competition for available labour is especially intense between laborious activities such as constructing terraces and off-farm employment that can bring immediate returns. The prevention of land degradation involves the investment of labour, both at the initial stages and on an ongoing basis for maintenance. Land users often overcome labour (and other capital) shortages by implementing conservation measures gradually, spreading the work over several seasons or years. Indirectly, the investment of family and hired labour is crucial to land degradation in enabling more intensive (and generally more conservative) production systems to be undertaken. Gender divisions of labour are also important: practices such as land preparation, tillage and weeding are normally assigned to one gender. If that gender has limited labour available at the right time, then there may be implications for land degradation which need to be noted.

In a situation where labour is already a scarce resource, it may not be possible to supply the additional labour required to avoid degrading activities or to undertake conservation. Migration to urban centers is a common feature of rural communities in developing countries. Whilst this may reduce the immediate pressure in terms of the numbers to be supported from a single smallholding, the loss to labour may increase the risk of degradation.

Economic incentives

There are a number of ways in which the markets may affect a land-user's decision about degrading or conserving farming practices.

- Price structures for agricultural produce often favour the urban purchaser over the rural vendor. As a result it may not be possible for a land user to recover the costs of more expensive non-degrading production methods in the selling price achieved for produce.
- Alternatively, quick profits may be possible by maximising production in the short term. The effects of potentially degrading activities may be ignored or, where additional inputs such as fertilisers are used, masked.
- High risk may attach to agricultural production due to market volatility or political instability. Land users may be less prepared to invest in the land where the potential returns are uncertain.
- Economic instruments such as subsidies and other incentives distort farmers' priorities. Conservation measures in many countries attract direct financial inducements based

upon measurable values, such as meters of terrace or number of trees planted. Such distortions often carry through to the withdrawal of subsidies, when farmers are no longer prepared to practice conservation without payment – a situation that is now common in South Asia, leading to considerable worries about the effects on land degradation.

Appropriateness of technology

Technologies developed on research stations may prove to be inappropriate when introduced to land users since research plots rarely mirror the actual conditions pertaining to smallholdings. For example, techniques may take too much land out of production, need too much labour to construct or maintain them, or compete with crops for water or nutrients. Where land users have had previous negative experiences with conservation technologies, they are likely to be reluctant to adopt new conservation plans. Similarly, where previous conservation attempts have been ineffective either through poor design and inadequate extension or poor execution and maintenance, land users may be unwilling to invest time, effort and space in new technologies.

Economic and financial returns

Most decisions made by land users are based upon economic rationality as perceived by the land user. Such rationality controls the willingness to invest in any practice, especially in demanding measures needed for land degradation control. Where a farmer's individual cost:benefit assessment concludes that the benefits of a prevention/ conservation course of action do not outweigh the costs, then the rational decision for that farmer is not to undertake the works. Where insecure tenure is also a factor, the anticipated benefits are reduced by the short-term time horizon of the land user. Field assessment is usefully supplemented by relatively simple cost:benefit analysis techniques, such as discounted cash flow analysis. With farmer participation, the financial worth of investing labour, land or capital in any land improvement may easily be assessed, using a criterion such as Net Present Value, Internal Rate of Return, or returns to land/labour/capital.

Off-site versus on-site costs

Costs and benefits incurred on-site (the farmer's field, for instance) are private or personal to that land user. Costs incurred, say, as a result of sedimentation into dams and rivers off-site are a consideration for society. Few land users will be prepared to invest private resources solely for the benefit of society, unless society supports such activities through subsidies (see 'economic incentives' above). Where the land user does not bear the full costs of land degradation, the incentive to take action to reduce land degradation may be insufficient for the land user to change practices or adopt new technologies. Costs that are incurred downstream of a land user's plot are unlikely to be incorporated in land use decisions. The field assessor needs to note *where* the land user's activities are having an effect – on-site or off-site – and *who* is being affected.

Power and Social Status

Some components of production are driven by a need to preserve social standing or to enhance prestige. In some cultures weddings and funerals are associated with an elaborate show of wealth. To pay for this, farmers may overuse their land. Common in pastoralist communities is the association of herd size with wealth and social standing. This association is one of the reasons why herders deliberately keep as many animals as possible, despite their impact on rangelands. The field assessor needs to be aware of cultural traditions in so far as they affect land use decisions.

These factors are not mutually exclusive. They may be cumulative and interactive. They all need attention as part of the diagnosis of why and how land degradation is occurring or not occurring.

3.5 Cost-benefit analysis

The identification and ranking of the risks of land degradation forms the data for further analysis. It enables farmers to estimate the costs and benefits of measures and techniques that will reduce or eliminate land degradation, and to compare these with the costs and benefits of doing nothing. This kind of assessment, known as cost-benefit analysis, underlies the process of making decisions about investment in land and farming activities in both smallholder and commercial agriculture. Whether or not to invest in a capital or labour intensive activity will depend on the perceived benefit of it to the person making the investment. This latter point is important – while economics enables us to carry out simulated cost-benefit analysis for decision-making purposes, ultimately the analysis is subjective relying on the values attached to specific costs and benefits by individual land users. Consequently, two farmers living side by side, with similar farms in terms of area, topography and fertility may make widely different decisions about land management issues, be it the crop to be planted, the fertility treatment to be undertaken or physical conservation measures to be dug. This subjectivity reflects the circumstances of the individual land user.

Cost-benefit analysis must not be seen as a prescriptive tool. It cannot be applied mechanically to arrive at a single 'right answer'. Capturing the costs and benefits that are important to the individual is the best way of getting close to the 'right answer' for that farmer.

These *Guidelines* will not deal with cost-benefit analysis in detail – it is really an extension of field assessment and a way of using data to gain a view of the likelihood of farmer's decisions on whether to invest. However, it is important that the field assessor gains the information about the important variables for undertaking cost-benefit analysis, so that the analysis can be accomplished later using any one of the many manuals that describe how to do it. The variables of greatest importance for a farmer-perspective cost-benefit analysis are:

- **Costs**: these must reflect the real costs to the farmer of undertaking any protection measure against land degradation. The largest cost is usually labour, and the field assessor needs to get a good view of what other activities the farmer cannot undertake in order to accomplish the conservation (this is the opportunity cost of labour). Similarly, there are costs in land and capital, which must be realistically assessed. The input of farmers is vital in making these assessments.
- **Benefits**: these must also reflect the real benefits to farmers. There are direct benefits such as increased yields; but the indirect benefits can be larger. For example, reduction in weeding because of a good cover crop, or reduced ploughing costs because of better soil structure, are legitimate ways in which reduction in land degradation brings benefits to land users.

Type of Benefit	*Examples (two of each only)*
Immediate production	• increased yield through better water conservation • less need for fertilizer because of better soils
Future production	• less risk of crop failures because of better soil quality • diversifying into higher-value crops now possible on better soils
Factors of production – land, labour, capital	• increased value of the land • reduced labour needed for weeding because of better plant cover
Farming practices	• easier access onto land along terraces • stonelines a useful place to put stones and to dry weeds for composting
By-products	• poles from conservation hedgerows sold for fuelwood • grass strip vegetation cut and carried for dairy cows
Farm household	• fuelwood available from farm means less time spent walking to forest for wood • better-fed cows now give milk all year, and children are healthier
Indirect, including economic and aesthetic	• greater sales of farm produce enable investment in home industry to add value to produce (e.g. sweet-making) • more wildlife attracted to farm

4 Meteorological measurements

Meteorological measurements are important as they re the most important driver for desertification processes. Measuring rainfall and evapotranspiration continuously during the years of monitoring, also enables us to evaluate these years with respect to the multi-annual weather and climate. In this chapter it is assumed that all plots are sufficiently close to have only one set of meteo measurements.

It is important to know whether the years under observation are average, dry or wet, to evaluate the effectiveness of the SWC measures. Therefore monthly values of rainfall and evapotranspiration should be obtained for the last 10-20 years. These values are also needed for the simulations with the PESERA model in work block 5.

4.1 Temporal resolution of meteo variables

The temporal resolution of the rainfall measurements depend on the type of desertification process that is most prominent on a site. If the processes related to runoff and water erosion, and flash floods, high resolution intensity values of rainfall must be obtained and event based information must be available. If the emphasis is on water shortage and soil moisture, daily or weekly values of rainfall and evaporation are sufficient. This is also valid for natural vegetation related research such as forest regrowth, grazing capacity etc. Table 4.1 gives an overview of processes, required meteorological variables and the temporal resolution needed for the analysis.

	Meteo variable	Time	**Use**
Runoff	Rainfall intensity Event size	5 minute Event duration	Infiltration, runoff simulation Frequency-Magnitude
Water erosion	Rainfall intensity	5 minute	Kinetic energy splash
Wind erosion	Wind seed and direction	Average hourly	Dominant wind pattern
Water shortage	Rainfall totals Evapotranspiration	Daily Daily	soil moisture balance cro/veg. water use
Drought	Rainfall totals Evapotranspiration	Daily-Monthly, long term	P-ET long term trend analysis (indices)
Salinization	Rainfall totals Evapotranspiration	Daily-weekly	Soil moisture, groundwater analysis
Vegetation/crop growth	Rainfall totals Evapotranspiration	Daily-Weekly	biomass growing season analysis

Table 4.1. Processes, required meteorological variables and the temporal resolution for analysis.

4.2 Rainfall

The temporal resolution of the rainfall measurements depend on the type of desertification process that is most prominent on a site (see table 4.1). For runoff, water erosion and flash floods, high resolution intensity values of rainfall must be obtained and event based information, in 5-m,inute intervals, must be available. In semi-arid areas the runoff mechanism is predominantly “Hortonian”, i.e. the rainfall intensity is higher than the infiltration capacity and runoff will occur. Using totals over time periods, such as the event total or daily total, does not give good information on runoff generation. If intensity data is not available the calculation of runoff is usually done with an assumed runoff fraction, determined by soil physical properties (see e.g. Morgan, 2006) or empirically such as the Curve Number Method. These methods are often based on averages and may not give good information on specific events. More important, changes caused by SWC methods such as an improved soil structure or increased obstruction to runoff, cannot be well predicted with rainfall totals.

According to Cammeraat et al, 2002) rainfall should be measured in two ways. The first method is by continuous registration by means of a tipping bucket. Tips should be stored with a high time resolution (every 5 minutes at least) or upon occurrence during the rainfall event, which gives information on rainfall intensity and duration. The second method is based on the sampling the total rainfall volumes by means of conventional rainfall gauges after each rainfall event. This will help to corroborate the rainfall measurement by the tipping bucket and provide information on the spatial distribution of rainfall totals. Classical rain gauges are easy to establish and should be emptied preferably after each event or on a daily basis. They can also be practical to assess the local spatial variability of the rainfall. All gauges should be installed at a standard level of 1.5 m height in an open field, and the distance to the nearest obstacle should be at least 3 times the height of that obstacle.

4.3 Evapotranspiration

Evapotranspiration (ET) is usually calculated using a Penman-Monteith equation. Evaporation is the water flux from the soil surface directly to the atmosphere, transpiration is the flux from the root zone of the soil through the plants to the atmosphere. Interception water is also counted as evaporation (drying out of a canopy after rainfall). This combines the available radiative energy with the atmospheric demand to the evapotranspiration flux. The net radiation is calculated from the net short wave incoming radiation (using albedo) for which several sensors exist, and the outgoing long wave radiation calculated from the temperature. The atmospheric demand is calculated from the relative humidity of the air, the temperature, wind speed and air pressure. These variables are all standard for a meteorological station. The meteorological equipment should be installed in an open field, similar to the rainfall measurements.

The Penman-Monteith equation provides an estimate for the potential ET. The actual ET depends on the soil moisture. When the soil becomes dryer, plants cannot maintain an optimal water flux, the stomata close and the transpiration stops. Also evaporation can decrease when the topsoil dries out, because the hydraulic conductivity of the dry topsoil layer is so low that it effectively becomes a barrier aginst further evaporation (sometimes called natural mulch). Plant mulch and plant canopy can shade the soil which reduces the direct incoming radiation and decreases the albedo, decreasing the evaporation.

Factors affecting ET

When assessing the ET rate, additional consideration should be given to the range of management practices that act on the climatic and crop factors affecting the ET process. Cultivation practices and the type of irrigation method can alter the microclimate, affect the crop characteristics or affect the wetting of the soil and crop surface. A windbreak reduces wind velocities and decreases the ET rate of the field directly beyond the barrier. The effect can be significant especially in windy, warm and dry conditions although evapotranspiration from the trees themselves may offset any reduction in the field. Soil evaporation in a young orchard, where trees are widely spaced, can be reduced by using a well-designed drip or trickle irrigation system. The drippers apply water directly to the soil near trees, thereby leaving the major part of the soil surface dry, and limiting the evaporation losses. The use of mulches, especially when the crop is small, is another way of substantially reducing soil evaporation. Anti-transpirants, such as stomata-closing, film-forming or reflecting material, reduce the water losses from the crop and hence the transpiration rate.

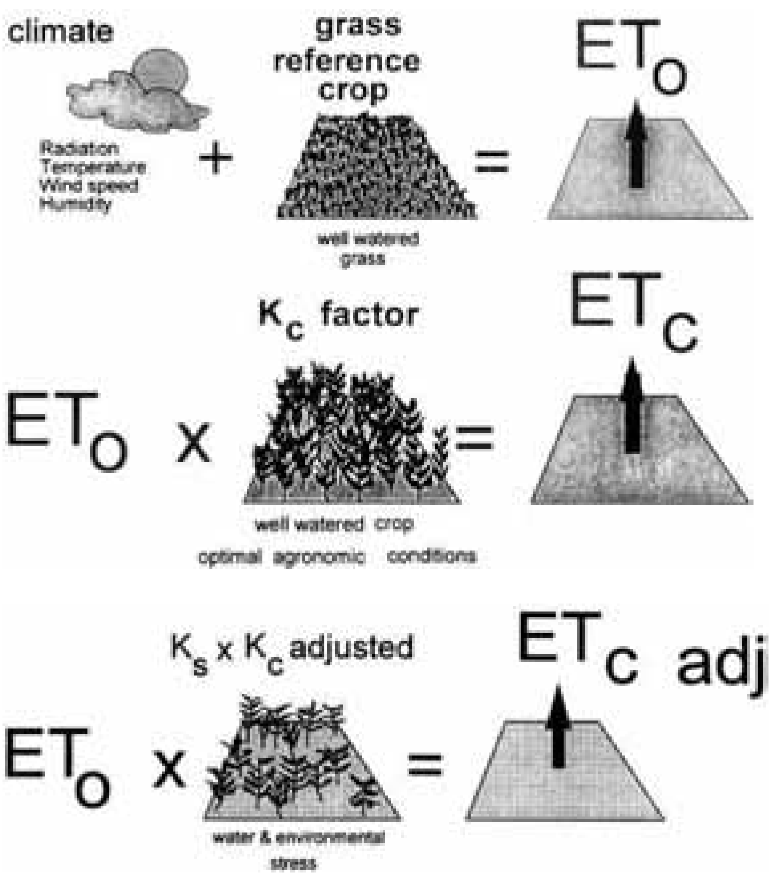


Figure 4.1. Reference (ETo), crop ET under standard (ETc) and non-standard conditions (ETc adj)

Allen et al. (1998) explain the distinctions that are made (Figure 4.1) between reference crop evapotranspiration (ETo), crop evapotranspiration under standard conditions (ETc) and crop evapotranspiration under non-standard conditions (ETc adj). ETo is a climatic parameter expressing the evaporation power of the atmosphere. ETc refers to the evapotranspiration from excellently managed, large, well-watered fields that achieve full production under the given climatic conditions. Due to sub-optimal crop management and environmental constraints that affect crop growth and limit evapotranspiration, ETc under non-standard conditions generally requires a correction. The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ETo. The reference surface is a hypothetical grass reference crop with specific characteristics. The only factors affecting ETo are climatic parameters. Consequently, ETo is a climatic parameter and can be computed from weather data, for which the Penman-Monteith equation is suggested. The crop evapotranspiration under standard conditions, denoted as ETc, is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the standard reference crop to determine its evapotranspiration rate, i.e., ETo. Experimentally determined ratios of ETc/ETo, called crop coefficients (Kc), are used to relate ETc to ETo or ETc = Kc ETo. Due to variations in the crop characteristics throughout its growing season, Kc for a given crop changes from sowing till harvest. The crop evapotranspiration under non-standard conditions (ETc adj) is the evapotranspiration from crops grown under management and environmental conditions that differ from the standard conditions. When cultivating crops in fields, the real crop evapotranspiration may deviate from ETc due to non-optimal conditions such as the presence of pests and diseases, soil salinity, low soil fertility, water shortage or waterlogging. This may result in scanty plant growth, low plant density and may reduce the evapotranspiration rate below ETc. The crop evapotranspiration under non-standard conditions is calculated by using a water stress coefficient Ks and/or by adjusting Kc for all kinds of other stresses and environmental constraints on crop evapotranspiration.

5 Soils and soil properties

As Kosmas et al. (1999) state, soil is a dominant factor of the terrestrial ecosystems in the semi-arid and dry sub-humid zones, particularly through it's effect on biomass production. Desertification will proceed, in a certain landscape, when the soil is not able to provide the plants with rooting space and/or water and nutrients. In the semi-arid and the sub-humid zones, the land becomes irreversibly desertified when the rootable soil depth is not capable to sustain a certain minimum vegetation cover. There are cases that desertification proceeds in deep soils, when their water balance is incapable to meet the needs of the plants. In these cases the phenomenon is reversible. Nutrient supply to plants seldom becomes critical in the two climatic zones mentioned above.

Soil quality indicators for mapping ESAs can be related to (a) water availability, and (b) erosion resistance. These qualities can be evaluated by using simple soil properties or characteristics given in regular soil survey reports such as soil depth, soil texture, drainage, parent material, slope grade, stoniness, etc.

It should be noted that physical soil properties are generally considered to be constant in time, such as porosity, plant available water, saturated hydraulic conductivity, bulk density. However, in practice this is often not the case as these depend on soil structure. In an agricultural environment soil structure can be subject to abrupt changes because of tillage practices, while rainfall (splash detachment) and temperature changes influence the structure throughout the season. Thus some researchers assume there is a “baseline” value associated with these properties, which is then altered in the course of the year. In practice this means that the methods described below can be done multiple times if it is suspected that the properties change over time by climatic drivers, or by human intervention. Some will be more static and only need to be assessed once.

5.1 Static quality indicators

Kosmas et al. (1999) have compiled a large set of indicators and descriptions in a “Manual on key indicators of desertification and mapping environmentally sensitive areas to desertification” (MEDALUS report EUR 18882). The descriptions in this section are directly copied from that report.

5.1.1 Parent material

Soils derived from different parent materials react differently to soil erosion, vegetation and desertification. Limestone produces shallow soils with a relatively dry moisture regime. Soils formed in flysch are deep, and well vegetated. Areas with soils in limestone are characterised by high erodibility and slow vegetation recovery. Several areas on limestone formations in the Mediterranean region are already desertified with the soil mantle eroded, and the vegetation cover completely removed. Under Mediterranean climatic conditions, regeneration of soils and vegetation is impossible, and desertification is irreversible. Similarly, acid igneous parent materials such as pyroclastics produce shallow soils with high erodibility and high desertification risk. Extensive areas on hilly agricultural lands in the semi-arid zone of the Mediterranean region are cultivated with rainfed cereals. Areas with soils formed in marl are very susceptible to desertification. Such soils cannot support any annual vegetation in particularly dry years, despite their considerable depth and high productivity in normal and wet years (Kosmas et al., 1993). On the contrary, soils formed on shale-sandstone, conglomerates, basic igneous rocks, etc. despite their normally low productivity in wet years, may supply appreciable amounts of previously stored water to the stressed plants and to secure a not negligible biomass production even in dry years.

The presence of cracks or fractures and faults into the bedrock favours the soil formation by weathering or the removal of soil aggregates into the cracks by gravity. The formed 'tube' type soils are well protected from erosion and the percolating water can be stored into and protected from evaporation. The presence of deep soils in cracks and faults is of great ecological importance, supporting relatively well the natural vegetation under Mediterranean climatic conditions and preventing large hilly areas from desertification.

5.1.2 Rock fragments

Rock fragments have a great but variable effect on runoff and soil erosion (Poesen et al. 1994; Danalatos et al., 1995), soil moisture conservation (van Wesemael, et al., 1995; Moustakas et al., 1995) and biomass production (Poesen and Lavee, 1994), so playing an important role on land protection in the Mediterranean region. Generally, runoff and sediment loss are greater from stony than stone-free soils, apart from soils rich in coarse gravel (Fig. 1) on the surface subjected to heavy and prolonged showers. Bunte and Poesen (1993) found that interill sediment loss increased with increasing rock fragment percentage up to about 20%. Beyond this value, the limited space between fragments prevents development of scour holes and thus limits soil loss. For sheet and rill erosion, however, rock fragments cover always reduces sediment production in an exponential way (Poesen et al., 1994).

Stony soils along slope catenas of parent materials rich in rock fragments such as conglomerates, shale-sandstone, etc., despite their normally low productivity, may supply appreciable amounts of previously stored water to the stressed plants and ensure an adequate biomass production in dry years (Kosmas et al., 1993). As Fig.3 illustrates, the biomass production of wheat growing under water- limiting conditions was reduced by 10-30% in plots in which the rock fragments were removed from the soil surface during cultivation, as compared with the stony plots of the same soils along hillslope catenas. Soils formed on marl are free of rock fragments and despite their considerable depth and high productivity in normal and wet years, they are susceptible to desertification in particularly dry years. In such dry years, they are unable to support any vegetation due to adverse soil hydraulic properties and the absence of gravel and stone mulching.

Measuring stoniness

Stoniness can be assessed by placing a tape along the surface in a number of random directions and counting the number of stones or measuring the fraction of stones. Stoniness can also be visually estimated using frames, the same way as vegetation cover is estimated (see section 9.3).

5.1.3 Soil depth

Dryland soils on hilly areas are particularly vulnerable to erosion, especially when their vegetation cover has been degraded. Soils on Tertiary and Quaternary consolidated formations usually have a restricted effective soil depth due to erosion and limiting subsurface layers such as petrocalcic horizon, gravely and stony layer, and/or shallow bedrock. Therefore, the tolerance of these soils to erosion is low and, under hot and dry climatic conditions and severe soil erosion, rainfed vegetation can no longer be supported, leading to desertification. Soils formed in various parent materials show different ability to support a considerable vegetation cover for erosion protection under given climatic conditions. Soils formed in pyroclastics are the most sensitive in supporting adequate Macchia (Maquis) vegetation with a crucial depth of 10 cm under which the existing vegetation can not longer survive (Kosmas et al., 1998). Below that crucial depth, all the perennial vegetation disappears and only some annual plant species can survive. The erosion rates below that critical depth are very high, favouring the appearance of the underlying bedrock on the soil surface. Soils formed in schist-marble metamorphic rocks have a higher ability to support perennial vegetation under the same climatic conditions with crucial depth around 4-5 cm.

Given certain physical characteristics and underlying parent material, two soil depths, very important for land protection, can be distinguished, the critical and the crucial depth. The critical depth can be defined as the soil depth in which plant cover achieves values above 40%. On soil less than that depth the recovery of the natural perennial vegetation is very low and the erosional processes may be very active resulting in further degradation and desertification of the land. When a hilly landscape of marginal capability is cultivated, agriculture should be abandoned before the soil reaches the critical depth. While the critical depth is a limit to cultivation, the crucial depth can be defined as a lesser soil depth on which the perennial vegetation can no longer be supported, and the whole soil structure is rapidly washed out by wind or water erosion. This is an irreversible process.

Measuring soil depth

Although a very clearly defined variable, it is not that easy to measure. Soil depth is usually determined by augering, digging soil pits and observations along roads, channels and construction sites. This does not however give a very clear spatial pattern of soil depth. Generally there is a relation between soil depth and relief parameters (see figure 5.1).

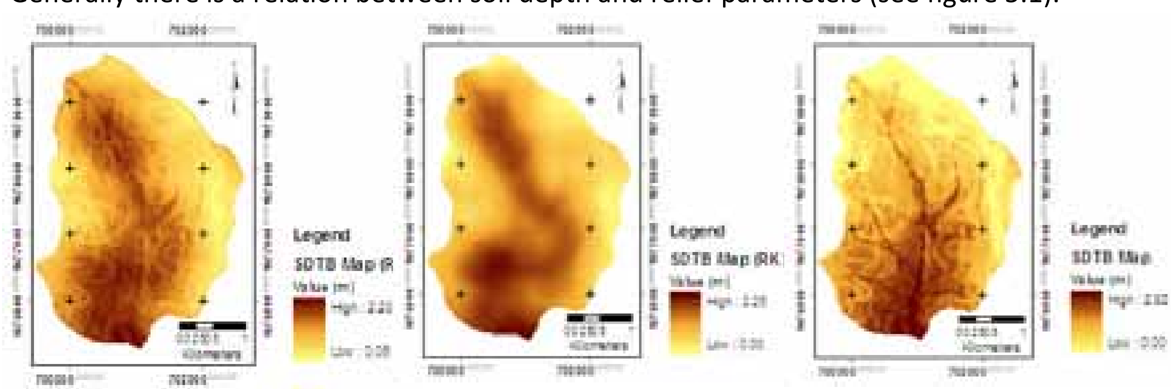


Figure 5.1. Soil depth predicted from slope (left), elevation (middle) and multi linear regression (right) for 10 km² catchment in South Indi, which has shallow soils that are strongly determined by the relief. R²is between 0.5 and 0.6 for all metjods (Devkota, 2008)

5.2 Pedotransfer functions

Assuming that baseline values exist several researchers have created pedo-transfer functions that relate texture, organic matter content and usually some compaction indication to soil physical properties such as porosity, permeability, soil moisture indicators using multiple regressions. An example are the equations by Saxton and Rawls (2005), that are built into the free water balance model SPAW (see figure 5.2). Note that the results should be seen as first approximations of baseline values and may not be close to the real values at a given location.

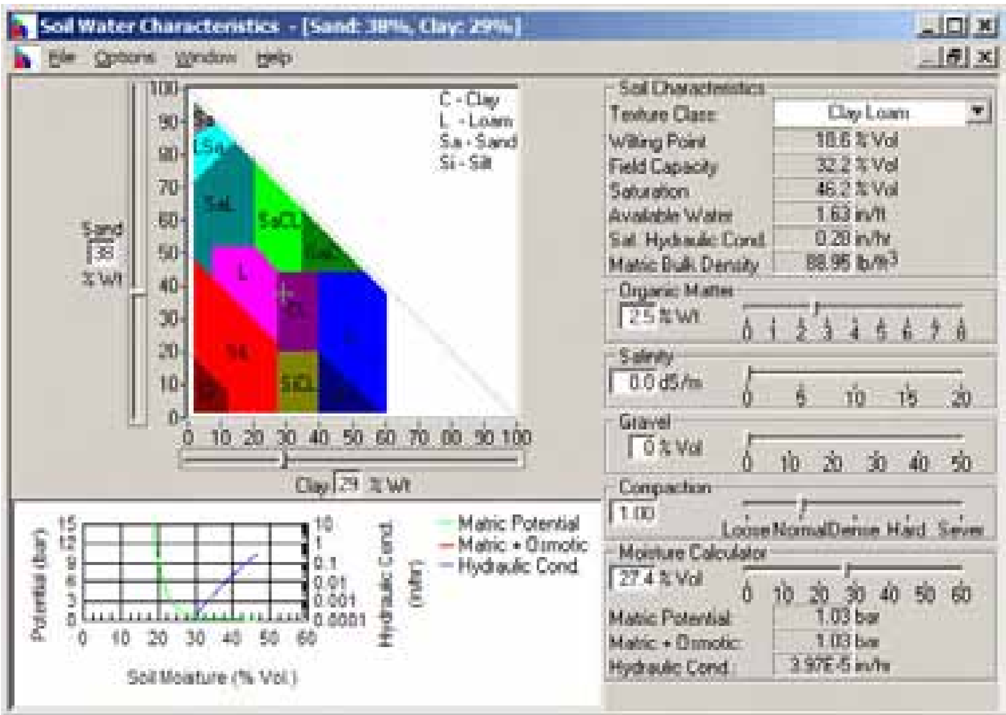


Figure 5.2. Soil water characteristics tool as part of the SPAW model, based on Saxton and Rawls (2005).

5.3 Soil moisture monitoring

The SWC methods related to water harvesting, improvement of soil structure and other ways of improving crop yield under dry circumstances might be directly monitored by taking regular soil moisture samples. There are many methods for soil moisture sampling. Giving a full description of measurement methods that have been standard methodology for a long time is beyond the scope of this document. Also issues of spatial variability and the way to handle this with various (geo)statistical methods will not be explained here in depth.

5.3.1 Soil moisture sampling

The most common way of measuring soil moisture is taking samples of a known volume, which are then dried and weighted in the laboratory (usually 100 cc steel rings that are dried for 24 hours on 105 ^oC). This gives the volumetric soil moisture content expressed in volume % or cm^3 moisture/cm^3 soil. A sample ring may be too small to include variation in soil structure, often the more solid matrix of the soil is sampled, avoiding cracks and roots. Nevertheless it is still one of the most accurate ways of measuring soil moisture. It is however also labour intensive and slow. Gravimetric (i.e. weight based) soil moisture can be taken faster simply taking a random volume which is then expressed as g water/g soil. For comparative measurements this may be enough, although the bulk density is needed to recalculate these to volumetric moisture content. Since the bulk density is spatially variable, this adds an uncertainty to the measurements.

Methods based on the di-electric constant

In soils, dielectric permittivity is directly related to the water content. Dry soil has a di-electric constant of 2-5 and that of water is 80 when measured with high frequency radio pulses between 30 MHz and 1 GHz. TDR and FDR devices are based on the reflection of a signal that is transmitted into the soil along guiding pins and from the shape and frequency of the return signal the moisture content can be deduced. FDR stands for Time Domain Reflectometry, FDR stand for Frequency Domain Reflectometry. The pins are usually regular steel pins of 10-20 cm length. The volume measured depends on the setup with two or three pins and includes concentric areas of several cm around the pins. These are normal steel pins, in fact TDR probes are easy and cheap to fabricate. The device to send, and analyze the reflecting signal is expensive. TDR probes can be installed at varying depths on permanent locations, or are also available as hand held probes that allow rapid measurements over larger distances (see below). However TDR probes are sensitive to stones and cavities in the soil and the accuracy is 2-4% volumetric moisture content (meaning e.g 35% moisture ± 2%, but also 8% moisture ± 2%). This accuracy can be improved to 1% when calibrating the device for local soils with volumetric moisture samples.

A Theta probe is a small hand held device that works along the same principles. The 4 pins are small and thin and brake relatively easy, especially in stony soils.

The ECHO or ECH_2O Probe is a relatively new sensor for measuring volumetric water content of soil and other porous materials. It is a capacitance probe that measures dielectric permittivity of the surrounding medium. The ECH_2O probe outputs a voltage proportional to the dielectric permittivity, and therefore the water content of the soil. The probe is a flat plastic ruler of 5-20 cm length with an accuracy given by the manufacturer is ±4% on low EC and medium-textured mineral soils, and ±1-2% with soil-specific calibration. Probes that can measure moisture, temperature and EC simultaneously are also available.

Methods based on hydraulic potential

Tensiometers have been around for a long time and consist of a tube with a porous ceramic cup at the end. The tube is a closed system filled with de-aerated water that reaches an equilibrium with the soil. It outputs the hydraulic potential of the soil at a given depth, which can be recalculated to the matric potential and, with the help of a pF curve, with the moisture content. The range of measurements depends on the air entry potential of the ceramic cup and is usually in the range of 0 to -800 cm (with a corresponding moisture content that depends on the soil type). Since dry soils in semi-arid areas may easily reach a matric potential lower than -800cm it is not very suitable in these environments.

Porous blocks are made of a porous material such as gypsum or ceramic/nylon materials. They reach an equilibrium with the soil moisture. Electrical resistance between two probes in the blocks can be measured and related to soil moisture.

5.3.2 Measurement frequency

It is known that the soil moisture variability can be high especially close to the surface, where the moisture content is most influenced by surface evaporation and rainfall. Below the surface fluctuations are less rapid because of the generally low unsaturated hydraulic conductivity and consequently slow water movement. This translates to a certain frequency of moisture measurements. Moisture measurements in the top soil should be done relatively frequent, such as every one or two days, deeper measurements may have a lower frequency. Even with frequent measurements a rainfall event may be missed, or not documented properly. An added problem is that when comparing two or more areas, the measurements should be done at the same time, which is not always possible. If one plot is measured in the morning and the reference plot at noon, there is a strong chance of bias: the top layer of the latter will almost always be dryer. Also large areas cannot be measured simultaneously which causes a similar bias when a certain part of the area is always measured later than the other.

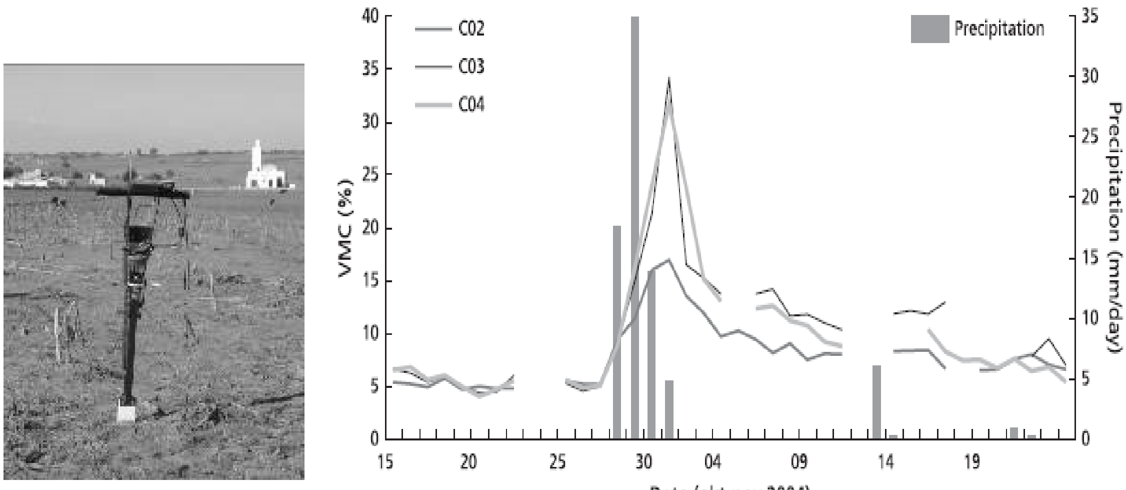


Figure 5.3. Left: handheld TDR measuring 0-12 cm, right: resulting moisture measurements at three 1 ha sites in Morocco (Van der Kwast, 2008).

Enough samples must be taken to obtain a good average value. This suggests that rapid measurements are to be preferred over taking sample rings that have to be dried and weighted in the laboratory. As an example Van der Kwast (2008) has used the following sample scheme near the DESIRE Morocco site (see figure 5.3). At the three sites soil moisture was measured on a daily basis, using a Fieldscout TDR 300 with an attached handheld GPS (Garmin eTrex). The accuracy of the TDR is ±3% (Spectrum, 2003). The sampling time on each day was chosen close to satellite overpass time: all sites were sampled between 9.00 and 12.00 am. Soil moisture was sampled on a regular grid, with a gridspacing of 20 m. The TDR gives the average volumetric soil moisture content between 0 and 12 cm depth. For each plot of 1 ha the daily average top soil moisture content and its standard deviation were calculated from the daily grid measurements. It is assumed that small differences in sampling times give a negligible bias to the measured top soil moisture content."

5.4 Infiltration

Infiltration measurements are common in geographical sciences and precise descriptions of the calculations are beyond the scope of this document. When rain falls on an initially dry soil the infiltration capacity is large due to the capillary suction of the soil, commonly indicated as sorptivity. In general most rainfall can enter the soil at the start of an event. As the soil becomes wetter the influence of the sorptivity decreases rapidly until gravity is the main driving force. The infiltration rate becomes steady state rate. If at any time during this process the rainfall intensity is larger than the infiltration rate, ponding and eventually runoff will occur.

5.4.1 Measuring infiltration

With infiltration measurements the steady state infiltration rate can be measured. The sorptivity depends on the initial moisture content and cannot be easily determined. Most models estimate it based on the law of Darcy or a simplified version of Darcy such as the Green and Ampt equation or equivalents (Smith and Parlange, Morel-Seytoux). The steady state infiltration rate when calculated for an infinite time equals the saturated hydraulic conductivity (ksat) in its 1D form. Infiltration measurements are mostly based on controlled ponding of the surface and measurement of the water level.

Single/ double ring

Single or double ring infiltration tests (see fig 5.4) are among the oldest and most used. The method consists of saturating a soil while keeping a constant water level of 1 or 2 cm at the surface wit a Mariotte bottle. The water level in the bottle I measured to get the infiltrating volume with time. A two ring test consists of an inner ring of minimally 20 cm and an outer ring that is minimally 10 cm in diameter larger. The water level in both rings are kept more or less the same, but only the inner ring level is monitored. The purpose of the outer ring is to have buffering water layer that forces the inner ring water to infiltrate vertically downward, instead of getting a conical volume that is larger than he ring surface. When the water infiltrates vertically the surface of the ring is representative for the infiltrated volume, and the 1D steady state infiltration rate can be calculated. Thus the disadvantage of singe ring measurement is that the water may spread below the surface horizontally, and he ring surface is not representative, causing an overestimation of the infiltration rate. Singe ring infiltration tests should be avoided. Measurements of the water level are continue until a constant infiltration rate is achieved (sometimes > 60 min). The water level depth should be included in the calculations as an overpressure, but can be neglected if the ring surface is large and the water level small.

The advantage of this method is that it is easy to do and cheap, rings can be constructed easily. Also the surface is relatively large for a good sample. The disadvantage is the connection of the ring to the soil and the effect of non-vertical flow of water, causing an overestimation or underestimation. On slopes the water level will not be the same everywhere in he ring. Thus he surface should be graded horizontally, but that means that the surface I not measured but a layer below the surface.

Figure 5.4. Left: single ring and right: double ring infiltration test. Here the water levels are not controlled by a Mariotte bottle an need to be carefully maintained. This is only possible for soils with a low infiltration rate (photo: http://en.wikipedia.org/wiki/Infiltrometer)

Sample ring for saturated hydraulic conductivity

A common way to determine saturated hydraulic conductivity is by taking soil samples with steel rings. These sample rings are 100 cm^3 or 250 cm^3 in size and are inserted into the soil, usually with a special steel sleeve that fits on the top of the ring and the assembly is pushed or hammered in to the soil. Care must be taken that there are no large stones, roots or cracks inside the ring. The ring is then slowly saturated from the bottom up by placing it 24h in a tray of water, and the hydraulic conductivity is determined by measuring the water flux through he ring under a carefully maintained overpressure (of e.g. 1-2 cm water). The method is widely applied and very robust, but it samples the soil matrix only and the rings are generally too small to account for stoniness etc.

Disk infiltrometers

Disk infiltrometers follow almost the same principle and maintain a certain water pressure that controls the infiltration rate. The device has a flat disk wit a permeable membrane of fine cloth that must make contact to he soil. The soil surface must be graded before positioning the disk. To improve the contact a thin layer of fine sand may be applied to fill up small irregularities. Mounted on top of the disk is a double container, or two separate containers (depending on the design). The larger one contains the infiltration water, the other one controls the pressure/suction applied (figure 5.5).

The tension-disk infiltrometer can handle a suction that can be applied to he disk (underpressure), enabling the calculation of the unsaturated hydraulic conductivity at the suction level applied. Thus a k(h) curve of up to -50cm pressure can be constructed. Some types have different mountable ring sizes with which also a k(h) curve can be constructed through a specific us of the equations. It should be noted that all infiltrometer calculations assume a homogeneous circular infiltration from the disk downward, which may not be the case, especially when there are cracks in the soil. Even microcracks can obstruct the spread of water through the soil matrix.

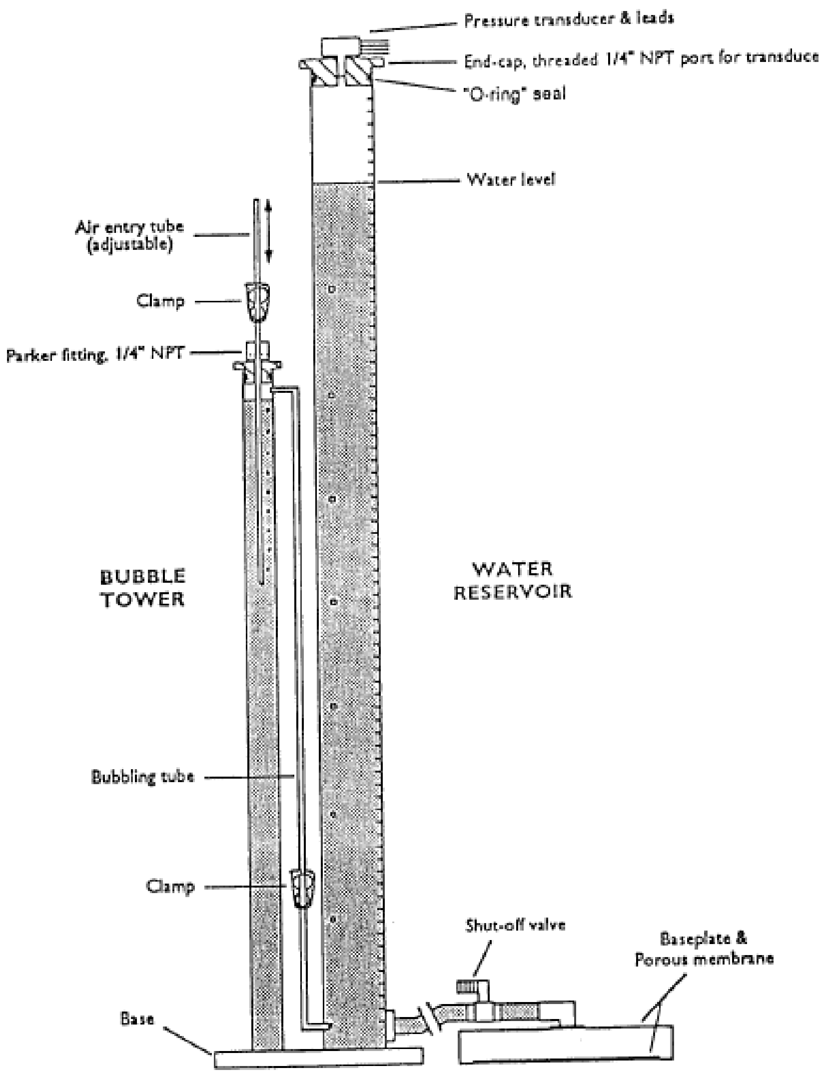


Figure 5.5. Example of a tension disk infiltrometer (source: Eijkelkamp Agrisearch equipment) with a separate container system and infiltration plate with porous membrane.

Rainfall simulator

Rainfall simulators come in various sizes, form the small "kamphorst" simulator (see figure 5.6) to larger devices. There are two types, either the rainfall is applied through a set of capillary tubes set in a plate and let to drip on the soil, or the water is applied through a spray nozzle, like a sprinkler system. Note that rainfall simulators are also used to calculate erosion from plots but in the case of the small simulators this is debatable, the artificial raindrops do not have the same fall velocity and kinetic energy as natural rainfall drops. Also sprinkler systems often produce a fine spray, with different erosivity than natural rainfall.

The advantage is that the sample size is fairly large (30x30 cm^2) and the measured plot is undisturbed. The disadvantage is that the infiltration is measured by catching the runoff, so a slope is needed, and the surface roughness and ponding have an effect. Also it is known that the infiltration rate is partly determined by the rainfall intensity applied: if this is higher, more of the pore-system contributes, and the infiltration rate will be higher too.

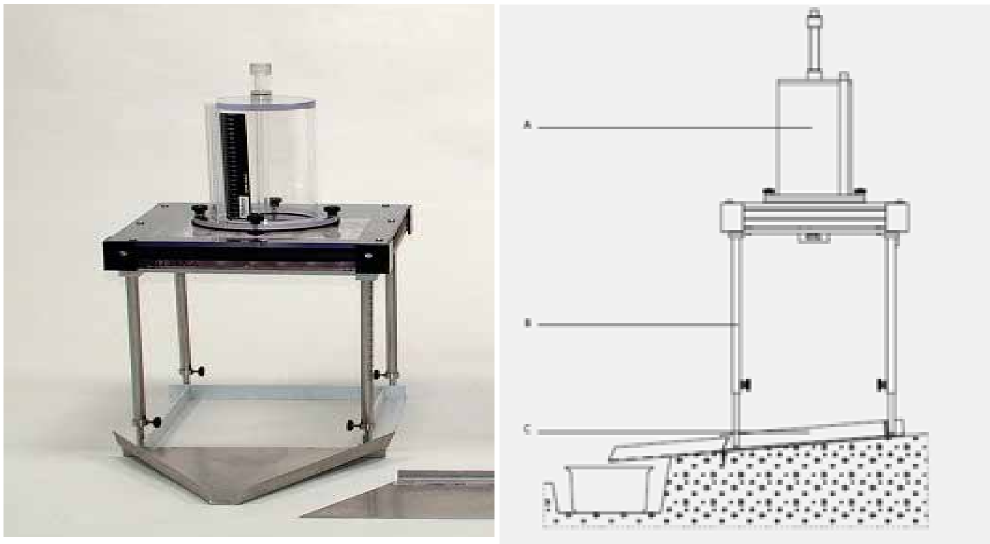


Figure 5.6. "Kamphorst" rainfall simulator to determine in situ rainfall characteristics without disturbing the soil.

5.5 Soil Strength parameters

The erodibility of the soil is often related either directly to a the strength when applying some force to a soil sample, or indirectly by relating soil loss values from sample plots to the properties that give strength to the soil. These properties are texture (in particular clay content) and organic matter. In these empirical relation sometimes bulk density or a rating for compaction is included, and sometimes also stoniness. It should be noted that strength of the soil with respect to rainfall splash and to flowing water is not the same. Also wind erosion is a very different force that requires its own strength parameter.

5.5.1 Erodibility

Erodibility is often split in to interrill erodibility (for sheet flow or splash detachment) and rill erodibility for concentrated flow. It is defined simply as the amount of soil that is detached relative to the detaching agent. Erodibility can thus be measured in the field with splash cups or with runoff plots. The best know erodibility equation is from the USLE and derived models. A useful algebraic approximation (Wischmeier and Smith 1978) for those cases where the silt fraction does not exceed 70% is:

$$K = 7.59[2.1.10^{-4}(12-OM)M^{1.14} + 3.25(S-2) + 2.5(P-3)]$$

Where: OM is % organic matter, M is the product of the primary particle size fractions: (% modified silt or the 0.002-0.1 mm size fraction) * (%silt + %sand). S is the soil structure class and P is the soil permeability class. The factor 7.59 converts K into SI units as t. ha.h.ha^{-1} $MJ^{-1}$$mm^{-1}$. Note that there is a lot of literature producing modified values of the K value.

5.5.2 Aggregate stability

Aggregate stability is a measure of the direct impact of raindrops on splash and can be used to calculate the amount of splash erosion. The test description here (the drip test of Low, 1954) aims at simulating the impact of falling rain on an aggregate (Hessel, 2001; EROAHI project field measurement manual). To be able to compare the results from different drop tests, the moisture content of the aggregates is standardized. This is done by leaving the aggregates on a sand tray covered with filter paper, while a constant water level in the sand is maintained. A drip bottle is mounted 1 meter above the aggregates and used to produce drops of equal size (independent of water level in the bottle!) and constant rate. The soils sieved with a 5 and subsequently with a 4 mm sieve. The drip bottle is set up with a hose for air entry and drip point, so that drops will fall at a constant rate of about 50 drips pr minute. The aggregates are put on a 3 mm sieve below the drip bottle and the amount of direct hitting drops are counted that are needed to pass the aggregate through the sieve. Move the sieve around to treat all aggregates. The median of the number of drops is the aggregate stability.

5.5.3 Cohesion with shear vain

Cohesion is a measure of the strength of the soil for a shear force such as flowing water. Shear stress is expressed in kPa or N/m^2 and the strength is expressed in the same way. Cohesion of an unconsolidated material changes with its moisture content, and field measurements of cohesion should be taken with a similar moisture content. Since we are interested in cohesion with respect to flowing water, saturated (or very wet) soil samples should be measured. Figure 5.7 shows pocket shear vane with various disk sizes for different texture classes.

Figure 5.7. Pocket shear vane with various disks for different types of soils: sand requires larger disks, clay requires the smaller disk.

6 Soil surface dynamics

Monitoring the state of the soil surface is treated separately in this document. Although many measurements are described in the section on soil properties, the soil surface can be monitored visually and with photographs, as relatively easy alternatives to measurement setups. SWC techniques such as mulching, intercropping, additional grass cover etc. aim at improving the soil structure to promote infiltration, avoid crusting, increase the surface resistance to flow, strengthen the soil provide direct cover protection to splash impact. Also no-tillage or minimum tillage techniques aim at improving the soil structure and soil fauna over a period of several years. Observing the soil surface in a structured way may provide

Many of these effects can be directly observed with simple means, visually or by digital photographs. Also the absence of SWC can be observed even more clearly especially as a changing soil surface structure in time. The effect may be more or less visible, depending on the type of soil and soil material.

6.1 General visual monitoring

The soil surface is visible and we should not neglect the value of documenting changes at the soil surface of SWC plots, without deriving directly quantitative measures from these images. Also for demonstration purposes series of photo's showing comparable situations "with and without" SWC measures can convince stakeholders to adopt certain method. Especially when imagery is backed up by values of runoff, erosion, infiltration, soil moisture etc. it gains in importance. Images in frames are commonly used to follow changes. Images can be taken at various scales:

- Image documentation of the whole plot from a distance at a fixed location is valuable to judge the total effect of a SWC measure. These photos should be taken at regular intervals throughout the growing season. Not only agricultural environments should be followed in this way, also effects of forest fire and regeneration can be documented, and effects of grazing trials for instance.
- Images of the soil surface can be taken to follow the effects SWC measures using mulch, intercropping or grass cover under trees, i.e. all measures that aim at reducing the amount of bare surface and improve the soil structure. A simple system of taking photo's using a fixed frame (0.5 - 1 m^2) at a series of predefined location can be immensely helpful to understand what is happening at the plots.
- Remote sensing is les detailed but provides additional spectral information that can be used in various ways (see section on Remote Sensing)

Important with detailed surface images is to assign a series of predefine locations, using e.g. a GPS, and find locations that are similar in slope, aspect, position on the slope, soil characteristics etc. between the SWC plots and the reference plots. Important is also to have sufficient replicas to have a good statistical sample. Figure 6.1 gives an example of the effect of mulch on runoff and rill formation.

Figure 6.1. Example of the effect of mulch photographed with standard frames photo by A. Romain)

6.2 Crusting dynamics

Crusting or surface sealing occurs on many different soils but is most visible on silty loams (such as soils derived from Loess deposits). Silty loams and silty clay loams have sufficient clay content to make them attractive to agriculture (well aerated structured soils, easy to work) but the structure is weak and easily breaks down under the impact of rain splash. This creates structural crusts, a thin seal of broken down aggregates with a higher bulk density, followed by sedimentary crusts where micro depressions are filled up with sediment layers. The first effect of surface sealing is increased runoff, the infiltration dramatically decreases compared to the initial state (see figure 6.2 and 6.5). The breakdown of the aggregates and crusting happens in subsequent rainfalls and thus the decrease in infiltration can be theoretically related to the cumulative rainfall or cumulative rainfall energy.

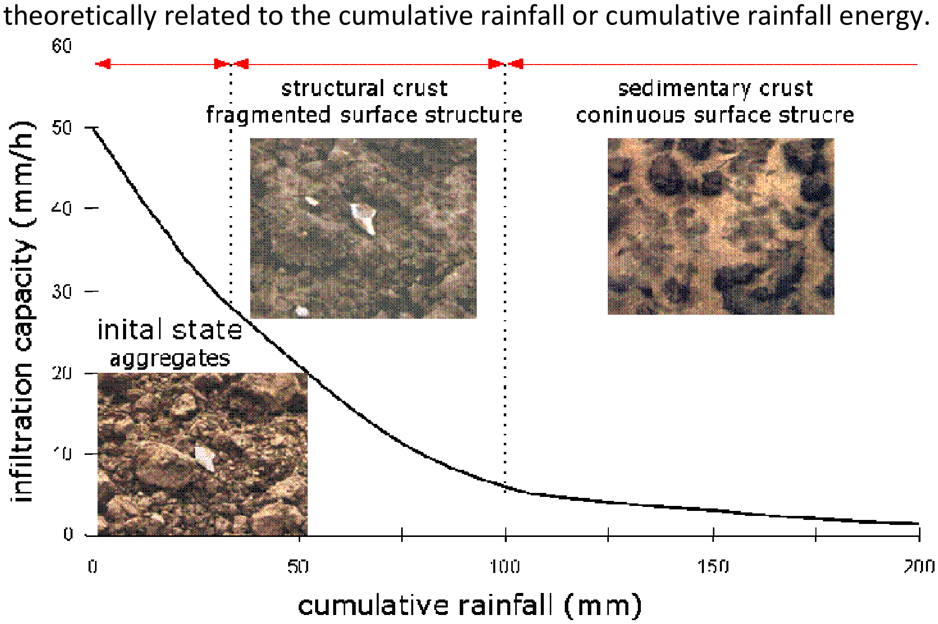


Figure 6.2. Examples of crust stages on a silt loam with decrease in infiltration capacity and cumulative rainfall (graph by V. Auzet).

It should be noted however that the smooth decline in infiltration rate has been primarily observed in the laboratory with continuous rainfall simulation of constant rainfall. Intermittent rainfall gave a different crust dynamics (Fohrer et al., 2001) because of drying out of the soil and cracks developing. Field observations of decrease of infiltration with cumulative rainfall were even less clear as shown in figure 6.3, among other things because the growth of a crop influences the surface and the impact of rainfall.

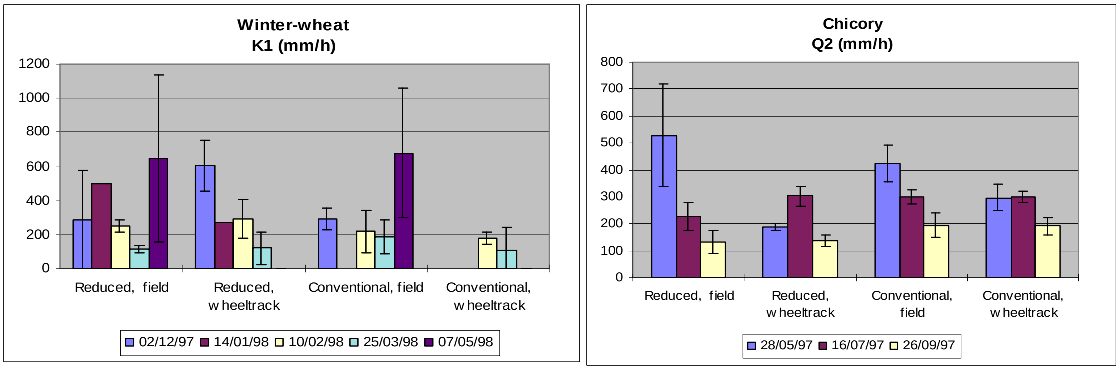


Figure 6.3. Examples of infiltration rates since sowing in consecutive periods during a cropping season. Although some general decline is measured, increases in infiltration at the end of the season can also be seen (Guerif et al., 1998).

6.2.1 Monitoring crusting

Visual assessment of crusting is based on the logic of several stages of crusting that follow each other. In France, Cerdan (2002) describes crust stages on silty loams, where four stages can be recognized:

F0 *Initial fragmentary structure, all particles are clearly distinguishable*
F11 *Altered fragmentary state with structural crusts*
F12 *Transitional: local appearance of depositional crusts*
F2 *Continuous state with depositional crusts (fig 5.4)*

Boifin et al (1984) showed that measuring the size of the smallest aggregate still visible is a good measure of crust extent, as the smallest aggregates are the first to disappear (see figure 6.4). Also the fraction of the crust can be estimated of the thickness. He also assumed a better relation between crust formation and cumulative rainfall energy, not considering rainfall with an intensity of less than 10 mm/h for Northern France which has no aggregate breakdown effect there. In other areas this threshold value may be different.

Figure 6.4. Sedimentary crust formation in micro depressions (photos left B. Ludwig, right I. Takken).

Figure 6.5. Different stages of soil structure alteration and crust forming (photo Scottish Agricultural College).

In the DESIRE project there are of course many different soil types, and the system developed for Northern France may not be relevant for other areas. Nevertheless it is an example of a visual and structured method to appraise alterations at the soil surface which might be adaptable to the local situation. Once a method has been formulated, large areas can be characterized rapidly. These observations are especially valuable in combination with quantitative measurements of steady state infiltration rate runoff, erosion, water availability etc. Figure 6.6 shows for instance relations between crust stages and runoff fractions (Cerdan, 2001).

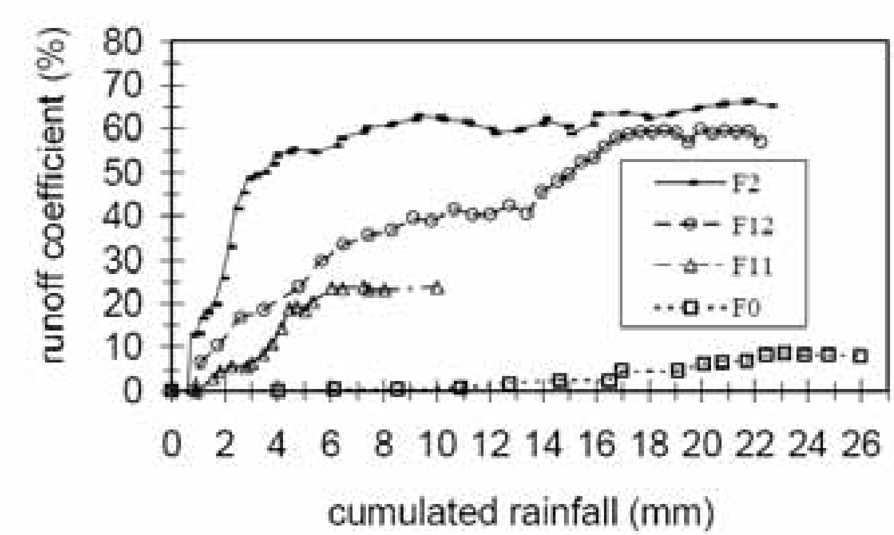


Figure 6.6. Example of runoff coefficient curves (average 2 - 4 replicates) measured under simulated rainfall (30 mm h^{-1}) in the field on 10 m² plots for various initial surface conditions (Cerdan, 2001).

6.3 Roughness

Surface roughness is usually divided in randomly oriented micro roughness, such as caused by loose aggregates and stones at the surface, and oriented micro roughness, such as is caused by tillage operations (planting, ploughing). Roughness interferes with runoff process in that a higher roughness causes more depression storage and more flow resistance (together with denser vegetation), thus slowing down the water and increasing infiltration. Also a higher roughness may be caused by a looser soil structure (loose aggregates and clods create by tillage) and thus it can be seen as an indicator for infiltration rate.

Roughness indices
Random roughness is usually described by a roughness index. Kamphorst et al. (1999) compared 6 different indices varying from standard deviation of heights, tortuosity (see below) to a spatial depression storage index. They found on for over 360 surfaces ranging from ploughed to seedbed on various soils, that the standard deviation is the most robust descriptor and best predictor of surface storage. The advantage of standard deviation is that it can be based on any sample size of relative surface heights, as long as the smple size is sufficient. A well known index is tortuosity, which is the ratio between he shortest distance between two points on a surface and the actual distance following the terrain. The value however depends on the resolution of measurement (usually a chain, see below) and this influences the value greatly.

6.3.1 Monitoring roughness

Roughness is easy to measure, where by there are two types of field measurements. More sophisticated methods exist such as 3D laser scanners but these are not for field use because they consume a lot of energy and are sensitive to scattered light.

Pinmeters
These consist of horizontal bar (wood, metal) with holes every 1 cm, and pins such as bicycle wheel spokes. More or less sophisticated devices exist (see figure 6.7). A white plate behind the pins serves to write location information and as a background for the digital photograph. A clamping device keeps the pins from falling down and damaging the surface or entering the surface when the soil is soft. Pins should be lowered gently to touch the surface, is necessary one by one.
Software exists to analyze the tops of he pins relative to a reference level and give several roughness indices. Using reference markers in the terrain the same location can be visited regularly, e.g. every two weeks or each time after an event. Note that pinmeters can also be used to determine rill cross sections.

Chains
A second fast measurement is positioning a chain on the surface and measuring the distance between the two end points. This gives an index called *tortuosity* (see above). The advantage is that it is a fast measurement but the disadvantage is that a regular fine chain often "snakes" around aggregates instead of going over the top of them, creating a false roughness. A more rigid bicycle chain that can only bend in one direction is relatively course influencing the tortuosity value. In any case within a monitoring program of a site, the method of operation must be clearly agreed upon.

Visual interpretation
In the same way a system for crust recognition can be set up (see above) the micro roughness can be visually judged and described. This again enabled a fast evaluation of bare surfaces (fields). A system of 5 roughness classes by Ludwig et al. (1995) uses microdepressions and the lowest point of their divide:

R0 0-1 cm: strongly crusted sown fields, harvested fields with intense compacting
R1 1-2 cm: sown fields with fine loosened or moderately crusted seedbeds
R2 2-5 cm: recently sown fields with a cloddy surface, crusted tilled fields without residue
R3 5-10 cm: stubble-ploughed fields and recently sown fields with a very cloddy surface
R4 >10 cm: ploughed fields

Figure 6.7. In situ semi-automated pinmeter and an application for analysing pinmeter measurements (REF)

6.4 Flow resistance

Resistance to overland flow can be a direct measure of the effectiveness of runoff control measures and also of infiltration and deposition behaviour of a plot. Slowing down the runoff increases the time for infiltration and decreases the streampower, directly influencing the deposition process. Also flow resistance values such as the Manning's n are used directly in many runoff and erosion models. Resistance is influence by surface roughness increasing the friction and by vegetation density. Vegetation density is often related to vegetation cover, but in the case of flow resistance it should be related to basal cover or stem cover. For instance Manning's n values range from 0.001 for very smooth surfaces, to 0.05 for medium rough agricultural fields, to 0.3 for dense grassland. Figure 6.8 below gives a number of guidance values taken from the manual of the Eurosem model (Morgan et al., 1998).

6.4.1 Measuring Manning's n

Flow resistance is more difficult to measure, but a simple field setup is available (figure 6.9), that can be operated with two people. Manning's n can be calculated using measurements of discharge Q, velocity V, flow width w, and slope S on small plots of 2-3m x 0.5 m. One measurement consists of 3 repeat runs. The reason for this is practical: repeat runs allow you to refill the water containers. Depending on the soil ad slope 30-40 l per un is needed. Water is let into the plots with a system of Mariotte bottles and a gutter with doormat to distribute the water evenly over the plot. The plot is bounded by earthen walls and a collecting gutter and bucket can be used to measure the outflow. Pre-wetting the plot to bring it at a steady state infiltration is advisable. The width of the flow is measured on several points along the plot, the velocity is measured by a colouring dye injected into the water. The discharge is measured in the lower container and from the inlet with marked cylinders and averaged. Measuring Q and V gives the cross section A of the flow and the average width gives the average depth. Manning's n can then be calculated. Repeated runs should be done for a good average. In practice small rills may develop during the run.

Land use or cover		**low**	**mean**	**high**
Bare soil: roughness depth	< 25 mm	0.010	0.020	0.030
	25-50 mm	0.014	0.025	0.033
	50-100 mm	0.023	0.030	0.038
	> 100 mm	0.045	0.047	0.049
Bermuda grass: sparse to good cover				
very short grass	> 50 mm	0.015	0.023	0.040
short grass	50-100 mm	0.030	0.046	0.060
medium grass	150-200 mm	0.030	0.074	0.085
long grass	250-600 mm	0.040	0.100	0.150
very long grass	> 600 mm	0.060	0.150	0.200
Bermuda grass: dense cover		0.300	0.410	0.480
Other dense sod forming grasses		0.390	0.450	0.630
Dense bunch grasses			0.150	
Annual grasses (e.g. Sudan grass)			0.200	
Kudzu		0.070	0.150	0.230
Lespedeza (legumes)			0.100	
Natural rangeland		0.100	0.130	0.320
Clipped range		0.020	0.150	0.240
Wheat straw mulch	2.5 t/ha	0.050	0.055	0.080
	5.0 t/ha	0.075	0.100	0.150
	7.5 t/ha	0.100	0.150	0.200
	10.0 t/ha	0.130	0.180	0.250
Chopped maize stalks	2.5 t/ha	0.012	0.020	0.050
	5.0 t/ha	0.020	0.040	0.075
	10.0 t/ha	0.023	0.070	0.130
Cotton		0.070	0.080	0.090
Wheat		0.100	0.125	0.300
Sorghum		0.040	0.090	0.110
Mouldboard plough		0.020	0.060	0.100
Chisel plough; residue rate	< 0.6 t/ha	0.010	0.070	0.170
	0.6-2.5 t/ha	0.070	0.180	0.340
	2.5-7.5 t/ha	0.190	0.300	0.470
	> 7.5 t/ha	0.340	0.400	0.460
Disc/harrow residue rate	< 0.6 t/ha	0.010	0.080	0.410
	0.6-2.5 t/ha	0.100	0.160	0.250
	2.5-7.5 t/ha	0.140	0.250	0.530
	> 7.5 t/ha		0.300	
No tillage: residue rate	< 0.6 t/ha	0.030	0.040	0.070
	0.6-2.5 t/ha	0.010	0.070	0.130
	2.5-7.5 t/ha	0.160	0.300	0.470
Coulter		0.050	0.100	0.130

Figure 6.8. Manning's n guidance values from the EUROSEM model manual (Morgan et al., 1998).

Figure 6.9. Manning's n measurements in Morocco, left general setup, right dye tracer injected in flow (photo V. Jetten).

6.5 A combined soil surface index

Bergsma and Farshad (2007) have combined a number of the processes and indices explained above into one erosion indicator. The following text is directly taken from Bergsma and Farshad (2007).

Experience has shown that rain erosion-induced microtopographic features can be grouped into seven types: original or resistant clods, eroding clods, flow paths, prerills, rills, depressions and possibly basal cover. These features are recorded per 25 cm on lines of 12.5 m along the contour. An indicator of erosion intensity can be derived from the erosion feature distribution. The indicator is calculated as the percentage of eroded clods plus two times the percentage pre-rill and rill area. It shows significant to highly significant correlation with measured soil loss. This opens up the possibility of evaluating cropping systems and conservation practices for their protective effect against erosion. The erosion intensity can be compared for sites that represent the situation with and without conservation practices. The method can be used to monitor the development of erosion during a rain shower, a rainy season, or a series of years by recording the presence of the features at time intervals. The erosion related features are described in figure 6.10.

6.5.1 Methodology

In a field to be studied, the general eroded part indicates the place of highest erosion hazard. There, a measuring tape (of, for instance, 2.5 m length) is stretched along the contour, so that the features made by flow are met across the tape during recording. The tape has alternate coloured intervals of 25 cm. For each interval the dominant microtopographic feature type is recorded. The recording uses 50 intervals, following a contour line. Each tape interval represents 2% of the area and the percentage distribution of the seven features is determined. The procedure is repeated twice along parallel lines, situated at one or two metres above or below the first observation line. The procedure is not difficult to learn and does not take much time to apply. A short video shows the recognition of the features under natural rainfall (Bergsma, 2003). In a case of erosion plots bordering each other, up to 24 records have been made in one day. It is more efficient and stimulating to have a team of two persons in the field. The feature recording can be done on any type of land use, be it annual or perennial crops, grassland, forest, orchard or plantation.

Microtopographic feature	*Brief description*
Original or resistant clods (res)	Resistant forms and those created by recent tillage
Eroded clods or surfaces (ero)	Forms rounded by splash and disintegration
Flow paths or surfaces (flo)	Flat areas of shallow unconcentrated flow, often with braiding pattern of lag sediment
Prerills (pre)	Shallow channels of concentrated flow, up to 3-5 cm deep
Rills (ril)	Micro-channels deeper than prerills and up to 20 cm deep
Depressions (dep)	Small low areas, enclosed by clods
Vegetative matter (veg)	Basal cover of plants and litter

Figure 6.10. Microtopographic features used to describe the soil surface (abbreviations in parentheses are used in the following tables and figures).

A record of the different types of microtopographic erosion features allows the determination of an indicator of erosion intensity. Using this indicator, the intensity of erosion of different types of land use and cultivation systems can be compared. The indicator of the erosion intensity is derived from the most serious erosion features, which are rills, prerills and flow paths. The indicator is calculated as the percentage flow area plus two times the percentage prerill and rill area. The unequal weight allotted to features tries to represent the relative importance of the features in the erosion process that causes soil loss. The indicator values appeared to correlate with measured soil loss in previous research cases (Bergsma, 2001).

An example

In an area of about 30 km2 near the village of Lom Kao, north of the city of Phetchabun, Thailand, the erosion development in five major land use types was monitored using microtopographic features over a period of two months, starting roughly at the beginning of the rainy season. The sites were comparable in rainfall erosivity, general topography and soil. The microtopographic erosion features were recorded with repetitions situated in the upper, middle and lower part of the field. Records of features were made after each rain in June and July, and once in August. The last record had only two repetitions, both made in the middle part of the field with one metre between the lines. These records of feature distribution are shown in Figure 6.11. This pattern of change in microtopographic features under successive rains is often found in the development of erosion over time. On Site 2, the area of flow paths remains rather constant during the first five rains but increases strongly in August after harvest and the removal of residue. Prerills start after the second rain, and their importance remains rather constant till July, when basal cover increases. Rills occur after the third rain. They continue to cover a small part of the area and increase in August after basal cover disappears. The basal cover provided by the crop and the weeds remains low and constant during four rains. It increases in July because of crop residue and weed growth. It disappears after burning in August. Figure 6.12 shows percentage cover by features on two dates. On July 2 much basal vegetation exists on some of the five fields. A month later the fields have less basal cover, harvest has taken place, residues have been burned or have rotted, and land preparation by tillage has turned residues under. Field 1B has a relatively stronger increase in erosion intensity between the two dates. This reflects the different influence of the crop growth and the post-harvest situation. Field 3A of maize is 4-6% steeper than other sites. At the later date a number of rills has changed into prerills under the influence of splash in the uncovered stage. The sweet potato field 3B has cultivation ridges and furrows that run down the slope but are not formed by erosion. The data of all five fields studied by Woldu (1998) show a tendency of three stages in the development of erosion that has been found generally in our studies and that was also noticed by Valentin (1985) in the soil surface relief. There is a first stage of rapid change, a second stage of rather constant feature distribution, and a last stage of rapid change again. In the case of Site 2 of Woldu, the transitions are around the dates of 16/6 and 2/7.

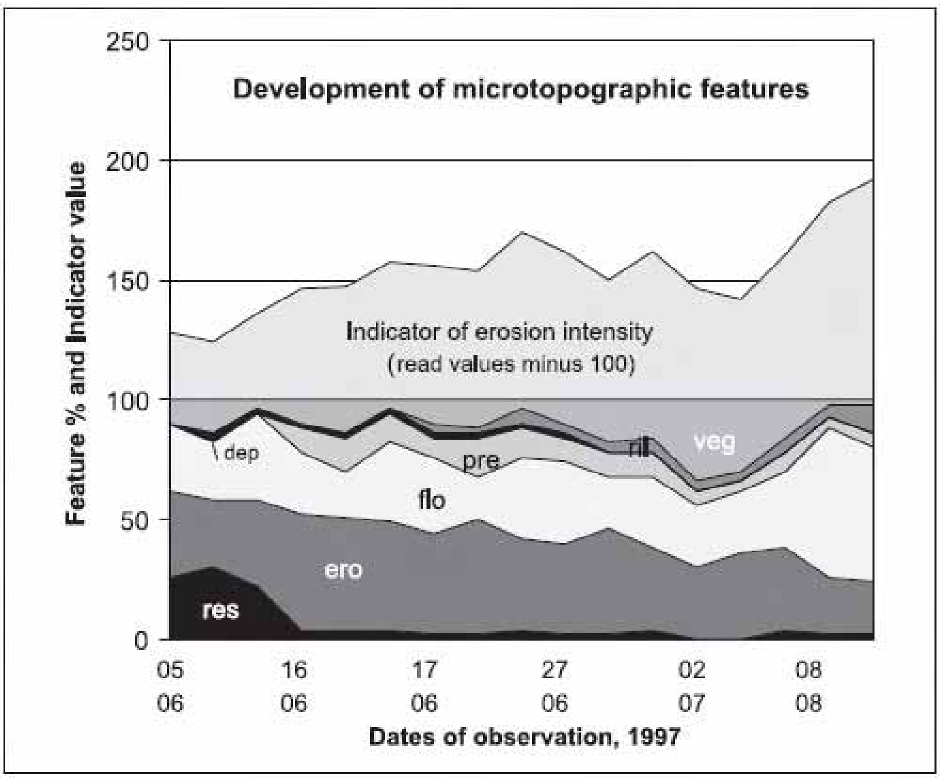


Figure 6.11. Microtopographic features during a two-month period (Site 2, Woldu 1998).Recording is repeated two times in August and three times at other dates.

Field	Features on 2 July 1997							Indicator of erosion intensity	
	res	*ero*	*flo*	*pre*	*ril*	*dep*	*veg*	*Value*	*Rank*
1A	4	40	20	1	2	1	32	26	1
1B	0	39	21	4	0	1	35	29	1
2	3	38	28	10	5	1	15	58	3
3A	1	39	24	19	15	0	2	92	4
3B	3	69	2	7	18	0	1	52	2
Field	*Features on 8 August 1997*							*Indicator of erosion intensity*	
	res	*ero*	*flo*	*pre*	*ril*	*dep*	*veg*	*Rank*	*Order*
1A	3	24	31	18	-	-	22	67	1
1B	2	13	61	20	-	-	4	101	4
2	2	23	59	14	-	-	2	87	3
3A	5	18	49	25	3	-	-	105	4
3B	2	40	36	1	21	-	-	80	2

Figure 6.12. Relative erosion intensity on 2 July 1997 and 8 August 1997.

7 Water erosion

The process of water erosion can be broken down into four processes: detachment by rainfall splash, detachment by overland flow, transport of sediment and deposition. Detachment and deposition can be measured and observed spatially on-site, or the total sediment production of a sample area (plot, field, catchment) can be monitored as a integral measure of erosion.

7.1 Splash detachment

Splash detachment is caused by the impact of raindrops, whereby the kinetic energy of the rainfall causes soil aggregates to break down and particles to be moved over short distances depending on the slope (typically 10-50 cm). The main effect of splash is readying particles for transport, so that they can be transported by overland flow.

Short process description

Spash detachment is usually calculated as the product of kinetic energy of the rainfall and an empirical soil strength parameter. The energy of the rainfall is empirically related to its intensity and duration. There are several non-linear equations for this (logarithmic or negative exponential), more general and also region specific.

Visual effects

Visually the effect of splash (fig 7.1) can be seen as a smoothening of the surface and the formation a crust (see section on monitoring the soil surface). Also "pedestals" may be visible, i.e. stones on the surface that become elevated because the underlying soil is protected while the rest of the soil is washed away.

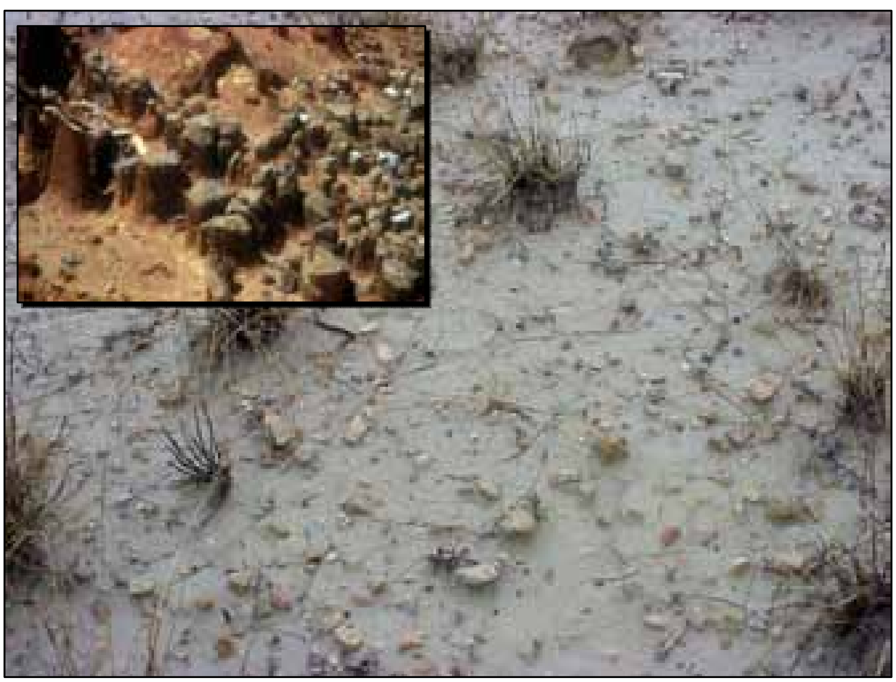


Figure 7.1. A splashed surface with elevated stones. The inset shows pedestals (source: FAO Land and water division, http://www.fao.org/ag/agl/agll/photolib/photolib.jsp?lang=s&nav=back&photo=044).

7.1.1 Monitoring splash

Splash monitoring always needs so called break point rainfall measurements (high resolution rainfall intensity) such as provided with a tipping bucket. The rainfall intensity is converted to kinetic energy. Kinetic energy can also be measured directly with a so called disdrometer [REF] an instrument used to measure the drop size distribution and velocity of raindrops.

Splash cups

Splash can be directly measured with splash cups, tray with soil that are weighed regularly to determine the decrease of material. The amount of splashed soil over a given time period is related to soil strength parameters, such as shear vane cohesion, aggregate stability, or a more empirical erodibility parameter. This is however mostly done with laboratory experiments or with controlled rainfall (see e.g. Mermut et al., 1997). The amount of sediment collected in the splash cup depends not only on splash rate, but also on splash distance (Van Dijk, 2002), making conversion to an erosion rate more difficult. As can be seen from figure 7.2 splashed sediment is caught on the surrounding cloth that covers a metal mesh to let the water drain. Since the cup is divided in two parts downslope splash and upslope splash can be measured separately, and the difference between them will be net splash erosion.

Figure 7.2. Splash cup, Embu, Kenya . Picture by B.Okoba

Combined splash-flow box

An example of a field setup for a combined splash and flow erosion measurement is given by Van Dijk (2002) in a research on erosion of bench terraces on Java. He gives the following description (see fig 7.3). In an attempt to separately measure splash and wash on terrace risers, a Gerlach trough was combined with a modified type of splashboard, or splash box. The splash box used in the present study was made from a plastic box with inner dimensions of 32 x 22 x 5 cm (LxWxH) that was retailed as an assortment box for screws and bits. It had a lid that was kept upright as a final splashguard. The splash box was divided into four compartments separated by 5 cm high partitions about one mm thick. On one side of the box, sections were cut out of each compartment to facilitate sediment sampling and drainage of rainfall. To prevent the loss of sediment, these lateral openings were covered with sliding folded pieces of sheet metal that left just enough space for excess water to drain while at the same time containing the sediment in the compartment. Finally, the inside of the hinging part of the box was covered with tape while strips of nylon 1 mm wire mesh lined the compartments to prevent sediment from splashing out again.

The runoff trough was a bucket having the same width as the splash box. A piece of U-shaped sheet metal with a lip inserted into the riser prevented runoff from infiltrating below the level of the splash box and guided the water into the bucket. A sheet metal cover prevented rainfall and water draining from the splash box from entering the bucket. The bucket and splash box were contained in a metal frame with four pins attached to it that were inserted into the riser. The frame could be adjusted so as to position the splash box horizontally, while the horizontal distance from the riser could also be varied.

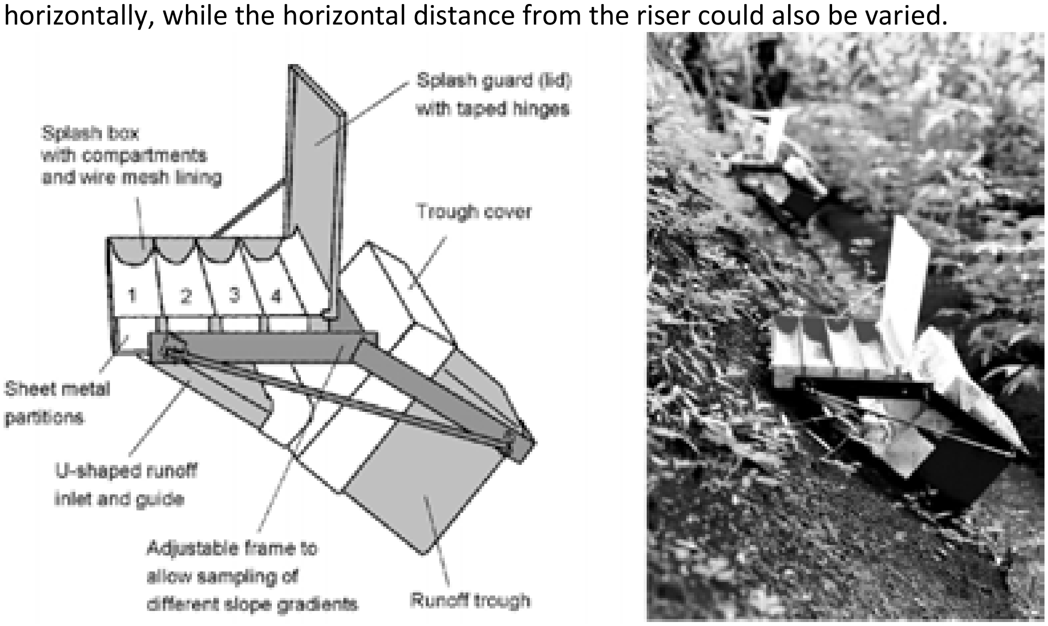


Figure 7.3. The splash box / runoff trough device used in the present study: (a) design and (b) devices III and IV, installed on a 36 degrees terrace riser (Van Dijk, 2002).

7.2 Flow detachment

Overland flow washes away soil particles. When water flows downslope it usually concentrates, thereby increasing in quantity and speed of flowing water. The increased discharge and velocity cause an increase in kinetic energy of the flow and consequently particles can be picked up and transported.

Process description

The energy of the flow can be expressed as streampower, which is proportional to product of the square of the discharge with the slope (Q^2S). hence flow detachment and sediment transport are non-linear processes with respect to overland flow. Theoretically there is a critical streampower below which no transport takes place. Furthermore while transport is directly related to streampower, the flow detachment process needs to overcome an initial soil strength, in order to loosen the particles from the soil surface.

Visual effects

The type of visual evidence of flow detachment depends on the amount of overland flow. Unconcentrated overland flow, for instance on relatively flat areas primarily washes away the particles detached by splash. Once the overland flow concentrates rills may start to appear. Often rills are formed by predefined oriented microtopography, such as planting/seed lines and wheel tracks. A more "natural" rill system based on steepest slope shows a dendritic pattern (see fig 7.4). Larger incision by flowing water causes gullying, often combined with mass movement processes and backward/headward erosion. Gullies occur in many shapes and sizes. Generally a distinction is made into ephemeral gullies and permanent gullies. Ephemeral gullies can be very flat and wide, whereby a broad shallow swath of soil and crops are eroded (see fig 7.5).

Figure 7.4. Rill systems in central Belgium following seedlines (left) and steepest slope (right). Photos: Physical and Regional Geography Research Group, K.U.Leuven).

Figure 7.5. Example of a permanent deep gully caused by backward erosion in Morocco (photo: V. Jetten) and a wide ephemeral gully in Belgium (photo: Physical and Regional Geography Research Group, K.U.Leuven).

7.2.1 Monitoring flow detachment on-site

Flow detachment causes rills and gullies. Rills can be monitoring simply by measuring their length, width and depth. The value of these measurements greatly increases with a good knowledge of the rainfall that caused the rills. Since rill systems can be large and complex, their total volume can be estimated by measuring a few characteristic rills and multiplying this by a total count of rill branches. For practical reasons the difference between a rill and a gully can be set at 1 square foot of cross section.

Rills

The usual method of measuring rill erosion is by measuring length, width and depth of the rills, e.g. using tape. To convert to soil loss bulk density of the eroded sediment should be known. If rills are measured on erosion plots, sheet erosion rates can be derived by subtracting rill erosion from total sediment yield for the plot. Results of erosion plots depend on scale, at least partly because at different scales different erosion processes will dominate. On small plots only sheet erosion is measured, but on larger plots rill erosion is likely to increase in significance, while at hillslope scales gully erosion can occur too. On small plots, divisor systems are usually sufficient, but for larger plots tipping buckets or flumes may be used to measure discharge. Ciesiolka & Rose (1998), for example, advise to use tipping buckets for plot sizes of up to 600 m^2.

Gullies

Poesen et al (2003) mention a number of methods that have been used to measure gully erosion at different time scales. On short time scales, the most usual methods are direct measurement of gully volume, e.g. with tape and the use of benchmark pins around the

gully head to determine headcut retreat. Hudson (1993) also mentions the use of erosion pins driven horizontally into the gully wall, but cautions that inserting the pins might change resistance to erosion. At medium time scales (aerial) photos taken at different moment can be used, while on long time scales historical data (documents and maps) might be available.
Another method is to measure the amount of water and sediment that leaves the gully. Such measurements require that water level is measured (preferably at a weir or flume), and that sediment concentration in the runoff is determined. These methods will be more fully explained in the section on river gauging. If these techniques are used for gullies one should be aware that most gully catchments do not consist of only gullied terrain, so that gully erosion rates cannot be extracted easily from those data.

Piping

Piping is difficult to measure since the pipes are usually inaccessible. Often, the only method is to measure the amount of water and sediment emerging from the pipe outlets. This can not give a precise measurement of piping since the water entering the pipes already contained sediment.

Erosion pins

Erosion pins consist of driving pins into the soil so that the top of the pin gives a datum from which changes in the soil surface level can be measured (Hudson, 1993). Alternatively called pegs, spikes, stakes or rods, the pins can be of wood, iron or any material which will not rot or decay and is readily and cheaply available. Off-cut lengths of round iron bars for reinforced concrete can usually be picked up at little or no cost from construction sites. In some developing countries, iron or steel pins or nails might be stolen, in which case bamboo or reed canes cut locally might be more suitable. The pin should be a length which can be pushed or driven into the soil to give a firm stable datum: 300 mm is typical, less for a shallow soil, more for a loose soil. A small diameter of about 5 mm is preferable, as thicker stakes could interfere with the surface flow and cause scour. A rectangular or square grid layout will give a random distribution of points with a spacing appropriate to the area being studied.

Recently the pin method has been modernized with the Photo-Electronic Erosion Pin (PEEP) sensors (Lawler et al., 2001). It automatically measures surface lowering by erosion or rising by deposition over time by detecting with light diodes when part of the pin becomes unburied (see figure 7.6). The PEEP was used to monitor river bank erosion but could also be used in gully wall retreat or other erosion applications.

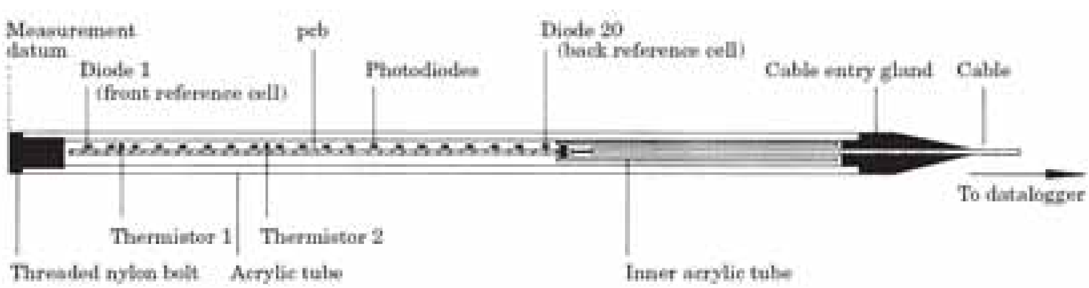


Figure 7.6. The Photo-Electronic Erosion Pin (PEEP) sensor for the automatic monitoring of sediment erosion and deposition events. The STAR20 version depicted is 0·66 m long, contains an array of 20 photovoltaic cells, including two reference cells for signal normalization, and incorporates two thermistors for temperature

monitoring at the sediment surface and at 68 mm depth (pcb=printed circuit board). Different designs are possible to suit the application (Lawler et al, 2001)

Tracing

Most of the measurement techniques discussed above are meant to measure current erosion rates. Using radioactive tracers, however, information can be obtained on longer term erosion rates. Several elements have been used for this purpose, the most widely used being 137Cs. 137Cs is a fission product of nuclear weapons tests and has accumulated in the topsoil due to atmospheric fallout, mainly in the 1950's and 60's (Loughran, 1989), but in parts of Europe also after the 1986 Tsernobyl accident. Since it is quickly and firmly adsorbed it is only translocated if sediment is moving. The principle is to determine 137Cs contents in the soil and to compare those contents to that of sites that can be assumed to be undisturbed since the 1950's. Lower amounts than indicate erosion, while higher amounts indicate deposition. Since only the topsoil contains 137Cs the technique is best suited to determine long term erosion rates for processes that erode the topsoil, such as sheet erosion, rill erosion and tillage erosion. Other elements like excess 210Pb, 59Fe, 46Sc and 7Be have also been used. The advantage of tracing with radioactive elements is that a single measurement is needed (contrary to constant monitoring with other methods), that a spatially distributed picture of erosion and deposition can be obtained and that sediment budgets for entire catchments may be developed. Some tracers with short half-lives might also be useful to study event erosion rates.

7.2.2 Monitoring flow detachment from plots

Flow detachment is usually measured by collecting all overland flow and suspended sediment from runoff plots. These plots can vary in size from micro plots (several meters) to entire fields. Obviously the dimensions of the equipment must be adapted to the amount of runoff expected. This depends on total circumstances: the size of the plot, the climate, the infiltration rates of the soil, land use and vegetation.

A direct and clear advantage of plots is that they can be used directly for demonstration purposes with stakeholders, especially in a comparison of "with and without" SWC measures.

There is a lot of debate on the usefulness of plots as a predictor of erosion or soil loss. Many researchers are negative about plot research when used to predict the soil loss of larger areas. There are several reasons for this:

i) bounded plots will not have inflowing water and thus will not be representative in circumstances with long stretches of free flowing water;
ii) plots may be too small to contain a representative amount of rills, and almost never will contain gullies;
iii) there are many sinks in a catchment such as sharp changes in slopes, edges of fields, boundaries and obstacles, micro and macro depressions etc., where water is slowed down and sediment is deposited. Hence the soil loss from an area decreases in a relative sense when moving from a small plot to a catchment, and the soil loss rates from plots can certainly not be scaled up directly to the catchment size.

Plot research can however be used in a relative sense as is done in the DESIRE project, to determine the relative difference between situations with and without soil and water conservation measures. One should be very careful however in scaling up the results of these experiments.

Wischmeier plot

The so called Wischmeier plot is the basis of all USLE type measurements. It measures 6x72.6 feet. The origin is these dimensions is that a width of 6 feet was considered convenient and a surface of 0.01 acre was then selected. The dimensions have no physical meaning.

Replication

There must be sufficient replications, that is exactly similar repetitions, to allow a measure of the variance within treatments. This is the experimental error caused by unknown and uncontrollable variations in the soil, or the crop, or the treatment, or the equipment, which cause differences in what theoretically should be identical measurements. For agronomy trials of crop varieties, or fertilizer trials, it may be adequate to have only two replications because one expects that the variation will not be large, but with runoff plots there are the same agronomic possible sources of error and in addition many more which can arise from the installation or operation of the plot equipment. As a result three replications should be considered as an absolute minimum, with more if possible. There is no absolute mathematical answer to the number of replications because it is a question of what level of accuracy is expected from the experiment.

Sediment sampling

Sediment from plots can be samples in various ways. The following descriptions are partly copied from the "Guidelines for mapping and measurement of rainfall-induced erosion processes in the Mediterranean coastal areas" (FAO, 1997, section 2.4) and " Field measurement of soil erosion and runoff" (FAO bulletin 68, Hudson, 1993). Basically there are two strategies: collecting the total amount of sediment over a given sample period, or taking small samples and use the runoff amounts to calculate total sediment content.

Total sediment collection

A total collection tank may be constructed to measure erosion in small test plots. The collection tank should be large enough to contain the total runoff (water and sediment) expected in a 24- or 48-hour period. The volume of the water-sediment mixture is then determined and the solid sediment material sampled for subsequent laboratory analysis and computation of its weight and volume. Total collection devices are often unsuitable because runoff storage requirements may be excessive. Also, very small drainage areas are generally not representative of field conditions. To remediate the drawbacks of total collection tanks, slot samplers, which collect a predetermined percentage of the runoff-sediment mixture, are preferred because they can be used for larger test plots. The sampled volume of water-sediment mixture is then reduced to manageable quantities. The two main types of slot samplers are the stationary multislot divisor and the Coshocton wheel sampler equipped with a revolving slot.

Multislot divisor

Runoff is routed from the collector through a conveyance channel to a sludge tank where the heavier sediment particles are deposited (fig 7.7). Overflow from the sludge tank is then routed through the multislot divisor where a sample is obtained from a single slot and routed to a sample storage tank. A second or third sample storage tank may be connected to the first in a cascade setup, if additional sample storage is needed. There will always be considerable amounts of floating organic material in the runoff, and this must be caught on screens if any type of divisor or sampler is used. Sometimes a wire mesh screen is placed over the collecting trough, or alternatively one or more screens may be placed in the collecting tanks. A device widely used in the USA for many years is the GEIB Divisor, which consists of a number of equal rectangular slots. Only water passing through the central slot is collected and stored. This requires a high degree of accuracy in its manufacture and so a number of simpler alternatives have been developed. These include a series of V-notches or vertical rows of holes drilled in a steel plate or a series of pipes built into the wall of the tank. Any of these can be constructed to take a sample of between one fifth and one twentieth of the total flow.

It is always desirable that any divisor should be checked to see that the sample is exactly the proportion that it is supposed to be. There are several possible sources of error, such as the different sampling points not being at exactly the same level, blockages or partial blockages of some of the outlets, or that the sampling mechanism interferes with the flow through the divisor. The velocity of approach to each slot, or notch, or pipe, must be the same. If the divisor is built into a narrow channel the flow through the end slots can be reduced by friction against the channel walls.

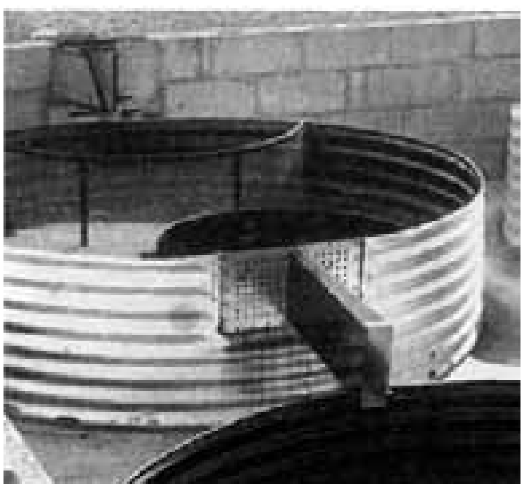


Figure 7.7. Sediment sampling: multislot divisor (left, Hudson, 1993)) and Cochocton wheel (right, USDA North Appalachian Exp. Watershed website)).

Coshocton wheel

The Coshocton-type runoff sampler (fig 7.7) collects and concentrates runoff from an erosion test plot or a natural watershed into a collector at the plot end from which it flows into an approach channel. Water discharge from this channel falls on a water wheel, which is inclined slightly therefore causing the wheel to rotate. An elevated sampling slot mounted on the wheel extracts a sample of water-sediment mixture with the representative proportion.

Suspended sediment samplers

Several types of samplers of suspended-sediment have been developed such as trap samplers, direct pumping, integrating samplers, etc. However, only few of them are designed so that the intake velocity into the sampler is equal to the actual stream velocity. This characteristic is essential for the samples to be representative of the suspended-sediment concentration of the stream at the point of measurement. A well-designed sampler faces the approaching flow and its intake extends upstream from the zone of disturbance caused by the presence of the sampler itself.

Instantaneous samples are usually taken by trap samplers consisting of a piece of horizontal cylinder equipped with end valves which can be closed suddenly to trap a sample at any desired time and depth. The pumping sampler sucks water-sediment mixture through a pipe or hose, the intake of which is placed at the sampling point. Regulating the intake water velocity in order to be equal of that of the stream, the operator can obtain a sample that is representative of the sediment concentration at the point of measurement.

The automatic suspended sediment sampler is a system which automatically pumps up water and sediment samples from flowing water, storing up to 24 individual samples. The sampler can be used for routine monitoring and for recording the variation of sediment loads during transient floods. The automatic sediment sampler can pump sediment suspensions through pipe lengths of up to 10m from flowing water, without altering the sediment concentrations or particle size distributions. It has a variable sampling time, intervals ranging from one a minute to one a day. The sampling schedule can also be programmed to trigger on rising water level for recording during transient floods.

The single stage suspended sediment sampler operates on the siphon principle. It is used to automatically collect suspended sediment samples from flash floods in intermittent streams at remote locations. The sampler consists of a bottle or other suitable container with about Ø 5 mm copper tubes that are formed to a siphon shape and inserted through taps which fit tightly into the tops of the bottles. Several samplers are mounted at various depths on a support that is fixed on the side of the stream so that samples are obtained at several water surface elevations as the water level of the stream rises. Field experience suggests that sediment concentration obtained with this type of sampler may not be closely representative of that of the stream as the sample is always taken near the water surface during the rising stage, and the original sample may be altered by subsequent submerging. Intake velocities may not be the same as streamflow velocities. Because of these drawbacks, concentration data obtained with these samplers should be used with caution.

A variation on this is a simple device where sample bottles are taped to a measuring rod. The bottles fill up during the rising stage of a runoff event and the bottles close of with floating balls to avoid mixture with the descending part of the runoff wave (see fig 7.8).

Turbidity

A different type of sediment sampling through turbidity. Turbidity is an optical measure of the cloudiness of water caused by light scattering from suspended particles, organics, and dissolved constituents. With frequent calibration, the relation of turbidity to suspended sediment load can be used. The advantage of turbidity measurements is that it is near continuous, while collecting samples with containers is more laborious. The disadvantage is that the turbidity of the runoff water depends on the depth of the measurement and turbulence, among other things.

Figure 7.8. Bottle sediment sampling of runoff at the outlet of a catchment (photo ALTERRA Erochina project).

7.3 Deposition

Deposition takes place on all locations where the flow is interrupted and slowed down. From a physical process point of view, streampower decreases and directly causes transport capacity to decrease, in its turn causing the surplus of sediment to be deposited. A decrease in velocity can be the result of abrupt changes in surface resistance, for instance because of vegetation barriers, or edges of fields. Also an abrupt change of slope can trigger deposition (hillslope-thalweg). Lastly also an increase in infiltration may simply cause the runoff water to be (partly) infiltrated, leaving the sediment on the surface.

Estimates of deposition by modelling show that in a small catchment deposition can be half of the amount of detachment, causing the soil loss from a catchment. A good example is given in figure 7.9 by Takken et al (1999), who measured the total soil loss and deposition in the a 290 ha catchment in Belgium, as a result of a 1:200 year event (> 60 mm in one hour). They also gave a breakdown of measured deposition rates. This shows the importance of not only focusing on detachment, but including deposition as well. These figures show the importance of deposition on a landscape catchment scale, and show why soil loss determined from plots cannot be used to determine the soil loss from a catchment.

Visual effects

Deposition when fresh is easy to see as flat patches and sometimes damage to seedlings or crops (see Figure 7.10) . Sometimes deposition in microrelief puddles can be very diffuse and is in fact a form of sedimentary crust formation (see soil surface monitoring).

7.3.1 Monitoring deposition

Deposition is relative easy to see when it is fresh and its extend can be mapped visually or with the help of a GPS. Nevertheless amounts of deposition are difficult to quantify as the depth is not easily determined. By digging trenches one could try to estimate the depth to the original surface but that is not always visible. Special measurements could include deposition mats, such as are used in river flood sedimentation measurements. Mats or plates can be positioned at spots where sedimentation is likely to occur and fastened with pins, to serve later as reference levels. In terms of frequency, deposition should be measured/mapped after each event.

Measured	(ton)	(%)
Erosion		
Interrill	1066	9
Rill	9818	87
Gully	375	3
Total	11,259	100
Deposition		
Total	4510	40

Deposition factor	(ton)	(%)
Slope only	2802	62.1
Slope-vegetation	451	10.0
Slope-road	226	5.0
Vegetation only	833	18.5
Vegetation-slope	121	2.7
Road only	77	1.7
Slope dominant	3878	77.1
Land use dominant	1032	22.9
Total	4510	100

Figure 7.9. Left: a summary of measured and erosion and deposition of a 290 ha catchment as a result of a large event. Right a breakdown of the deposition with causes (Takken et al., 1999).

Figure 7.10. Crop burial by deposition against the edge of a field (above) and at the bottom of a slope (below).

8 Runoff

Runoff or overland flow is one of the main causes of water erosion. It occurs when the rainfall intensity is larger than the infiltration rate of the soil (Hortonian overland flow), or when the soil storage is exceeded (saturation overland flow). The latter may occur in places where the soil is very shallow (and often stony) or where the groundwater is close to the surface and the soil is already very wet. In all cases, quantitative knowledge of soil physical properties is needed to predict runoff.

Process description

Generally runoff is generated when the rainfall intensity exceeds the infiltration rate. Since infiltration rates of dry soils are high at the start of a rainfall event, only a small percentage (generally less than 20% depending on the circumstances) of the event will become surface runoff. The velocity of the runoff increases with increasing water depth, increasing slope, and decreases with increasing surface resistance.

Visual assessment

Runoff is rarely measured directly in the field and visual observations and photographs are rare. Both observations and model simulations indicate that runoff depth on hillslopes is typically less than 1 cm in depth. Also concentration in depressions and flow lines cause a rapid increase of depth, leading to incision. Figure 8.1 below shows runoff in various stages of concentration. Because of its shallowness, the water is rapidly saturates with sediment because of flow and splash detachment, except in cases where the soil is very stony or has a low erodibility otherwise. After an event runoff can be seen by traces of flow in the vegetation (displaced litter or flattened crop in case of heavy rainfall events.

8.1 Monitoring runoff

Runoff can be measure from a plot or reference area (see remarks sediment sampling from plots), or small runoff traps can be put in the field to show that runoff took place. These are not meant to sample amounts of runoff, rather signal activity.

8.1.1 Unbounded plots and runoff Gerlach sampler

In some cases unbounded plots are used with sampling devices that are known generally as Gerlach Troughs after their inventor (Hudson, 1993). They consist of a small collecting gutter which is let into the soil surface and connected to a small collecting container on the downstream side. There are various degrees of sophistication in the construction of the gutters and containers but expensive or complicated construction is not justified because what is required is a large number of replications to overcome the variation which arises from the fact that, without any boundaries to direct or limit runoff into the collecting gutter, the amount collected depends on the chance occurrence of minor depressions or rills. Figure 8.2 shows simple devices made from a dustpan (Hudson, 1993) and from PVC tubes (Van Loon, 2002) to signal runoff activity. The pointed lower part is pressed into the soil until the holes are level with the surface so that overland flow can enter and collect in the vertical tube. If the micro catchment leading to a Gerlach trough can be determined they may be used to actually quantify runoff rather than an on/off type of signalling, but this can be prone to errors. Gerlach type collectors are often used along transects on a slope, so that not only they function as a on/off signal of runoff, but also give some idea of the spatial extent of runoff (Morgan, 2005).

Figure 8.1. Various runoff events: top left: 80 mm event on 17/9/2007 near Octon (S. Fr, photo: S. de Jong); top right: runoff in vineyard near Mont Ventoux (Fr, photo); bottom left: runoff in Pays de Caux (N. Fr.), regular event on winter wheat; bottom right: detail of unconcentrated flow on seedbed (photos: B. Ludwig);

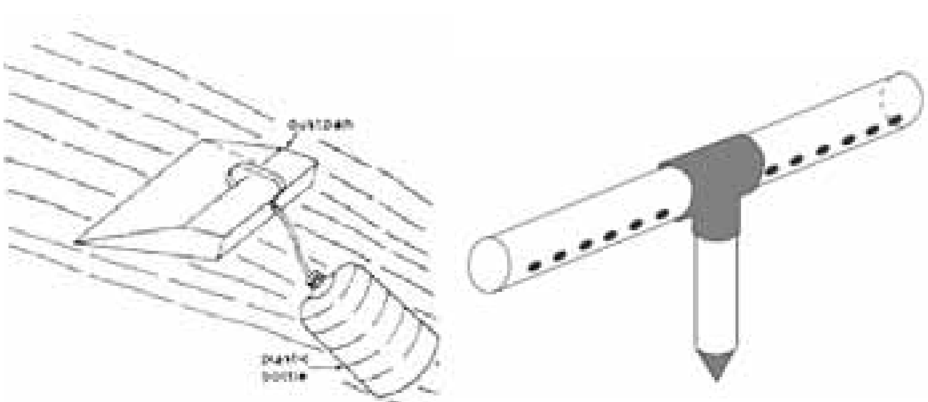


Figure 8.2. Simple runoff sampler made from a dustpan (left) and PVC tubes (right), to signal if runoff took place (Hudson, 1993; Van Loon, 2002).

8.1.2 Size of plots

The following description of plot size is based on Hudson (1993). He states that the size of plots must be related to the purpose of the trial.

- Microplots of one or two square metres may be appropriate if the objective is a simple comparison of two treatments where the effect of the treatments is unlikely to be influenced by scale. An example is the difference in surface runoff when a grass mulch was applied to newly planted tea bushes.
- Small-scale plots usually of about 100 m^2 are most commonly used for trials of cropping practices, cover effects, rotations, and any other practice which can be applied to small plots in the same way as it would be on a field scale, and where the effect can be expected to be unaffected by plot size. The original size and shape for this type of plots adopted in the USA was extremely arbitrary - six feet wide seemed to be a suitable width, and an area of one hundredth of an acre sounded like a convenient size for calculations, and so gave a length of 72.6 feet. There is some justification for following a well-established practice so that direct comparisons may be made, but there is no justification for suggesting that these precise measurements should be followed in metric units. In fact plots only six feet wide are liable to have a significant border effect and a more sensible size in metric units would be five metres wide and twenty metres long.
- When assessing the effect of earth-moving practices such as channel terraces, bench terraces, or any structures which depend for their effect on interruption to the surface flow, larger plots must be used. In such cases the amounts of runoff and soil loss are dominated by the occurrence of weaknesses or failures in the system, i.e., breaks or overtopping in channels or the collapse of banks or walls, and these are not properly reproduced on small plots.
- Field sized plots of about 1 ha are appropriate for assessing any treatment which cannot be applied realistically to small plots. Plots of the order of 1 ha are necessary to assess any form of terracing, contour operations and also to assess the effect of grazing or livestock management. In case of the latter care must be taken not to influence the cattle behaviour by e.g. elevated plot boundaries.

8.1.3 Bounded plots and runoff Measurement

Runoff can be measured with flumes and weirs, which both serve the same purpose of creating a stable relationship between water height and water discharge. They are often combined with sediment samplers.

A **weir** is a small overflow-type dam commonly used to raise the level of a river or stream. Water flows over the weir or an opening in the weir to be able to measure a range of discharges. Only the water height needs to be measured in order to calculate the discharge. This can be done with a pressure transducer in a stilling well that measures the water column above the bed, or with ultrasonic devices that are mounted above the water and measure the surface level. Weirs are normally used to measure streams that have a constant water flow. They are less useful for intermittent flow because the weir first has to fill up and overflow before the measured water level can be recalculated to discharge. Weirs can be broad crested, submerged broad dams that cause an acceleration and constant drop in the water level, or sharp crested (V-notch weir, see figure 8.3), that cause the overflowing water to free fall to the river bed below.

Flumes are artificial small canals with a predefined shape that cause a stabilizing and acceleration of the flow. Again the water height can be measured and recalculated to the discharge with equations that are related to the shape of the flume. Flumes have the advantage that they can be used to measure intermittent flow although there is a minimum flow needed to gain some accuracy in measurement and predicted discharge. Flumes come in many shapes and sizes, from plot size capable of measuring several liters/second to catchment size capable of measuring several 1000 liters/sec (see figure 8.4 and 8.5).

Figure 8.3. Large sharp crested weir (wall with steel knife top) to measure catchment discharge with ultrasonic level measurement. Although an ephemeral stream, construction of a flume was no feasible so a flat weir was chosen as design. (photo Erochina project ALTERRA).

Figure 8.4. Small flume with ultrasonic water level sensor and turbidity sensor built into the hillside slope at the bottom end of the gully (photo Erochina project ALTERRA).

Figure 8.5. Placement of catchment level flume with stilling well (photos Physical and Regional Geography Research Group, K.U.Leuven).

9 Vegetation properties

Vegetation properties such as plant density and structure, and vegetation species or vegetation type composition are important factors for monitoring. They relate directly to a number of desertification processes, and they are often a direct indictor for the measure of success of a SWC method.

9.1 Processes

The processes affected by plants are:

- Transpiration by plants depletes the soil water. Generally it is assumed that water is depleted directly from he soil layers proportional to the fraction of roots in the soil (if the top 20 cm of the soil contain 60% of the roots of a plant, it is assumed that 60% of the transpiration comes from the soil moisture of that part of the profile). Thus it may be that a grass cover with shallow roots below trees with deep roots do not actually compete with the water storage in the soil. When the soil becomes dry enough the transpiration decreases until it stops completely near the wilting point of the soil, because the stomata close. If this continues long enough (depending on the species) the plant eventually dies. In semi-arid areas various species have protective strategies against drying out. This can be for instance a specific leaf structure or coverage with wax, or a specific structure that captures and conserves water (grass clumps, extended root systems far beyond the canopy). Crops are usually les well adapted to drought.
- Interception of rainfall by the canopy, influencing the net amount of rain added to the soil. Interception is determined by the canopy storage capacity which is related to leaf surface (see below).
- Interception by litter on the surface: this is not often studied but litter of course also intercepts rainfall decreasing the net amount of rain into the soil. On the other hand a litter layer prevents direct heating up of the soil which leads to evaporation. This litter works both ways.
- Surface cover protects the soil from splash impact, decreasing the splash erosion. However, in the case of greater canopy height above the surface, the fall velocity of leaf drip increases and erosion can certainly occur. Also leaf drainage drops are larger than rainfall (up to 10x) having a greater mass. Finally leaves tend to funnel water causing more intense fluxes on isolated locations. Thus the protecting effect of leaves on splash erosion is not self evident and depends on the plant structure.
- A dense stem cover or basal cover has a double function: a high basal cover provides flow resistance to the runoff, which decreases erosion because the flow energy of the water is decreased. Moreover, because of slowing down water, it effectively increases the time for infiltration.
- Crops are often dosed with chemicals such as insecticides, that remain on the leaves. Leaf drainage washes away these particles and concentrate them in the top oil. Many researchers find for instance significantly higher copper concentrations beneath grapes than between the grape vines (copper is used as an insecticide).

9.2 Sampling strategy

The above means that observing the vegetation or crop growth and development are important variables to monitor. This can be done in various ways.

Frame observations
Many vegetation studies use frames of $1m^2$ that have a grading of 10 cm on the sides, or wires every 10 cm (which may however cause inconvenience). The frames are used every 2 weeks to determine the vegetation characteristics (height, density, species) on a for instance 20 locations. These are usually fixed locations, in which case also coloured pickets can be used instead of a frame. A portable frame however has the advantage that it doesn't obstruct the farmer. In natural vegetation plots (grassland, forest) fixed plots may be more convenient. It is advisable to select the locations according to a restricted random scheme, i.e. divide the field or plot in a number of sections and select a random location in each section. Do not hesitate to add sample positions later to document specific phenomena, such as rills or deposition and crusting patches occurring.
It may be easiest if the frame can be disassembled and assembled, in case the crop is high and it cannot be placed around stems easily. Once the fame I places a number of things can be determined, see below. Obviously with trees a frame is not convenient, in the case of forest research larger plots can be used (e.g. 20x20 or 50x50 meter), which smller plots inside when e.g. seedlings and saplings are to be assessed.

9.3 Canopy characteristics

As stated above the plant canopy is important for interception, leaf drainage and protection (cover). There are various ways to determine canopy characteristics. Some can be determined by remote sensing images (see chapter 10).

9.3.1 Cover and height

Direct estimation
Plant cover can be estimated using visual comparison charts such as shown in figure 9.1. Hessel et al. warn that this method may lead to overestimation and a test should be done, to ensure that different observers arrive at the same results. The chart is used by estimating the ground cover by plants by looking straight down. Note that the chart has many classes but to distinguish more than 4-5 classes is considered not very feasible or accurate. If different vegetation layers (weeds, shrubs, trees) exist in the field, make an estimation for every layer as well as a total estimation on all plant coverage. It is necessary to estimate total cover too, because this can not be calculated from the coverage of different vegetation layers without making assumptions about the distribution of the vegetation.

Height estimation is self evident, it can be measured directly with a tape or estimated using the angle to a tree top from a give location and the distance to its base.

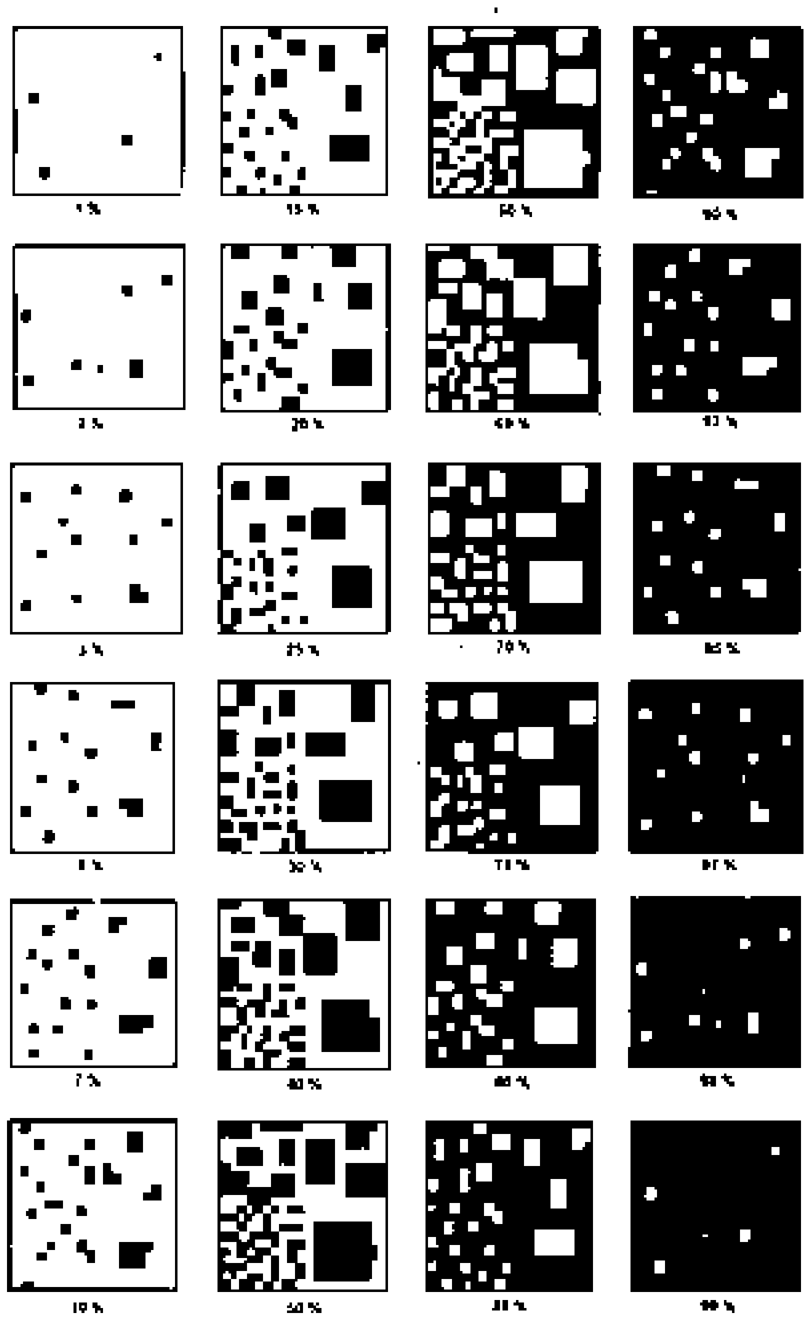


Figure 9.1. Proportions form (FAO handbook).

LAI

The Leaf Area Index (LAI) is the surface of leaves per projected ground surface, in m^2/m^2. It can be estimated by sampling a minimum of 20 leaves and scanning them for digital surface determination. The leaves can then be weighted to establish a weight-surface relationship. Subsequently a larger weight sample can be taken, e.g. a number of plants in case of crops, or branches in case of woody species. However this method is very labour intensive and not very precise, because the leaves are not horizontally spaces in a canopy but under various angles, e leaves grow in time etc.

Licor

A Licor[1] is a light sensor that measures the light energy in W/m^2. If measured below the canopy, and compared with light intensity outside he canopy, the light extinction can be determined. Light extinction in the canopy is exponential and is known for many species. The extinction can be related to cover fraction and Leaf Area Index. Licors and comparable devices come in many types, from fully automatic to handheld. The advantage is that an instantaneous reading is obtained which can be repeated many times, the disadvantage is that the unobstructed radiation should be known at the same time (thus two Licors need to be used simultaneously). The advantage of Licor is furthermore that it can also be used for smaller plants such as mature crops.

Hemispherical photographs

If the canopy is higher then the observer, hemispherical photographs can be taken with a fisheye lens and analyzed with specific software. The digital canopy photo (see figure 9.2) is converted to black and white or gray scales and the Leaf Area Index and cover can be determined from them. For software WINPHOT can be used by Ter Steege (1992)[2], or the CANEYE software (Jonckheere et al., 2004) [3]. The principle of this software is to sample the photos for leaves (dark) and non leaves (white) and translate that to a fraction of light transmission in he canopy. Light transmission can be translated to cover fraction and Leaf Area Index.

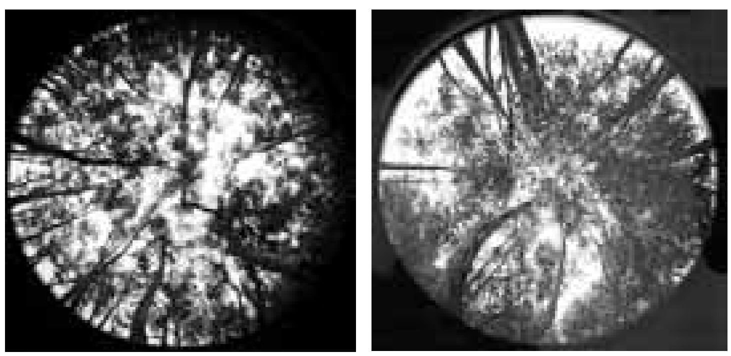


Figure 9.2. Hemispherical photographs of Quercus suber (left) and Eucalyptus (right) (photo J van der Kwast).

9.3.2 Interception storage

To estimate interception the canopy storage and canopy openness are important variables. Both can be related to the projected canopy cover. Based on a literature research De Jong and Jetten (2007) collected a number of storage values and related them to LAI, see figure 9.3). They also demonstrated that these values can be derived from remote sensing images (figure 9.4), where it must be said that the NDVI-LAI relation is empirical from Southern France and may not be applicable everywhere.

[1] http://www.licor.com
[2] http://www.bio.uu.nl/~herba/Guyana/winphot/wp_index.htm
[3] http://www.avignon.inra.fr/can_eye/

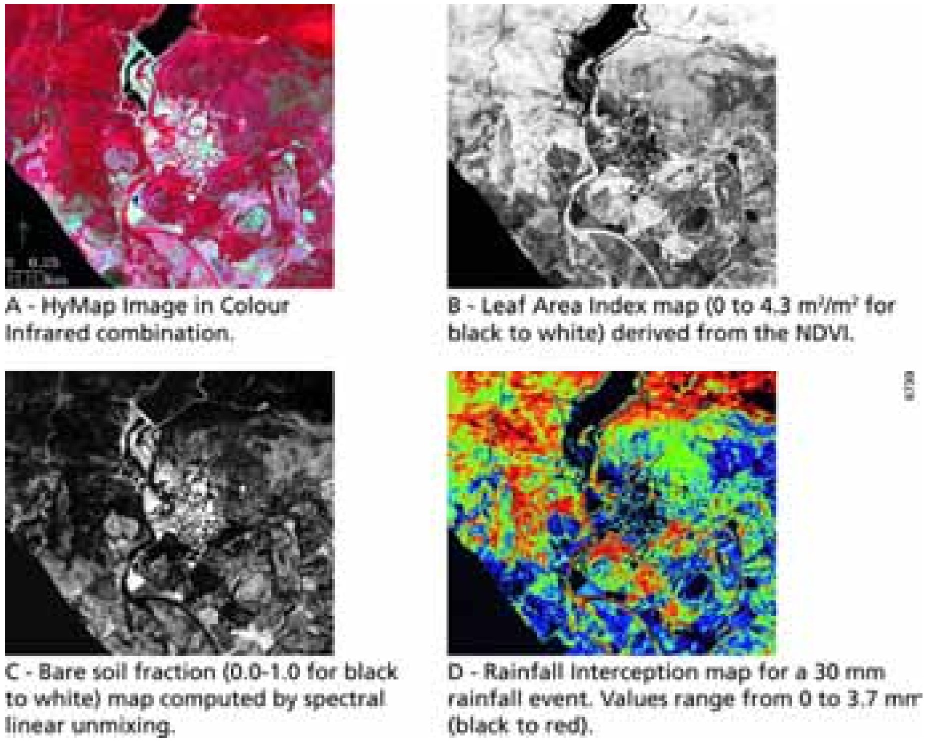


Figure 9.3. Interception parameters from spectral information in Southern France. The red area in the top left image is dense natural vegetation (Maquis), the lighter areas are vineyards (De Jong and Jetten, 2007).

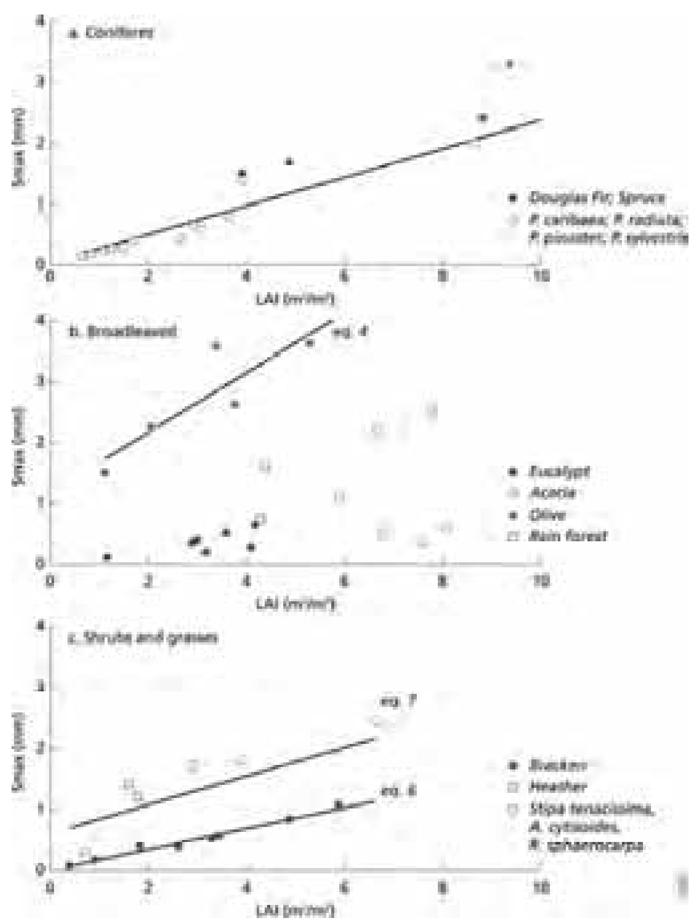


Figure 9.4. Canopy interception storage capacity Smax (mm) and LAI (m^2/m^2) based on literature values. For the data references and equations see De Jong and Jetten, 2007.

9.4 Species composition and functional types

For natural vegetation it may be important to record the species composition. For instance for grasslands, species are important for their protein content which translates directly to he rangeland carrying capacity. In case of natural regrowth of forests or shrubland (such as the Maquis or Maccia vegetation type in the Mediterranean), species composition may be important to characterize the general condition an restoration of the vegetation, for instance after overgrazing or fire. Species are not easy to detect and a good botanical knowledge of the region is needed. It is assumed ere that such knowledge is present and the methodology of species determination is not discussed in detail here.

Frames and transects

The following description is based on the Ecoslopes field protocol Cammeraat et al., 2002). Record at regular intervals cover and average height of the dominant species for a number of 5x5 meter areas for non-destructive vegetation sampling. For smaller plants use 1m^2 frame. Where a square sample area is not possible (e.g. dense forests), the vegetation can be sampled along transects with a similar area or larger, depending on the variability. For each plant, note its species name, abundance and average height. It is worthwhile to create a repository of the species that are encountered on the site. The observations can be used to group the vegetation in functional types. To this end, record those units that approximately 10% of the cover or more and note the species contributing the highest cover values in each functional type. For the characterisation of the vegetation, a classification in functional types can be used:

1. Winter-annuals
2. Drought deciduous perennial grasses
3. Winter deciduous perennial grasses
4. Drought deciduous herbaceous perennial
5. Winter deciduous herbaceous perennial
6. Drought deciduous shrubs < 50 cm in height
7. Winter deciduous shrubs < 50 cm in height
8. Evergreen shrubs < 50 cm in height
9. Drought deciduous shrubs 50 - 200 cm in height
10. Winter deciduous shrubs 50 - 200 cm in height
11. Evergreen shrubs 50 - 200 cm in height
12. Drought deciduous trees and shrubs > 200 cm in height
13. Winter deciduous trees and shrubs > 200 cm in height
14. Evergreen broad leaved trees and shrubs >200 cm in height
15. Coniferous trees and shrubs >200 cm in height

For cultivated fields, additional categories may be added if the crops can not be accommodated by this classification.

9.5 Biomass

Biomass can only be sampled destructively for lower plants and crops, while for certain tree species relations exist to estimate biomass from DBH (diameter at breast height) and height of the plant. In case of crops or grass the biomass can be sampled by cutting and drying the plants, to obtain he dry above ground biomass, in kg/m^2. Note that drying should occur at the same temperature always, to have comparable values. Drying in laboratory ovens should occur over 72 hours on not more than 70^{o}C. The temperature should not be higher because that would destroy the organic matter and give a false additional weight loss. Note that botanists often use "field stove" which consist of a wooden frame with an open bottom under which a series of 10-12 light bulbs are placed. Light bulbs generally produce 98% heat and 2% and are good for drying plants without over-heating. The plants are pressed between sheets of thick paper and arranged in vertical stacks above the light bulbs. Under no circumstances should plant samples be gathered in plastic bags, always use paper bags to prevent molding and rotting, which can occur very easily.

9.6 Root depth and density

Characterizing root structure by depth and density is also straightforward an a considerable amount of work. A pit has to be dug of 80-100 cm in depth and the a division of 10-20 cm layers has to be made on the side wall. A fixed volume is then dug out of the side of wall (e.g. 0-10 cm deep and 30x30 cm in surface) and the total volume of soil and roots have to be collected in a bucket. The sample has to be sieved to remove the largest clods and with water the soil can be washed away and the remaining roots air dried and collected in a separate paper bag to be dried (see above). This is repeated for every 10 or 20 cm layer, which results in a root weight versus depth relationship.

Note that roots have different functions: often natural vegetation has finer roots near the surface to retrieve nutrients from the litter layer, while water is obtained through a central tape root, that may reach very deep into water layers. This differs per species type: conifers are known to have such tape roots, while other species may not. Extremes are know for Acacia species in the Botswana desert, with roots that reach to depth of 60-70m. Similarly in limestone caves in the Alps, roots can be found more that 50m below the surface connected to living trees.

This difference in root function and root systems between tree species and crops is related to the discussion if undergrowth of grass in orchards, olive growth and vineyards is a competitor for water or not. On the one hand the grass most likely takes water from a different soil layer than the trees, on the other hand rainfall passes through the shallow root system first and may therefore be used by the grass before it reaches the deeper layers. It may well be that there is no generic answer to this and the level of competition depends on the local situation.

9.7 Litter, mulch and soil organic matter

Litter is the mass of decomposing organic material on the surface and in the fermentation layer (O horizon). Litter and mulch are important for many processes as described elsewhere in this report, ranging from protection of the surface to increased friction against flow, improve soil structure and provide protection against water loss through evaporation. It is important that if litter or applied organic mulch are followed in time, that photos are taken using standard reference frames of $1m^2$ (or a similar practical reference). This helps in judging their decomposition, cover fraction, occurrence of other features such as pedestals, crusting, rills or litter removal by runoff.

The following description is from Cammeraat et al. (2002). Brush the litter from the surface and store in a separate paper bag. Exclude anorganic material (stones and sediment), either manually or by flotation on a fluid of an appropriate density. Weigh this sample and dry it in a stove at 60°C. Reweigh. Excavate the O horizon to a measured depth over the 50x50 cm surface so that the volume of soil can be calculated. Dry it in an oven at 60°C. Weigh the dry weight of the total sample (Wd). If a large fraction of mineral soil is present in the O horizon, then homogenise the soil and take two sub-samples of ± 100 g from the total sample. Determine the exact total weight of these sub-samples (Wt). Remove the organic material with peroxide. Determine the weight of the mineral soil only (Wm). Calculate net weights of each sample/species and gravimetric moisture content. Calculate the dry bulk density of the O horizon. Calculate the total mass of dried organic material (Wo), of the O horizon using the mean weights of the sub-samples:

$$Wo = \frac{Wt - Wm}{Wt} Wd$$

It is also possible to capture litter in so called litter traps, above ground nets of a given surface that catch litter before it reaches the ground. The advantage is that this litter is not decomposed straight away which may be useful when a chemical analysis is made to determine natural nutrient fluxes and balances. The litter traps are empties at regular intervals, e.g. every 2 weeks.

10 Wind erosion

10.1 Monitoring wind erosion

For monitoring wind erosion it is necessary to assess current status of the problem and assess risk which may occur in future. Assessment of the current status reflects what has happened to date. It is assessed by direct observation and expert judgement. To predicts a potential situation that may occur in future a risk assessment can be made. Risk assessment is generally made based on modelling. For mapping purposes various techniques can be applied such as the use of remote sensing techniques and the use of models.

For monitoring wind erosion the approach described in the global assessment of human induced soil degradation (GLASOD) (Oldeman et al., 1991) will be very suitable. In the GLASOD methodology three wind erosion features are recognised: loss of topsoil (Et), terrain deformation (Ed) and over-blowing (Eo). Loss of topsoil by wind action is a widespread phenomena in arid and semi-arid environment. In general coarse textured soils are more susceptible to wind erosion than fine textured soils. In (semi-)arid environment natural wind erosion is often difficult to distinguish from human-induced wind erosion, but natural wind erosion is often aggravated by human activitites. Terrain deformation by wind erosion is a much less widespread type of degradation than loss of topsoil. It is defined as the uneven displacement of soil material by wind action and leading to deflation hollows and dunes. It can be considered as an extreme form of loss of topsoil, with which it usually occurs in combination. Overblowing is defined as the coverage of the land surface by wind-carried particles. It is an off-site effect of the wind erosion types mentioned above. When it is at extreme case the whole area is then be covered by sand. Over blowing may occur in the same mapping unit as those other types, or in adjacent units. It may influence structures like roads, buildings and waterways but it can also cause damage to agricultural land. Stereoscopic air photo interpretation can be used to delineate boundaries of erosion features.

In addition to mapping wind erosion features degree of degradation can be assessed. The degree of degradation can be categorized into 4 classes as follows: (1) Light: if the terrain has somewhat reduced agricultural suitability, but it is stuitable for use in local farming systems. Restoration to full productivity is possible by modifications of the management system. Original biotic functions are still largely intact. (2) Moderate, if the terrain has greatly recuded agricultural productivity but is still suitable for use in local farming systems. Major improvemtns are required to restore productivity. Original biotio functions are partially destroyed. (3) Strong, if the terrain is unreclaimable at farm level. Major engineering works are required for terrain restoration. Original biotic functions are largely destroyed and (4) Extreme, if the terrain is unreclaimable and beyond restoration. Original biotic functions are fully destroyed.

It is also useful to indicate whether the degradation type recognised in a mapping unit (geomorphic mapping unit?) occurred (1) infrequently (up to 5% of the unit), (2) common (6-10% being affected), (3) frequent (11-25% being affected), (4) very frequent (26 – 50% being affected) or (5) dominant (more than 50% affected). In addition, it would be also useful to indicate the causative factors. Causative factors could be over grazing, over exploitation of land, etc.

Mapping symbol could be combination of alphanumeric letters e.g. Eo2.3g (Eo = Overblowing, 2 = moderate degree of degradation, 3 = frequent or 11-25% of mapping unit affected, and g = overgrazing as being the cause of accelerated erosion).

10.2 Assessment of wind erosion

10.2.1 Use of Aerial Photography

Assessment of wind erosion can be made based on image interpretation. Air photos can be analysed stereoscopically to delineate areas of wind erosion features e.g. areas affected by loss of topsoil, active dune formation, areas affected by over blowing, etc.

If aerial photos are too old the new wind erosion features may not be possible to map. In such a situation a rapidly deployable and effective low cost method to detect and assess wind erosion damage in it early stages should be an alternative method. With such a method one should be able to:

- accurately establish the type, spatial extent, severity and spatio-temporal trends of the wind erosion pattern in the source areas;
- analyse the nature of the underlying erosion processes and causal factors involved;
- achieve the above within acceptable geometric accuracy limits and with due effectiveness and efficiency in terms of manpower, cost and time.

One of the alternate and rapid methods of assessing wind erosion damage is the use of small-format aerial photography (SFAP). SFAP has proven to be valuable instrument for various resource inventory studies such as in forestry, rangeland mapping, etc. (Tueller et al., 1988) used SFAP to measure changes in rangeland vegetation in north-eastern Nevada, USA using helicopter-borne 35 mm aerial photography. (Hennemann and Nagelhout, 2004) applied SFAP in Naivasha area in the Rift valley, Kenya as a tool to develop wind erosion detection and assessment method. In the Naivasha area in Kenya the SFAP photographs were taken with a 35 mm Minolta camera from a small Cessna 182 aircraft in the year 2000; a total of 130 photographs were shot in 4 flight lines to cover the study area. Sufficient ground control points were taken to rectify the photos. The photos were scanned and imported as raster data in a GIS system (ILWIS 3.4). Using old aerial photos from 1991 of the area erosion severity maps of the two different periods, general trends and rates of land degradation for the period 1991-2000 could be calculated and assessed. The use of small-format aerial photography applied in the Naivasha area, Kenya shows that an up-to-date colour photo cover of the entire study area can be generated at a scale of 1:5,000 at a reasonable cost and that erosion severity map can be generated quickly.

10.2.2 Use of satellite remote sensing techniques

Satellite image interpretation can be done monoscopically on colour composites at relevant scale. For making false colour composites the band combinations of Landsat TM band 4 (red), TM band 5 (green) and TM band 3 (blue) is commonly used. In case of ASTER and SPOT image the ideal combination would be band 3 (red), band 2 (green) and band 1 (blue). Once the colour composites are made interpretation can be carried out for wind erosion features following GLASOD approach.

If stereo pair of satellite data is available e.g. SPOT stereo pair or ASTER stereo pair interpretation can be carried out using stereoscope or directly on compute screen. Stereo pair can be also generated if digital terrain model (DTM) or contour data is available. To generate stereoscopic image from the combination of satellite image and DTM a software such as the remote sensing and GIS software, ILWIS, will be required. Explanation of using satellite image in combination with DTM data is explained in detail as follows:

For stereoscopic interpretation of satellite image a stereo pair is necessary (see fig 10.1). In case of unavailability of stereo pair (e.g. stereo SPOT image or stereo ASTER image) digital elevation model (DEM) can be also used. For this purpose a GIS software is indispensible. The ITC developed GIS software (ILWIS 3.4) is open source software. ILWIS is a remote sensing and GIS software which integrates image, vector and thematic data in one unique and powerful package on the desktop. ILWIS delivers a wide range of features including import/export, digitizing, editing, analysis and display of data, as well as production of quality maps. ILWIS software is renowned for its functionality, user-friendliness, and has established a wide user community over the years of its development.

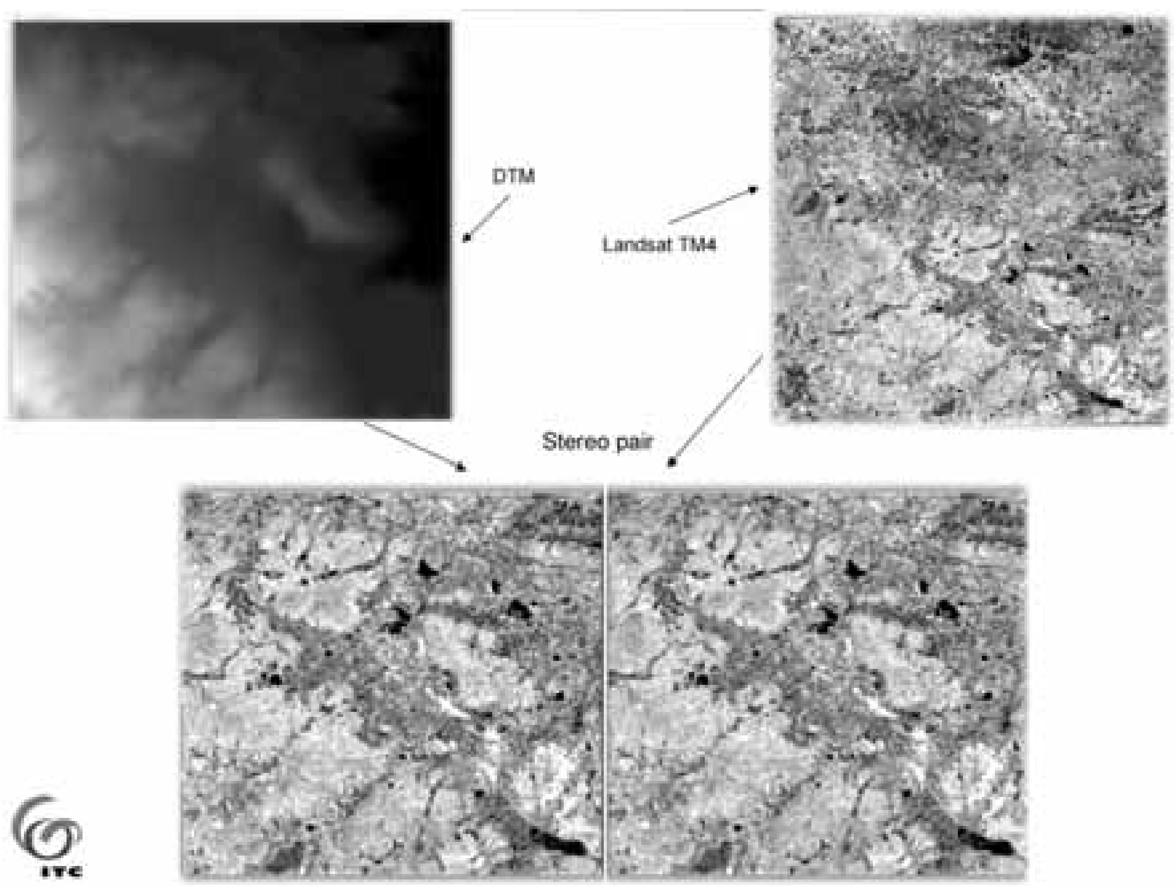


Figure 10.1. Generation of stereo pair from DTM and Landsat TM data

Apart from visual interpretation for wind erosion features, satellite data can be also used in computing vegetation canopy estimation which can be used for wind erosion hazard assessment. Canopy cover is generally computed using Normalysed Difference Vegetation Index (NDVI). A linear function to derive USLE C- factor in a case study in Southern France with the resulting equation of C = 0.431 – (0.805xNDVI) is described by (de Jong, 1994). For estimation of canopy cover exponential function seems to give better result than linear function (Van der Knijf et al., 1999). Exponential function is given by:

$$C = e^{-\alpha \frac{(NDVI)}{(\beta - NDVI)}} \quad (1)$$

where α and β are the parameter determining the shape of the curve with constants 2 and 1 used for α and β respectively.

Application of a wind erosion model

Modelling wind erosion started in the early sixties for semi-quantitative estimation of soil losses. Wind erosion modelling has been mainly semi-empirical and focussed mainly on on-site effects. The Wind Erosion Equation (Woodruff and Siddoway, 1965) is a good example. It has been applied in several locations (Klik, 2008; Panebianco and Buschiazzo, 2007; Wassif et al., 2002). (Klik, 2008) reports that soil erosion assessment by wind erosion equation linked to a GIS enables the designation of potential risk areas and that the results seem to be reasonable. The Wind Erosion Equation (WEQ) calculates potential average annual erosion rates as follows:

$$E = f(I, K, C, L, V) \quad (2)$$

Where,

E is the potential annual soil loss (t ha^{-1} yr^{-1}),

I is the soil erodibility, expressed as potential annual soil loss in (t ha^{-1} yr^{-1}) from a wide, unsheltered isolated field with bare, smooth, level, loose and non-crusted surface where the climatic factor C,

K is the surface roughness factor which is a measure of the effect of ridges made by tillage and planting implements, or other means of creating systematically spaced ridges. Ridges absorb and deflect wind energy and trap moving soil particles.

C is an index of climatic erosivity, specifically wind-speed and surface soil moisture. The factor for any given location is based on long-term climatic data and is expressed as a percentage of the C factor, which has been assigned a value of 100,

L is the unsheltered, weighted travel distance (in m) along the prevailing wind direction,

V is the equivalent vegetation cover expressed by relating the kind, amount, and orientation of vegetative material to its equivalent in kg ha-1 of small grain residue in reference condition (SGe).

The equation includes some functional relationship which are not linear mathematical calculations.

Soil erodibility factor I

The soil erodibility factor I is related to the percentage of non-erodible surface soil aggregates larger than 0.84 mm in diameter which can be determined by dry sieving method (Chepil, 1942). Based on the soil texture 8 Wind Erodibility Groups are distinguished. A distinction is made in calcium carbonate content because soils high in CaCO3 (> 5%) are more erodible. The Wind Erodibility Groups have been applied to the Austrian Texture Triangle (fig 10.2). The soil erodibility index was then calculated as weighted average of the area of each texture class (fig 10.3). The Soil erodibilty factor is also affected by topographic features like knolls. Knolls are topographic features characterized by short, abrupt windward slopes. Wind erosion potential is greater on knoll slopes than on level or gently rolling terrain because wind flow-lines are compressed and wind velocity increases near the crest of the knolls. Erosion that begins on knolls often affects field areas downwind. Adjustments of the soil erodibility index I are used where windward-facing slopes are less than 160 m long and the increase in slope gradient from the adjacent landscape is 3 percent or greater. Both slope length and slope gradient change are determined along the direction of the prevailing erosive wind.

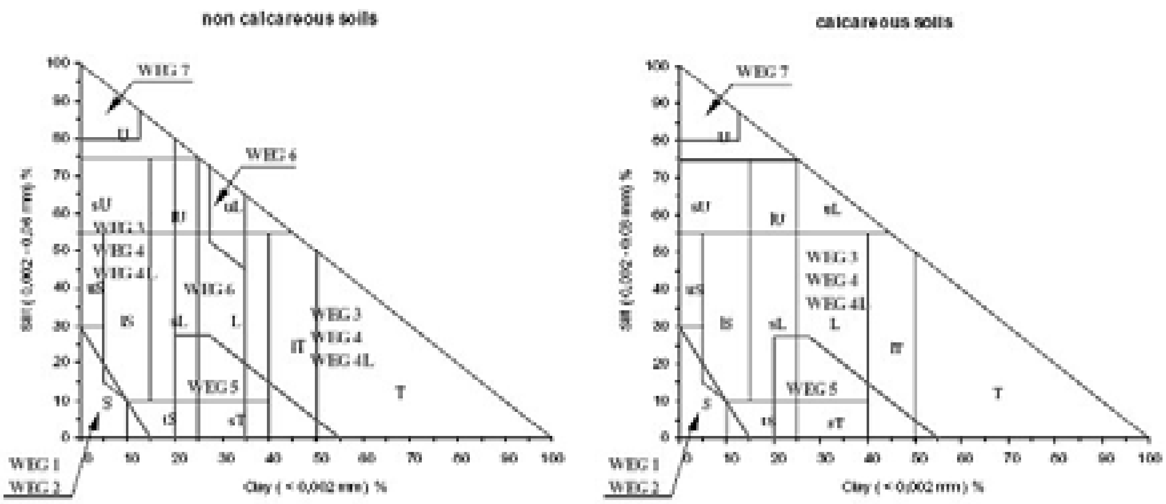


Figure 10.2. Application of wind erodibility groups to the Austrian soil texture triangle

Symbol	Texture	non-calcareous	calcareous
S	sand	544	544
uS	silty sand	213	213
lS	loamy sand	213	213
tS	clayey sand	245	245
sU	sandy silt	213	213
U	silt	130	136
lU	loamy silt	166	213
sL	silt loam	163	198
L	loam	149	193
uL	silty clay	67	213
sT	sandy clay	138	138
lT	loamy clay	198	198
T	clay	213	213

Figure 10.3. Soil erodibility index (t ha $^{-1}$ yr $^{-1}$) for soil textural classes

Surface roughness factor K

The roughness factor K describes the effect of soil surface roughness on soil erosion. It is distinguished between random roughness (Allmaras et al., 1996) and oriented roughness made by tillage and planting implements, or other means of creating systematically spaced ridges. K-factor for oriented roughness can be also determined using equations by (Williams, 1986) where ridge height and ridge distance in prevailing wind direction are considered.

The random roughness values used in the WEQ are the same values used in the Revised Universal Soil Loss Equation RUSLE (Renard et al., 1997). The effect of random roughness on K is only used with the Management Period Procedure. The random roughness factor accounts for roughness effects on soil erodibility. It considers that surface roughness of soils with high erodibility decreases faster than of less erodible soils.

Climatic factor C

The C factor is an index of climatic erosivity, specifically wind-speed and surface soil moisture, and is expressed as a percentage of the C factor, which has been assigned a value of 100 (Lyles, 1983). The climatic factor equation is expressed as:

$$C = 386.u^3 / (PE)^2 \quad (3)$$

Where,

C is the annual climatic factor, u is the average annual wind velocity,
PE is the precipitation-effectiveness index of Thornthwaite, which is calculated by:

$$PE = 3.16.\Sigma[Pi / (1.8Ti + 22)]^{10/9} \quad (4)$$

Where,

Pi is monthly precipitation in mm and Ti average monthly air temperature in °C.

The prevailing wind erosion direction is the direction from which the greatest amount of erosive wind occurs during the critical wind erosion period or time period being evaluated.

Beside wind speed the erosive wind energy (EWE) has the main impact on the erosion process. When hourly wind speed data are available the hourly EWE can be assessed by following equation:

$$EWE_{hr} = 3600.p.U^2 (U - Ut) \quad (5)$$

Where,

EWE_{hr} is the hourly erosive wind energy in g s^{-1}, p is the air density (g m^{-3}), U and Ut are the average hourly wind speed and average hourly threshold wind speed (m s^{-1}), respectively. For the threshold wind speed a value of 8 m s^{-1} is often indicated.

Unsheltered distance L

The L factor represents the unsheltered distance along the prevailing wind erosion direction for the field or area to be evaluated. It is the total length of the field reduced by the length

sheltered by protection measures. The determination of the unsheltered distance is done stepwise:
- Determination of an isolated field
- Determination of wind breaks and their properties
- Determination of prevailing wind direction
- Calculation of sheltered field length by wind breaks
- Calculation of unsheltered distance

L begins at a point upwind where no saltation or surface creep occurs (stable) and ends at the downwind edge of the area being evaluated. The investigation area had to be divided into a number of fields which could be considered as isolated from each other. This means that no soil particles are crossing these field boundaries. Field boundaries consist of wind breaks, roads and field paths, creeks etc.

For the determination of isolated fields topographical maps can be combined with information from satellite images and aerial photos. Satellite imageries or aerial photos can be useful for the knowledge of the field geometry, tillage direction, existence of wind breaks and roads. Determination of area sheltered by wind breaks can be estimated as a length of 15 times the height of the wind break assumed in prevailing wind direction (Tibke, 1988). However effectiveness of the wind break depends on the porosity of the wind breaks (fig 10.4).

Porosity	**Sheltered field length (x height of wind breaks) in m**
Low	15
Medium	10
High	5
Very high	2

Figure 10.4. Sheltered field length

Vegetation cover factor V

The effect of vegetative cover in the Wind Erosion Equation is expressed by relating the kind, amount, and orientation of vegetative material to its equivalent in kg per hectare of small grain residue in reference condition (SGe). This condition is defined as 25 cm long stalks of small grain, parallel to the wind, lying flat in rows spaced 25 cm apart, perpendicular to the wind. Position and anchoring of residue is important. In general, the finer and more upright the residue, the more effective it is for reducing wind erosion. (Williams et al., 1990) proposed an equation for the V-factor based on the small grain equivalent SGe:

$$V = 0.2533(SGe)^{1.363} \qquad (6)$$

The SGe can be assessed by:

$$SGe = g_1.B_{AG} +_{g2.} SR +_{g3.} FR \qquad (7)$$

where g1, g2, g3 are crop coefficients, B_{AG} is the above ground living biomass (kg ha^{-1}), SR is the standing residues (kg ha^{-1}) and FR is the flat residues (kg ha^{-1}). The variables g1 - g3 are derived from (Williams et al., 1990) and are shown in fig 10.5 for the main crops.

Crop	g1	g2	g3
Summer barley	3.390	3.400	1.510
Winter wheat	3.390	3.400	1.610
Sugar beet	1.140	0.600	0.330
Soybean	1.266	0.633	0.729
Corn	0.433	0.433	0.213
Sorghum	0.657	0.657	0.320
Summer wheat	3.390	3.390	1.610
Sunflower	3.390	3.390	1.610
Potatoes	3.390	3.390	0.320

Figure 10.5. Coefficients g1, g2, g3 for calculation of small grain equivalent SGe for main crops

The protective impact of the vegetation depends also on the angle between prevailing wind direction and the tillage direction or direction of planting. In the WEQ a correction factor considers this fact. For the Management Period Procedure the knowledge of temporal distribution of living biomass production, residue amounts and impact of tillage on soil surface roughness is necessary.

Depending on availability of detail data including wind velocity rates at a given storm event a dynamic process-based model such as the Texas Tech Erosion Analysis Model (TEAM) can be also applied to predict detachment, movement and deposition of soil particles associated with wind processes (Gregory et al., 2004). TEAM simulates the suspension and movement of dust above and downwind from eroding sites and predicts a horizontal movement in mass per unit width per unit of time for wind and humidity inputs.

11 Salinity

Temporal and spatial variation in salinity are fundamental in the identification phase, and must be foreseen in any monitoring activity (Biggs and Power, 2003). Salinity monitoring can be done by taking soil samples and analyzing for various salts, by sampling soil water, by measuring electrical conductivity and related parmeters, or by using irphoto's and remote sensing. Metternicht and Zinck (2003) give a list of a variety of remote sensing data, which have been used to identify and/ or monitor salt-affected areas. The list includes 'ground-based', 'air-borne', and 'space borne' data. Some of the ground-based devices for data collection are also available to be installed in an aircraft or helicopter. For instance, imaging spectrometry (hyperspectral) can be done either by using a hand-held spectrometer or in a flight using an aircraft equipped with the devised spectrometer. Note that remote sensing based techniques assume that the salt is visible at the surface. Not detecting salt may mean that salt is present, but deeper in the soil profile. None of the approaches mentioned above can be claimed to be fully accurate. This means that any attempt to use remote sensing and/or models should be validated by regular sampling (fieldwork) and laboratory analysis.

11.1 Saline and sodic soils

To give a general picture of agricultural management applicable to salt affected soils is not a simple task, knowing the great variability which exists not only amongst the soils of different areas, but also within a given area covered by salt-affected soils. The exact identification and classification of the salt-affected soils must be validated using laboratory data. To decide on the type of agricultural management for salt-affected soils, their physico-chemical properties must be well known. In broad lines, two large soil groups exist, namely saline (not alkaline) soils, and the salt-affected soils with high Na-saturation. The latter group includes saline-alkali and the alkali soils.

Experience has shown that reclamation/ management of the saline soils is easier than the saline-/alkali soils. The problem grows larger when alkalinity begins to disturb the physical soil properties such as break down of soil aggregates, formation of impermeable surface crusts, etc. One dares to say that real sodic soils with high ESP, where the impermeable surface crust is formed is actually a dead soil (must be classified as "other", where no agricultural management helps anymore.

Saline soils

Land preparation on saline soils is dependant on the soil profile. The management of the soils classified as slightly, moderately,... saline phase of a given soil may be easier, but obviously very critical as carelessness in management will sooner turn these soils to real salt-affected ones. In some cases - even in real Salorthids - where the Salic horizon lies below soil surface, i.e., the upper 20 - 30 cm is not fully affected, a shallow plow for crops with shallow superficial root system (eg., barley, wheat, etc) can be recommended. In connection with water management, it is very important to decide on the right irrigation method. Detail studies should clarify which of the basin, furrow, sprinkler, or drip irrigation methods is the most appropriate one. In places where climatic conditions suit and enough water is available, rice cultivation is the best landuse.

Seeding and planting time should also be decided upon for each type of soil. Traditionally, seeds are sown somewhere halfway between the bottom of the furrows and the top of the ridges in a prepared furrowed field (see also FAO, 1988).

Sodic soils

There are certain similarities with the management of the saline soils, but far more complicated. Any agricultural practice on sodic soils must aim at how to reduce the high ESP to its minimum.
There are several types of grasses which are very tolerant to sodic soils. This mean that agroforestry land use types can be recommendable knowing that some trees can also be grown well (depending on the soil profile) using the auger-hole technique (Yadav et al. 1975).
As conclusion, one may say in short that the salt-affected soils must be treated/managed with care. Farmers with high technical know-how are to be put on these soils.

11.2 Salinisation monitoring

Salinity refers to the presence of the soluble plus readily dissolvable salts in a soil sample, which influences the inherent ability of the soil (as a medium) to carry an electric current. Electrical conductivity (EC) is a numerical expression of that inherent ability. In other words, electrical conductivity indicates the soil materials’ electrical resistance (FAO, 1999).

11.2.1 Field studies and use of soil maps

Salinity maps often used to be derived from the multipurpose soil maps. Obviously soil maps are good sources to find the location and extension of salt-affected areas. In small- scale studies, potential salinity can be estimated from : (Szabolcs, 1977)

- climatic factors such as temperature, rainfall, humidity, etc;
- geological, geomorphologic, hydro(geo)logical, geochemical;
- some of the soil properties;
- agricultural practices;
- irrigation practices.

For salinization researches, particularly in the arid/ semi-arid regions special soil surveys will be required (Kovda 1970) where:

- special attention is paid to geomorphology of the terrain (watershed, low terrace, ancient
- upper terraces, colluvial fan, etc)' also lithology becomes more important;
- phenology of plants (eg., rate and number of germinating seeds, quality of seedlings) is
- regularly described;
- soil profiles are much deeper than in the case of survey for dry farming. A depth of 2 to
- 2.5 m for pits, with some drilling up to 4-5 m (for limited number of typical points drilling
- must reach 6 to 7 m) is recommended;
- loose soil samples are collected from all (sub)horizons; samples from topsoil will
- preferably taken from 0-2, 2-5 or 7, 5- 15 etc;
- subsoil samples are taken from every 30 to 50 cm;
- if groundwater has reached, sample must be taken for analysis;
- all water sources in the area such as deep wells, rivers, etc must be sampled and analyzed
- soil and groundwater dynamic must be seriously taken into account.

There are certain similarities with the study of the saline soils, but far more complicated. Alkalinity can be caused by the occurrence of alkaline elements in the soil, in which case pH is a good indicator, but the problem is more complicated if alkalinity is caused by exchangeable sodium. In this case pH may not be a good indicator, but ESP (Exchangeable Sodium Percentage).

	Saline	Sal.-Alk.	Alkaline (sodic)
EC (ds/m)	>4	>4	<4
pH	<8.2	>8.2	>>8.2
ESP(%)	<15	>15	>>15
desription	soluble and non-hydrolitic salts of Ca, Mg (SO_4, Cl) with low Amounts HCO_3	Na salts are dominant	$NaHCO_3$ or Na_2CO_3 are dominant

Figure 11.1. Salt-affected (general) classification

11.2.2 Field and laboratory

Apart from direct chemical analysis of soil samples and soil water samples, salt can be detected by electrical conductivity, pH, ESP and SAR.

Electrical conductivity (EC)

The salt content of the soil can be estimated roughly from an electrical conductivity measurement on a saturated soil paste or a more dilute suspension of soil in water. A better estimate can be obtained from the conductivity of a water extract of the soil. The greater the EC the higher the materials' electrical resistance, which is stressed in 'the greater is the salt content'. The SI unit of conductivity is 'Siemens' symbol 'S' per meter. This has replaced the old unit "mho" (1 mho = 1 Siemens). The most common unit was "mmhos/cm", which is exactly equal to "dS/m" (FAO, 1988).

pH measurement

pH meters are used to measure the negative logarithm of the hydrogen-ion activity. The value can be determined potentiometrically by means electrodes, or colorometrically, by indicators whose colors vary with the hydrogen-ion activity. pH readings can be influenced by the composition of the exchangeable cations, the composition and concentration of soluble salts, presence or absence of gypsum and alkaline-earth carbonate. Soil-water ratio plays a very important role in pH readings. It has been assumed that pH values of 8.5 and greater should correspond with ESP of 15 or more.

ESP (Exchangeable Sodium Percentage)

The total amount of exchangeable cations that a soil can retain is designated as CEC (Cation Exchangeable Capacity). The percentage of CEC made up by Exchangeable Sodium (ES) is known as ESP, which is indeed a far better indicator for alkalinity; the sodic soils. However, there some laboratory arguments against the determination of ESP.

SAR (Sodium Adsorption Ratio)
This is used in estimations of water quality and it is quantitatively related to ESP of the soil thus recommended to be used instead of ESP. Some correction coefficients may be employed to find out the relationship between ESP and SAR (Landon 1984). The equation is:

$SAR = Na / (Ca + Mg)^{0.5}/2$

However, there are some problems with SAR too. The SAR values greater than 30 must not be trusted. In these cases the value of constant KG needs to be determined experimentally for each major group of soils (FAO, 1988).

11.2.3 Geophysical techniques

Electromagnetic induction (EM)
The shallow electromagnetic surveying system (EM-38, fig 11.2) was introduced in the 80's as a quick appraisal system for detecting soil salinity in the first 1.5 meter of the profile (Mc Neill, 1980). The device is moved above the soil surface, without touching the ground (nondestructive). Data can be obtained in two operating modes; the vertical dipole mode (EMv) measures average bulk conductivity (ECa) of the first 1.5 meter, while the horizontal dipole mode (EMh) measures the first 75 cm of the soil profile.

Figure 11.2. Top: EM38 in vertical (V) and horizontal (H) modes, bottom: use in the field

The EM technique depends on a transmitter coil and a receiver coil. The transmitter coil is energized with an alternating current. This will cause time-varying magnetic field which induces a very small current in the earth. These currents generate a secondary magnetic field, *Hs,* which is sensed together with the primary field, *Hp*, by the receiver coil (Mc Neill, 1980). Relation between the secondary and the primary magnetic fields at the receiver coil is defined as follows:

$$\frac{Hs}{Hp} \approx \frac{i\omega\mu\sigma(s)^2}{4} \quad (1)$$

Where,
Hs = secondary magnetic field at the receiver coil
Hp = primary magnetic field at the receiver coil
$\omega = 2\pi f$
f = frequency (Hz)
μ = permeability of free space
σ = ground conductivity (mho/m)
s = intercool spacing (m)
i = $\sqrt{-1}$

Following equation 1, since ground conductivity is related to the ratio of secondary to primary magnetic field the apparent ground conductivity, σa, can be calculated as follows:

$$\sigma a = \frac{4}{\omega\mu(s)2}\left(\frac{Hs}{Hp}\right) \quad (2)$$

EM 31, EM38, and like devices are commercially available for measuring bulk soil electrical conductivity (ECa) in an easier way than taking samples and analyze in laboratory. At farm level (FAO, 1999), the readings can be used to generate maps in a GIS environment, wherever interpolation is possible. The maps when generated for different seasons/ years can help monitoring the salinity distribution also at deeper layers (Figure 11.3).

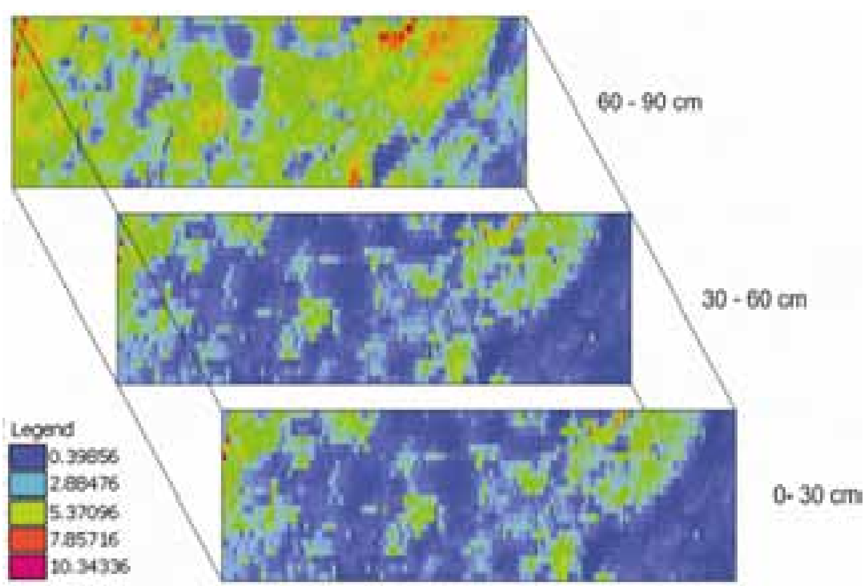


Figure 11.3.: example of different classes of ECa = Bulk Electrical Conductivity of the soil surface and at two depths. The advantage of the EM38 is the ability to detect salt at various depths (Source: Shrestha et al, 2005b)

Gamma-ray spectrometry (radiometrics)

Gamma-ray spectrometry measures the abundance of potassium (K), thorium (eTh) and (eU) in rocks and weathered materials to depths of 30 to 50cm. Gamma-rays emitted from the surface will relate to the primary mineralogy and geochemistry of the bedrock, and the nature of secondary weathering (regolith materials). Gamma-ray spectrometry (radiometric) data interpretations can be used to derive maps of soil and regolith units at farm and paddock scale in a shorter period than traditional soil mapping applications. By establishing a relationship between soil and regolith units and salt storage, salinity hazards may be identified. Improved delineation of geomorphology, soil units and salinity hazards using gamma-ray spectrometry contributes to improved land management decisions, and has proved to be particularly effective in the West Australian wheat belt (Wilkes & Beckett, 2003).

11.2.4 Remote Sensing

Aerial photography

This is the most commonly used remotely sensed data used in the study of salt-affected soils. Salinity/ alkalinity is considered as an inferred element (Farshad, 1999), where several photographic as well as landscape elements (features) will have to be used (fig 11.4). Depending on the type of saline/alkali soils, that is, whether the salinity is shown on the surface or not, detection may vary from very easy to impossible.

The saline soils of tidal zones, deltaic marshes and coastal depressions, continental lowlands, and the man-made soils in the irrigated areas are comparatively easier to detect provided the required local reference level is present. The soil type is generally classified as solonchak. Inference is made through relief (position in the landscape), greytone, drainage condition, lithology of the surroundings, vegetation and landuse (in crop land: how the crop stand looks like), and some special pattern (for instance, in case of takyric solonchaks).

Figure 11.4.: An example of an aerial photograph (panchromatic film) showing light coloured salt-affected areas

In saline soils where salinity is not shown on the surface, that is, those with a salic horizon somewhere below the soil surface, detection is very difficult or often not possible. The poor crop stand on the salt-affected soils without surface appearance will show different surface reflectance as compared to non-salt - affected soils with a better vegetative cover. The results of aerial photo-interpretation can be enriched if combined with the use of remote sensing data, regarding the wider spectrum benefitted in the latter case. Difference in surface reflectance will help to separate the salt-affected soils from the non-salt-affected ones. To delineate different patches with different salinity level is questionable. Salt-affected soils are identified not only because of the differences in reflectance or emittance but mainly due to the different landuse and the physiographic position they occupy.

Remote sensing detection platforms can be divided into airborne and spaceborne. Multispectral sensors have a few broad bands in visible and infrared wavelengths, while hyperspectral sensors have many narrowly defined bands. It is characteristic of soil components to appear in narrow wavelength regions, which are not detectable when working with broad-bands sensors, such as the most commonly used Landsat TM, SPOT, and ASTER. These sensors are also limited in the number of bands, when compared to the hyperspectral sensors with more than 200 bands (e.g., the push broom imager—Hyperion—with 220 10nm bands, covering 400 to 2500 nm).

Airborne Magnetics (AEM)

Application of airborne electromagnetic, magnetic, and gamma-ray spectrometry techniques yielded successful results in Australia. The study shows that surface salinity hazard maps can be generated provided the remotely sensed data are integrated with proper ground data, borehole information, and Landsat TM images (Metternicht and Zinck, 2003). AEM data needs considerable ground validation.

Airborne videography and digital multispectral cameras

These cameras have also been trialed for direct and indirect salinity mapping and monitoring. Multi-temporal optical and microwave remote sensing also have the potential to contribute to detecting temporal changes of salt-related surface features (Metternicht & Zinck, 2003).

HyMap™ hyperspectral scanner

The HyMap provides 128 bands across the reflective solar wavelength region of 0.45 – 2.5 nm with contiguous spectral coverage (except in the atmospheric water vapour bands) and bandwidths between 15 – 20 nm (http://www.hyvista.com/).

Hyperspectral DAIS 7915 sensor

The European Unionhttp://europa.eu.int/ and DLR invested on a 79-channel Digital Airborne Imaging Spectrometer (DAIS 7915), which was built by the Geophysical Environmental Research Corp. (GER). This sensor covers the spectral range from the visible to the thermal infrared wavelengths at variable spatial resolution from 3 to 20 m depending on the carrier aircraft flight altitude.

Thematic Mapper (TM) sensor

The TM sensor has seven spectral bands: six acquire Earth reflectance data, and one acquires earth temperature data (http://edcwww.cr.usgs.gov/glis/hyper/guide/landsat_tm). The spatial resolution of bands in the visible and reflective infrared regions is 30 m. The TM sensor also has greater overall radiometric sensitivity than the MSS. Data must be ordered from the Earth Observation Satellite Company (EOSAT), who holds the commercial rights to all TM data less than 10 years old. The U.S. Geological Survey's Global Land Information System (GLIS) provides information on the sensor, and acquisition and availability of Thematic Mapper Landsat Data. Currently, the TM sensor on Landsat 5 is still collecting data. EOSAT's construction of a Landsat 6 satellite was intended to continue acquisition of TM data with a so-called "enhanced Thematic Mapper" (ETM). The ETM included the addition of a 15-m panchromatic band to obtain higher spatial resolution.

SPOT

In a comparative study Kalra and Joshi (1996; http://www.informaworld.com/smpp/title~content=t713722504) assessed the potential and limitation of various data products obtained from Landsat, SPOT and IRS satellites in order to identify the different kinds of salt affected soils in the Indian Arid Zone. The SPOT HRV2 PLA data with a resolution of 10m offered a delineation of saline and sodic soils due to brackish water irrigation and two levels of natural salinity. The SPOT HRVI MLA FCC was also helpful in mapping three levels of natural salinity as saline/sodic soils, due to the poor quality of irrigation water. They could infer the overall extent of salinity using April/May imageries, but the differentiation of salinity and sodicity for the 'rabi' crop season (January) could be achieved only by the FCC imagery of the three satellites.

ASTER

Aster (Advanced Spaceborne Thermal Emission and Reflection Radiometer, http://asterweb.jpl.nasa.gov/) is an imaging instrument flying on Terra, a satellite launched in December 1999 as part of NASA's Earth Observing System (EOS). ASTER is a cooperative effort between NASA, Japan's Ministry of Economy, Trade and Industry (METI) and Japan's Earth Remote Sensing Data Analysis Center (ERSDAC). ASTER is being used to obtain detailed maps of land surface temperature, reflectance and elevation. The three EOS platforms are part of NASA's Science Mission Directorate and the Earth Sun System, whose goal is to observe, understand, and model the Earth system to discover how it is changing, to better predict change, and to understand the consequences for life on Earth. http://science.hq.nasa.gov/earth-sun/index.htmlhttp://science.hq.nasa.gov/earth-sun/index.html http://science.hq.nasa.gov/earth-sun/index.htmlASTER provides high-resolution images of the Earth in 14 different bands of the electromagnetic spectrum, ranging from visible to thermal infrared light. The resolution of images ranges between 15 to 90 meter.

12 Remote Sensing vegetation indices

Remote sensing images, both space-borne and air-borne, are available in many different temporal and spatial resolutions. Some product are expensive and have to ordered in advance, hoping for a cloudless sky within a certain time window, some are cheap or free and can be simply downloaded.

The spectral information in visible and infrared wavelength give much information on vegetation. Because the state of the chlorophyll in plants can be assessed, various vegetation related parameters and indices can be derived (see below).

12.1 Sensors and satellites

12.1.1 High resolution

Quickbird

QuickBird is a high-resolution commercial earth observation satellite, owned by Digital Globe and launched in 2001 as the first satellite in a constellation of three scheduled to be in orbit by 2008. QuickBird collects the highest resolution commercial imagery of Earth, and boasts the largest image size and the greatest on-board storage capacity of any satellite. The satellite collects panchromatic (black & white) imagery at 60-70 centimeter resolution and multispectral imagery at 2.4- and 2.8-meter resolutions. An image normally covers 16.5x16.5 km^2 (nadir). It has 4 bands: blue (450-520nm), green (520-600nm), red (630-690nm), near-IR (760-900nm).

IKONOS

IKONOS is a high-resolution commercial earth observation satellite, and was the first to collect publicly available high-resolution imagery at 1- and 4-meter resolution. It offers multispectral (MS) and panchromatic (PAN) imagery at 4m and 1m resolution respectively. An image normally covers 11x11 km^2 (nadir). It 4 bands: blue (445-516 nm), green (506-595 nm), red (632-698 nm), near-IR (7570-853 nm) .

Cartosat 1 and 2

CARTOSAT 1 is a stereoscopic Earth observation satellite in a sun-synchronous orbit. The satellite was built, launched and maintained by the Indian Space Research Organisation. CARTOSAT-1 carries two state-of-the-art panchromatic (PAN) cameras that take black and white stereoscopic pictures of the earth in the visible bands. The swath covered by these high resolution PAN cameras is 30 km and their spatial resolution is 2.5 metres. Cartosat 2 is non-stereo and provides a resolution of 80 cm.

12.1.2 Medium resolution

Landsat

The Landsat program is the longest running enterprise for acquisition of imagery of Earth from space. The first Landsat satellite was launched in 1972; the most recent, Landsat 7, was launched on April 15, 1999. Landsat 7 data is acquired by the enhanced thematic mapper plus (ETM+) scanner has eight spectral bands with spatial resolutions ranging from 15 (pan) to 60 meters (thermal IR).

SPOT

SPOT (Satellite Pour l'Observation de la Terre) is a high-resolution, optical imaging earth observation satellite system operating from space. It is run by Spot Image based in Toulouse, France. It has a 5m resolution stereo capability, 2.5 m pan and 10 m multispectral. The last SPOT is launched in 2005.

ASTER

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is one of five remote sensory devices on board the Terra satellite launched into Earth orbit by NASA in 1999. The instrument has been collecting data since February 2000. ASTER provides high-resolution images of the Earth in 14 different bands, ranging from visible to thermal infrared light. The resolution of images ranges between 15 to 90 meter. ASTER data is used to create detailed maps of surface temperature of land, emissivity, reflectance, and elevation.

12.1.3 Low resolution

MODIS

MODIS (Moderate-resolution Imaging Spectroradiometer) is an instrument on board the Terra (EOS AM) Satellite, and in 2002 on board the Aqua (EOS PM) satellite. The instruments capture data in 36 spectral bands ranging in wavelength from 0.4 µm to 14.4 µm and at varying spatial resolutions (2 bands at 250 m, 5 bands at 500 m and 29 bands at 1 km). Together the instruments image the entire Earth every 1 to 2 days. They are designed to provide measurements in large-scale global dynamics including changes in Earth's cloud cover, radiation budget and processes occurring in the oceans, on land, and in the lower atmosphere.

NOAH-AVHRR

The National Oceanic and Atmospheric Administration (NOAA) is a scientific agency within the United States Department of Commerce focused on the conditions of the oceans and the atmosphere. AVHRR instruments measure the reflectance of the Earth in 5 relatively wide spectral bands. The first two are centred around the red (0.6 micrometer) and near-infrared (0.9 micrometer) regions, the third one is located around 3.5 micrometer, and the last two sample the thermal radiation emitted by the planet, around 11 and 12 micrometers, respectively. Resolution is 1 km^2.

12.2 Vegetation, soil surface and drought indices

Live green plants absorb solar radiation in the photosynthetic active radiation (PAR) spectral region, which they use as a source of energy in the process of photosynthesis. Leaf cells have also evolved to scatter (i.e., reflect and transmit) solar radiation in the near-infrared spectral region (which carries approximately half of the total incoming solar energy). Hence, live green plants appear relatively dark in the PAR and relatively bright in the near-infrared (Gates 1980). By contrast, clouds and snow tend to be rather bright in the red (as well as other visible wavelengths) and quite dark in the near-infrared.

These strong differences in reflection can be exploited to differentiate between live plant tissue and dead plants or soil and water. The Normalized Difference Vegetation Index NDVI is calculated from these individual measurements as follows:

$$NDVI = \frac{RED - IR}{RED + IR}$$

where RED and NIR stand for the spectral reflectance measurements acquired in the red and near-infrared regions, respectively. These spectral reflectances are themselves ratios of the reflected over the incoming radiation in each spectral band individually, hence they take on values between 0.0 and 1.0. By design, the NDVI itself thus varies between -1.0 and +1.0. The NDVI of an area containing a dense vegetation canopy will tend to values of 0.3 to 0.8, clouds and snow fields will be characterized by negative values, surface water has a low reflectance in both spectral bands results in very low positive or even slightly negative values, and finally soils generally exhibit a near-infrared spectral reflectance somewhat larger than the red, and thus tend to also generate rather small positive NDVI values (say 0.1 to 0.2).

NDVI is used in many studies on vegetation cover, LAI and vegetation type and health. A number of derivatives and alternatives to NDVI have been proposed in the scientific literature to address these limitations, including the Perpendicular Vegetation Index (PVI: Richardson et al. 1977), the Soil-Adjusted Vegetation Index (SAVI: Huete 1988), the Atmospherically Resistant Vegetation Index (ARVI: Kaufman and Tanre 1992) and the Global Environment Monitoring Index (GEMI: Pinty and Verstraete 1992). Each of these attempted to include intrinsic correction(s) for one or more perturbing factors.

SAVI and TSAVI

The soil-adjusted vegetation index (SAVI) incorporates an adjustment factor (a) to the NDVI to account for the amount of exposed substrate since soil reflectance strongly affects NDVI: (NIR-VIS)(1-a)/(NIR+VIS+a), where a is a soil brightness factor. Other indices—the optimized soil-adjusted vegetation index, the modified soil-adjusted vegetation index, and the transformed soil-adjusted vegetation index—specify SAVI's adjustment factor differently in an attempt to better account for substrate reflectance.

NDWI

The normalized difference water index (NDWI), is proposed for remote sensing of vegetation liquid water from space.

$$NDMI = \frac{R_{860} - R_{1240}}{R_{860} + R_{1240}}$$

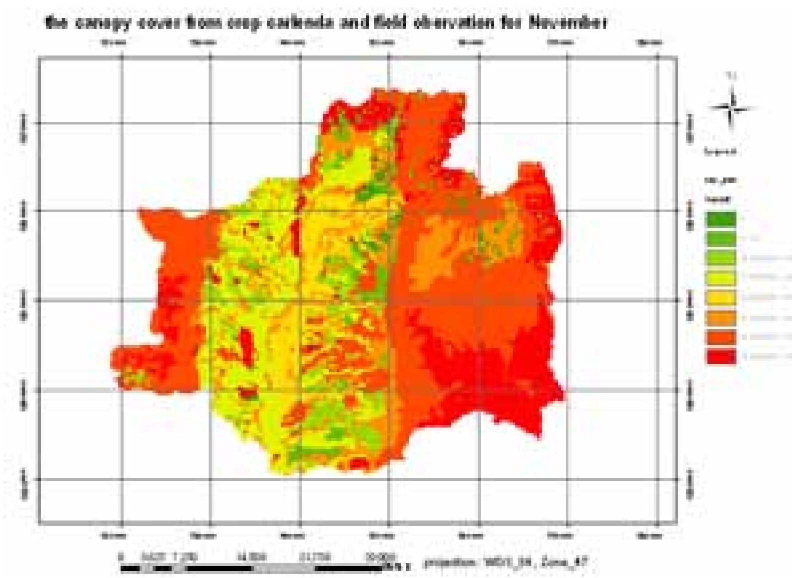
where R represents the apparent reflectance. At 0.86 micrometers and 1.24 micrometers , vegetation canopies have similar scattering properties, but slightly different liquid water absorption. The scattering by vegetation canopies enhances the weak liquid water absorption at 1.24 micrometers . As a result, NDWI is sensitive to changes in liquid water content of vegetation canopies. Because aerosol scattering effects in the 0.86-1.24 micrometers region are weak, NDWI is less sensitive to atmospheric effects that NDVI. Figure 12.1 shows plant cover derived from NDVI and a land use map.

NMDI

The Normalized Multi-band Drought Index (NMDI), is proposed for monitoring soil and vegetation moisture from space. NMDI is defined as:

$$NDMI = \frac{R_{860} - (R_{1640} - R_{2150})}{R_{860} + (R_{1640} - R_{2150})}$$

where R represents the apparent reflectance observed by a satellite sensor. Similar to the Normalized Difference Water Index, NMDI uses the 860 nm channel as the reference; instead of using a single liquid water absorption channel, however, it uses the difference between two liquid water absorption channels centered at 1640 nm and 2130 nm as the soil and vegetation moisture sensitive band. By combining information from multiple near infrared, and short wave infrared channels, NMDI has enhanced the sensitivity to drought severity, and is well suited to estimate both soil and vegetation moisture.



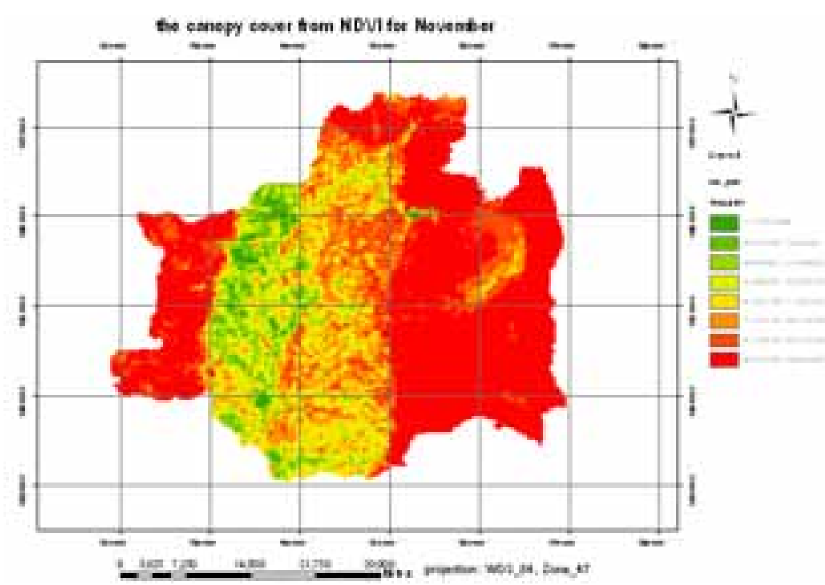


Figure 12.1. November cover fraction from crop calendar (upper image) and NDVI from a composite of MODIS images (lower image) in a province in Thailand.

Main references

Agricultural University of Athens. 2008. WB2 MANUAL for Describing Land Degradation Indicators, DESIRE project report.

Bergsma & Farshad. 2007. Monitoring Erosion Using Microtopographic Features. Ch 14 in "Monitoring and evaluation of soil conservation and watershed development", De Graaff et al. ed., p 239-256.

Cammeraat, L.P.H. van Beek & L.K.A. Dorren, 2002. Ecoslopes field protocol. Report Ecoslopes project, EU FP6, QLK5-2001-00289.

Heesel, R. 2001. Input Measurements For The Lisem Model. EROAHI project ALTERRA.

Hudson, N.W. 1993. Field measurement of soil erosion and runoff". FAO Soils Bulletin 68.

Kosmas, Kirkby, Geeson. 1999. The Medalus project - Mediterranean desertification and land use. Manual on key indicators of desertification and mapping environmentally sensitive areas to desertification. Project ENV4 CT 95 0119 report.

Stocking & Murnaghan .2000. Land Degradation – Guidelines For Field Assessment.

Allen R.G., Pereira L.S., Raes D., Smith M. 1998. Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56.