Assessing the space and time variations of the surface features and the cultivation profile

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Physical problems usually occur with chemical deficiencies and soil acidity. It is therefore necessary, before setting up experiments, to characterize the site by mapping the physical parameters which frequently govern overland flow, water intake, and erosion. This being the case, a survey method of the surface features is presented which enables the production of large-scale maps.

Furthermore, agricultural trials require the monitoring of the parameters which influence the crop yields, such as water infiltration and storage, and rooting. Methods to characterize the cultivation profile and to collect associated data are proposed. Finally, the identification of the main physical constraints in the field, combined with simple measurements performed at various key periods, provide a pertinent tool to implement better soil management.

Plot uniformity is a prerequisite for setting up agronomic experiments and for interpreting results. However, soil variability can occur even within small tracts of land. Even more changeable are the soil surface features and those induced by tillage. Such variations should not be ignored, since surface

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features, e.g. vegetation cover, microrelief and crusting, as well as tilled-layer characteristics, namely compacted structures and ploughpans, chiefly control seedling emergence, rooting, infiltration rate, and water-holding capacity (Valentin, 1988). In addition, other man- or soil fauna-produced variations (burnt patches, ash heaps, and termite mounds) may notably aggravate the variations in chemical characters (Pushparajah, 1990). Another aspect is monitoring changes in time. Such an approach usually provides valuable information on the intensity of degradation processes. This paper presents some methods for:

- surveying surface features when characterizing a site; and
- monitoring surface and cultivation profile characteristics over time.

Soil surface mapping

The area to be mapped

Water flows are key determinants of cropping. They influence mechanical and chemical erosion, possible running-on pollution, and spatial differences in water availability. Therefore it is necessary to map the catchment area which includes the selected site. This elementary hydrologic unit of 2-5 ha needs to be accurately delineated and surveyed so that a topographic map can be produced. The contour interval to be selected depends on the slope. For such an area, five contour lines should be considered as a minimum. If available, a computer programme can be used to draw a three-dimensional diagram. This figure gives a preliminary insight into surface water flow concentration hazards.

Mapping procedure

For very detailed surveys on a scale of 1:1000, the most accurate mapping procedure is the grid method. It consists of describing the features of each point of the grid of squares and in surveying the changes along the lines forming the grid pattern. For an idealized square watershed of one hectare, 10 x 10 (= 100) points are described on a 10-m grid, along 10 transects of 10-m length. Each transect is surveyed, beginning at either the dividing or the drainage line. Within the points the surveyor makes notes of the changes in surface features. On each selected point, two scales of observations must be considered: 100 m^2 and 1 m^2.

Observations on 100 m^2

The 10 x 10 m quadrats need to be centred on the sample points so that the characteristics listed below can be described readily.

Vegetation cover and land use

Several classes of height can be differentiated, including trees, bush, grass, crops, weeds, and creeping plants. For each layer, the basal and aerial covers must be estimated in tenths of the total area, or in percent. These additional characteristics can also be noted:

- the main species;
- the plant association, or the planting pattern;
- the history; and
- deficiency or pathology symptoms.

In a field with only a few trees, it may be helpful to indicate the location and the extent of the influence (shadow) of each tree.

Ground cover

- the percent cover of decaying vegetal matter, surface litter, crop-residue mulch, burnt patches, ash heaps, leftover tree stumps, and gravel or rock outcrops;
- the thickness of each layer; and
- specific associated features: litter dams and microterraces (Mitchell and Humphreys, 1987).

Microrelief

- slope form, topographic accident (slope break) depressions, and sedimentation zones;
- termite mounds: height, basal area, type, general pattern;
- rills and gullies: density, size, general pattern; and
- man-made features: furrows, ridges, conservation structures (size, angle with the slope). These raise the following questions: do these structures concentrate to divert overland flow? Are the paths functional as transport channels for eroded sediment? Do wheel tracks foster overland flow concentration?

mall-scale observations

More detailed observations on the soil surface are made over areas of 1 to 4 ^{2}, centred on the sample points:

- mesofauna: termite tunnels at the soil surface (Photo 1), worm casts, ant pellets (size, surface cover, associated porosity);

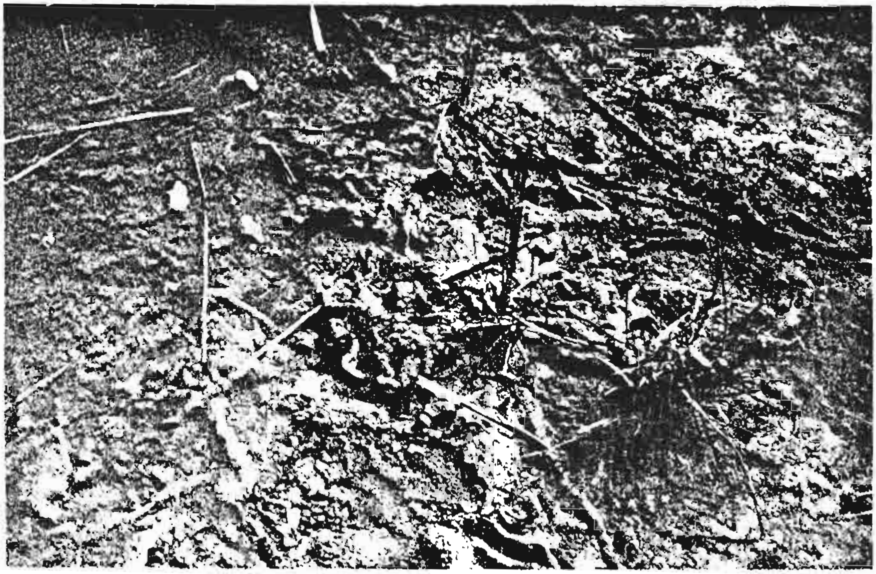

Photo 1. Surface termite tunnels built to avoid sunlight. Such constructions are associated with surface porosity connected to subsurface galleries (Booro-Borotou, northern Côte d'Ivoire).

- superficial porosity: cracks (width, depth, pattern), vesicles within the surface crust (density, diameter); these vesicles indicate restricted infiltration;
- pedological characteristics of the soil surface: colour, mottles, texture, coarse material (size, percent of surface cover, nature), rock outcrops (percent of surface cover, nature), structure, and consistence;
- erosion features: exposed roots (size, density), pedestals (height, nature - Photo 2);
- surface crusts: it may be useful to refer to a typology, corresponding to six main genetically related types of surface crusts based on the nature of the outcropping microhorizon, the number of microhorizons, and their continuity (Valentin, 1989a):

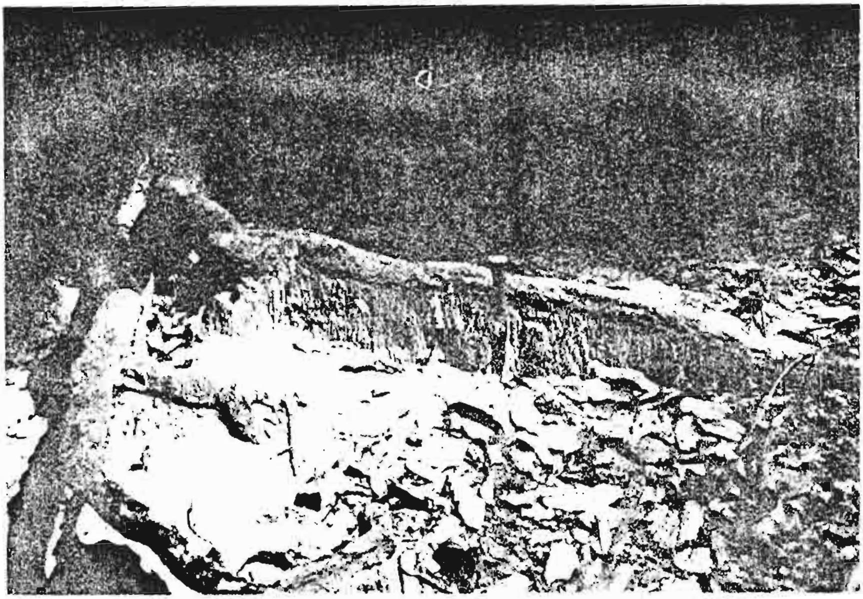

Photo 2. Spectacular pedestal feature associated with a root which has protected the soil from removal by splash erosion (Ton Nga Chang waterfall park, southern Thailand).

- o *Drying crust*: This type of crust is characterized by the outcropping of a single sandy microhorizon, with a weak massive structure, being very fragile, and possibly as much as several tens of millimetres thick. When the soil is protected with a vegetation cover, surface structural changes are restricted to a slight cementation of the upper millimeters due to the repeated wetting and drying cycles. However, crust strength remains low and the processes are revertible.
- o *Structural crusts*: these are of three types:
  - Structural crust 1. Frequently quite thick (as much as 10 mm or more); it contains partially slaked aggregates.
  - Structural crust 2. This crust is composed of a sandy microhorizon, often massive and continuously overlaying a seal made of finer particles.
  - Structural crust 3. This crust is located at the top of a coarse sandy microhorizon; then at a fine sand microhorizon with a massive and vesicular structure, and finally at the bottom with a plasmic seal of

vesicular porosity. When it is walked on the crust may break due to the pronounced porosity and sink a few millimeters making a well-defined track in the surface.

- o *Erosion crust* (Photo 3): This type of crust is formed from a single plasmic seal, which is smooth, rigid and often very thin. It results from the evolution of structural crust with:
  - One microlayer: in this case, erosion caused by splash and runoff has obliterated the remains of incorporated clods.
  - Two or three microhorizons: the firm plasmic seal is the residue remaining after the coarse particles of the above sandy microlayers have been removed by runoff and possibly by wind.

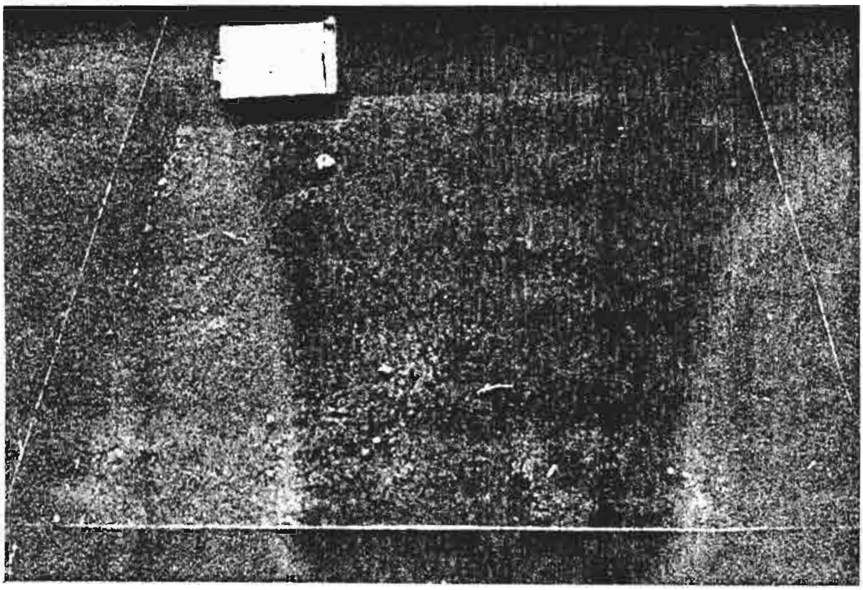

Photo 3. Erosion crust in a 1 m^2 plot. The outcropping plasmic seal is smooth and very impervious. Even under dry conditions, runoff occurs after 1 mm of rainfall (Oursi, northern Burkina Faso).

- o *Runoff depositional crusts* (Photo 4): These are composed of sandy microhorizons interbedded with thin plasmic laminae. Two main types must be distinguished:
  - runoff depositional crusts, which form under water flow and often show marked vesicular porosity, on a gentle slope, they may be as much as several centimeters thick, particularly between ridges.
  - aeolian crusts, which are built up from wind-deposited materials. Their laminar structure is very fragile.

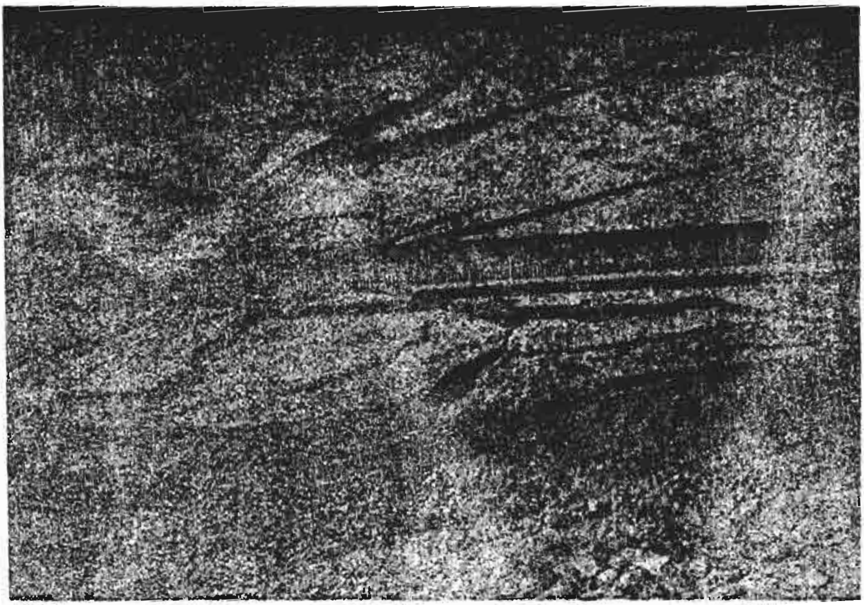

Photo 4. Runoff depositional crust in a maize field. Note the numerous interbedded microlayers (Hat Yai area, southern Thailand).

- o *Sedimentation crust* (Photo 5): the textural sorting which governs the formation of this type of crust is induced by the sedimentation process: the larger elements sink to the bottom, and the finer elements stay at the top, thus giving an inverse distribution to that found in the structural crusts with two or three microhorizons. When dry, these crusts often break up into curled-up plates.

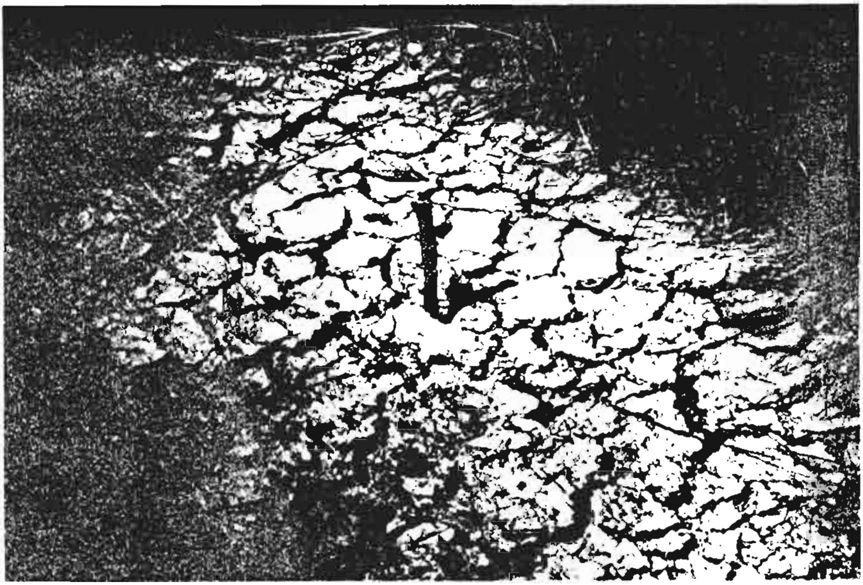

Photo 5. Sedimentation crust in a pond. Note the cracks and the curled-up plates (near Chiang Mai, northern Thailand).

- o *Gravel crust* (also called "pavement crust"): this consists of a more or less dense surface layer of gravel and stone-size coarse material incorporated in a structural crust with three layers and a marked vesicular porosity.

The percentage area of each type of surface crust must be indicated in accordance with the classifications given above, as other surface features like microtopography are associated with cultivation. Structural crusts usually occur at the top of the ridges, and erosion crusts on their microslopes. Runoff depositional crusts are commonly formed in waterways, and sedimentation crusts in depressions.

Recording sheet

For reference purposes, a standard registering procedure is proposed. A recording sheet lists the main information required (Figure 1). To facilitate comparisons, regrouping, and processing of the data, simple scoring systems for rating surface roughness erosion and surface crusting can be adopted. Each characteristic is rated on a scale of one to five for the observations collected at both scales. The scoring is arranged so that one is associated with the lowest class and five with the highest. Such semiquantitative systems have to be adapted to local conditions, but require standardization to be used by surveyors with a minor bias.

Surface features' map

Slope, land use, and erosion-hazard maps can be compiled from field measurements on observations and they may be helpful in setting up the experimental plots. However, in a practical surface features' survey, there is usually a danger of using too much detail. Therefore, factors must be ranked according to the local conditions and the use of the map. In site characterization, the preparation of a surface features' map aims to delineate fairly homogeneous land units both in terms of morphology and hydrological properties.

The grouping of surface features' can be performed by hand, or by using multifactorial analysis so that units are defined as clusters of sample points. In this case, integrated information is derived from statistics' analysis. For example, in arid and semiarid West Africa, Casenave and Valentin (1989) proposed a typology including eleven unit surfaces (Figure 2). The data collected from 78 plots submitted to rainfall simulation were used to determine the range of their main hydrological parameters, namely the final infiltration rate at saturation, the infiltration coefficient and the preponderant rainfalls under different antecedent moisture conditions. Besides the type of crust, some other variables, like the vegetation-cover percentage, surface roughness and faunal activity, were used as modifiers. This simple, efficient system, based upon both statistical and natural approaches was satisfactorily validated in 47 plots not included in the previous sample. This typology comprises three types of cultivated unit surfaces (Table 1) primarily based upon the vesicular porosity within the surface crust. Under temperate conditions, Boiffin *et al.* (1986) proposed five types (Table 2).

Location:	**Date:**
Sample point coordinates:	**Observer:**

(a) Observations on 100 m²

Vegetation cover and land use			
Method:	Visual estimation O		Measurement O
Classes of height	Basal cover (%)	Aerial cover (%)	Remarks (dominant species, natural or planted, plant association, pattern, history, deficiency, and pathology symptoms)
> ...m	....	....	....
... m - ... m	....	....	....
... m - ... m	....	....	....
... m - ... m	....	....	....
... m - ... m	....	....	....
< ... m	....	....	....

Ground cover			
Method	Visual estimation O		Measurement O
Type	Cover (%)	Thickness (cm)	Remarks : pattern, associated features (microdams, ...)
Litter	....	....	....
Crop residue	....	....	....
Ash	....	....	....
Clumps	....	....	....
....	....	....	....

Mesorelief			
Method	Visual estimation O		Measurement O
Type	Height or depth	Basal area or width	Remarks : pattern, direction with reference to the slope
Rill	....	....	....
Gully	....	....	....
Termite mound	....	....	....
Furrows	....	....	....
Ridges	....	....	....
Conservation structures	....	....	....
Paths	....	....	....
....	....	....	....

Figure 1. Example of a surface features data sheet adapted to a large-scale survey.

(b) Observations on one or a few m²

Vegetation cover			
Method: Visual estimation O	Measurement:	pint-point frame O	line transect O
Classes of height	Basal cover (%)	Aerial cover (%)	Remarks (dominant species, plant association, pattern, history, deficiency and pathological symptoms)
> ...cm	....	....	....
... cm - ... cm	....	....	....
... cm - ... cm	....	....	....
< ... cm	....	....	....

Ground cover			
Method: Visual estimation O	Measurement:	pint-point frame O	line transect O
Type	Cover (%)	Thickness (cm)	Remarks : pattern, associated features (microdams, ...)
Litter	....	....	....
Crop residue	....	....	....
Ash	....	....	....
....	....	....	....

Microrelief			
Method: Visual estimation O	Measurement:	pint-point frame O	
Type@	Height or depth	Basal area or width	Remarks : pattern, direction with reference to the slope, associated porosity for the faunal constructions)
....	....	....	....
....	....	....	....
....	....	....	....

@: termite mound, termite surface tunnels, worm casts, ants pellets, furrows, ridges, ...

Soil surface			
Cracks	Width:	Depth:	Pattern: ....
Vesicles	Density:	Diameter:	Pattern: ....
Colour	....	....	....
Mottling	....	....	....
Texture	....	....	....
Stoniness	Surface cover:	Nature:	....
Rock outcrop	Surface cover:	Nature:	....
Structure	....	....	....
Consistence	....	....	....
Surface crust type*	Surface cover:	Thickness:	Continuity: ....
....	....	....	....
....	....	....	....
....	....	....	....
Exposed roots	Density:	Size:	....
Pedestal	Density:	Height:	....

* For example: drying crust, structural crust, runoff depositional crust, erosion crust, sedimentation crust or pavement crust; see the determination key in Valentin (1988).

Preliminary unit surface type# :

For example: cultural 1, 2 or 2, termite and worms, drying, structural, erosion, sedimentation, or gravel unit surfaces (see the determination key in Figure 2).

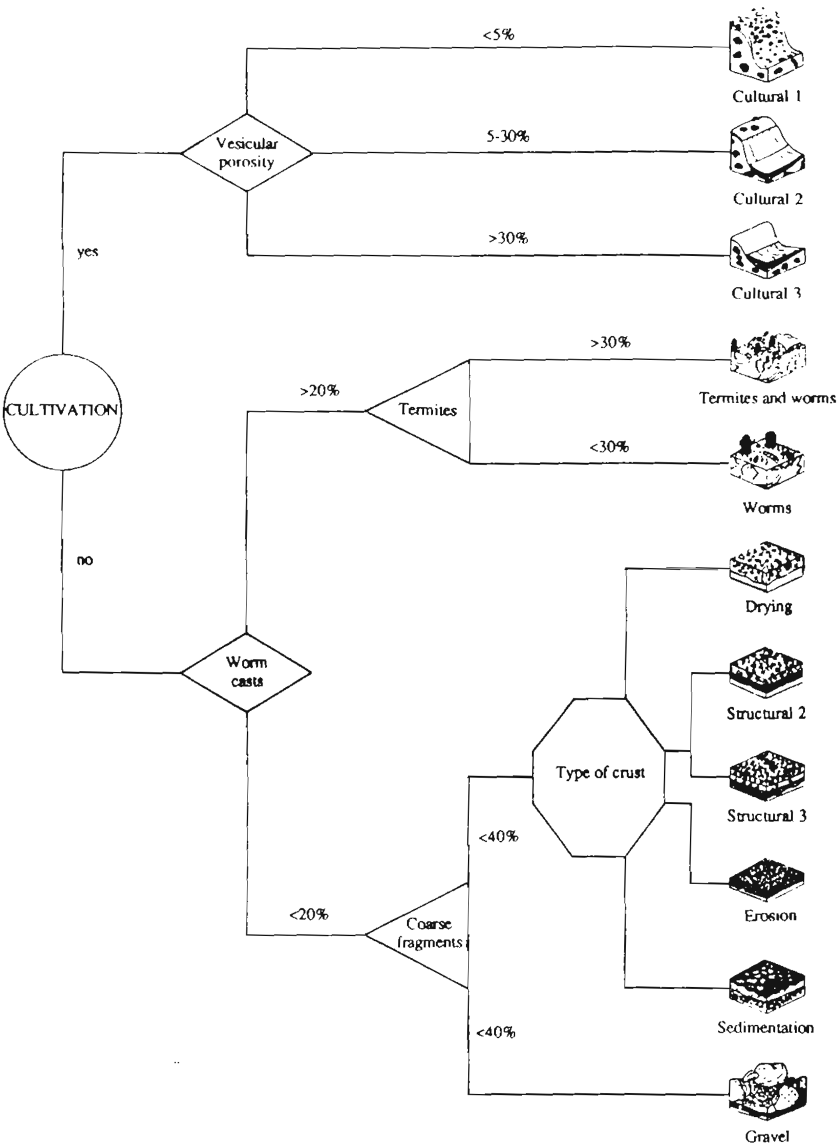

Figure 2. Determination key of the main types of unit surfaces in the arid and the semiarid zones of West Africa (Casenave and Valentin, 1989).

Table 1. Types of cultivated unit surfaces in the arid and semiarid zones of West Africa and their main hydrologic properties.

Type	Main features	Main hydrologic properties					
		Ki (%)	Ki0 (%)	Ki20 (%)	IR (mm h^{-1})	Prd (mm)	Prw (mm)
C1	Vesicular porosity <5%						
	No surface crust or rough structural crust	60-75	80-90	75-85	15-25	25-30	May-15
	Modifiers:						
	Vegetation cover >50%	80-95	90-100	85-95	25-35	30-40	20-30
	Coarse fragments >40%	40-50	55-65	45-55	7-15	5-15	1-5
C2	Vesicular porosity 5-30%						
	Structural and erosion crust > runoff depositional crust	40-60	60-80	50-70	1-7	8-15	2-4
	Modifiers:						
	Very rough surface	60-75	80-90	75-90	10-20	15-25	5-10
	Clay > 40%	15-25	25-40	20-30	1-5	8-12	2-4
C3	Vesicular porosity >30%						
	Prevailing runoff depositional crust	15-25	25-40	20-30	0-3	8-15	2-4
	Modifier:						
	Very rough surface	40-60	60-80	50-70	5-10	20-30	5-10

Ki : mean infiltration coefficient
Ki0 : infiltration coefficient under dry conditions
Ki20 : infiltration coefficient under wet conditions
MIN : minimum infiltration rate
Prd : preponderent rainfall under dry conditions
Prw : preponderent rainfall under wet conditions
Source: Casenave and Valentin (1989).

Taking topography and hydrology as guiding principles for mapping, the divide, the slope-breaks and the main-drainage lines are plotted as well as the land subject to overland flows and the areas of flow convergence. The mapping units consist of fairly homogeneous surface features with a simple typology. When homogenous units are too small to be mapped, they have to be combined in one association. Each association must be defined by the percentages of each subunit and by the patterns they form: random, grid, dot, dot-grid, transition, zonation, and alternation. For statistical reasons, each unit in the final classification should preferably be presented with a minimum of ten samples.

Table 2. Time sequence types of cultivated unit surfaces in the temperate zone and their wet infiltration ability.

Type	Main features	Range of wet soil infiltration ability mm h^{-1}
F0	Initial fragmentary structure	30-50
F1	Altered fragmentary structure state with structural crusts	5-30
F1-F2	Transition (local appearance of depositional crusts)	2-5
F2	Continuous state with depositional crusts	1-2
F3	Disturbed depositional crusts (climatic and biological factors)	> 5 ?

Source: Boiffin *et al*. (1986).

Furthermore, natural and man-made waterways must be reported in the previous document. They include not only rills and gullies but also the paths and tracks which collect runoff from the interrows and where evidence of runoff occurs. Factors denoting the existence of active erosion such as the ploughing up to the surface of the substratum are indicated. The zones where drainage is impeded and where overland flow accumulates must also be mapped.

Resulting from this field work, a synthetic map of the soil surface features' is then produced (Figure 3). This document is essential in laying out the experiment plots and in planning, for example, some protection to limit running-on pollution and erosion hazards.

In addition, the comparison of the various factors can reveal the existence of unsuspected land-degradation factors: a pathway, an ill-designed conservation structure, the direction of the furrows. Since this map deals with dynamic and time-dependent factors, it can be used to guide the morphological observations and the physical properties for monitoring during the experiments.

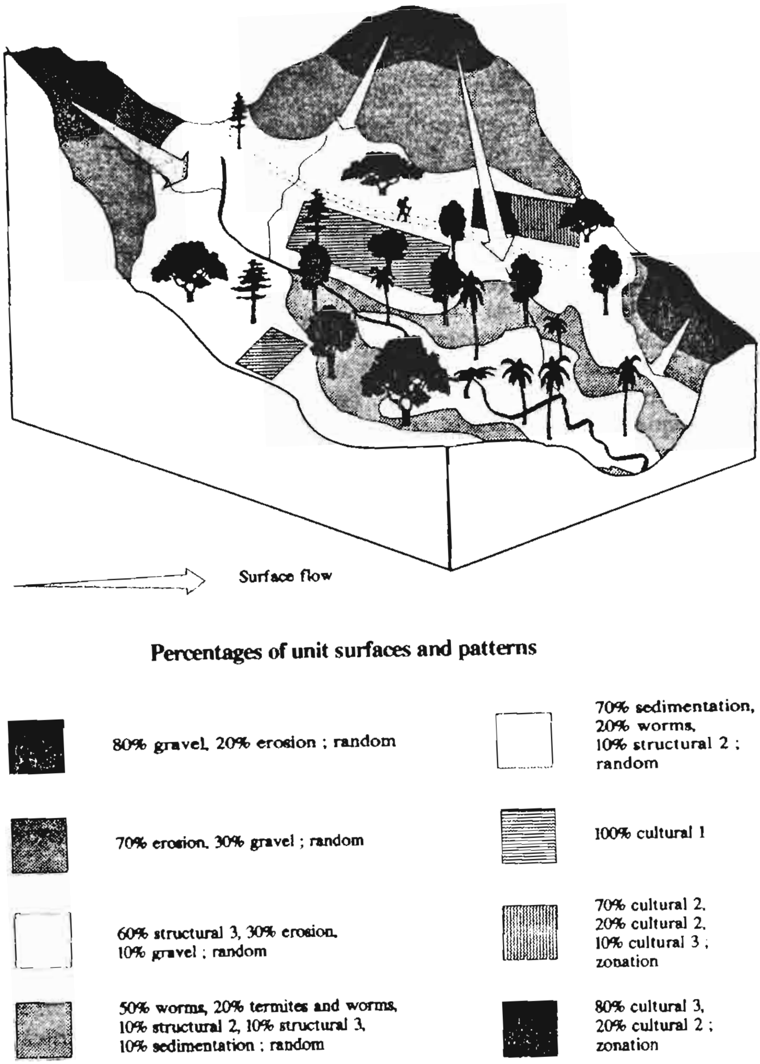

Figure 3. Main surface features and overland flow zones of a water catchment covering an area of a few hectares.

Monitoring the characteristics of soil surface features and the cultivation profile

Procedure

The unit of the soil surface features form a reasonable basis for stratified sampling. Within these units, random sampling may be used to select one or more sample spots. Sample size refers to the question on minimum area: how large should one spot be to represent a whole mapping unit? For short crops, weeds, surface roughness, and surface crusting, a few m^2 are usually more than enough. Sometimes it may be advisable to adapt the form of the sample spot to the terrain. The use of permanent pegs to demarcate these spots would be useful. A sufficient buffer zone needs to be preserved for digging shallow pits for the subsequent descriptions of cultivation profiles and associated physical measurements. At this detailed scale, observations should be performed at a minimum of five key periods: the initial stage, just after land preparation; the flowering time, just before harvesting; the start of fallow, after harvest or after the last weeding for tuber crops; and the end of the fallow. To monitor morphological changes at a finer scale, as the development of a rill network, a survey similar to the one performed for the site characterization will be carried out every year, or at least at the end of the trials.

Morphological features

Surface features

On each sample spot, the surface features as previously described for the m^2 squares will be monitored. Measurements are preferred to visual estimation. Two techniques can be adopted:

- *The pin-point contact method*: sampling is executed with pins which, by means of special devices (Figure 4), are placed vertically on the ground. To assess the biovolume, the heights of the higher and the lower intercepts of the pin with the crop or weed cover are recorded. Also noted are the ground elevation (for soil surface roughness assessment), and the type of surface touched by the pin: coarse, fraction, faunal constructions, cracks, and surface crust (the type is indicated). The pins are arranged on a grid pattern at 5 or 10 cm intervals (100 to 400 measurements per m^2).
- The line-transect method: a measuring tape is stretched on the ground across the diagonal of the plot. The surveyor records the number of cm or dm interception with plants, gravelly or crusted areas. If the surface features'

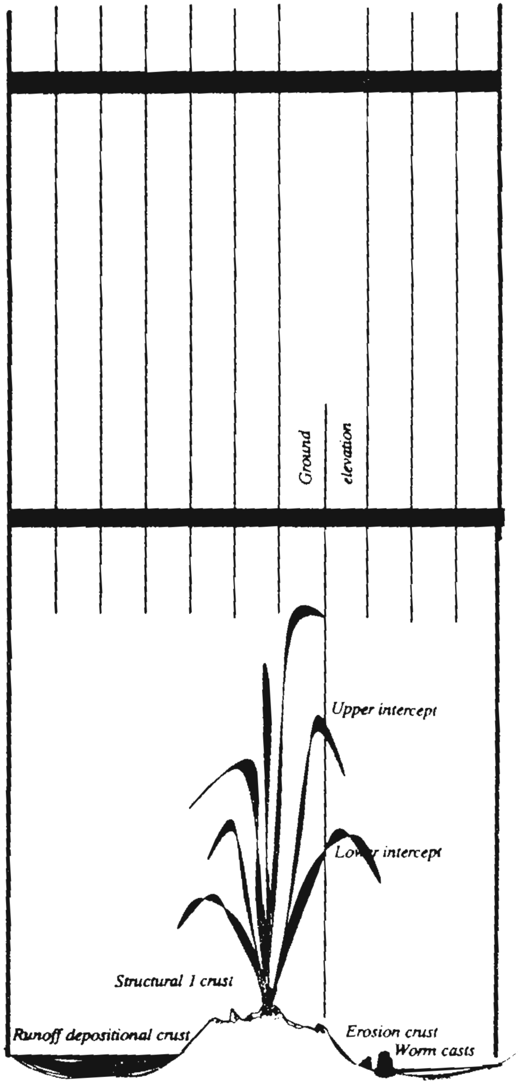

Figure 4. Sketch of a pin-point frame device. The interval between the rods is 10 cm (or 5 cm). This frame is moved along another perpendicular frame so that 100 points (or 400 points) can be considered.

are fairly homogeneous, the line-transect method can produce results quite as reliable as those of the previous method and more rapidly. The accuracy can be increased provided two measurements are performed along both diagonals of the plot or simply in a cross.

Cultivation profile

The cultivation profile is formed from the successive layers of soil, individualized by the intervention of cultivation tools, vegetation roots, and natural factors which react to these actions (Photo 6). Improper management of the cultivation profile leads to compaction and the formation of plough pans which can reduce rooting and water intake. As a result waterlogging, runoff and

Photo 6. Cultivation profile in a maize field. Note that the profile is severely crusted and strongly differentiated: the tilled layer of this loamy soil is moderately structured, soft, and has a high root density, whereas the layer below is massive, compacted, and has a low root density. (Maize field installed in a rubber tree plantation recently cleared with heavy machinery, near Hat Yai, southern Thailand).

erosion can be fostered. Therefore, once the surface features are determined, these observations must be supplemented with a description of the cultivation profile. In a pit, the investigator should look after tillage-induced features (Photo 7): shining pressure surfaces, compacted volumes and plough pans. He should try also to relate them to the root distribution (for more details, see Valentin, 1989b).

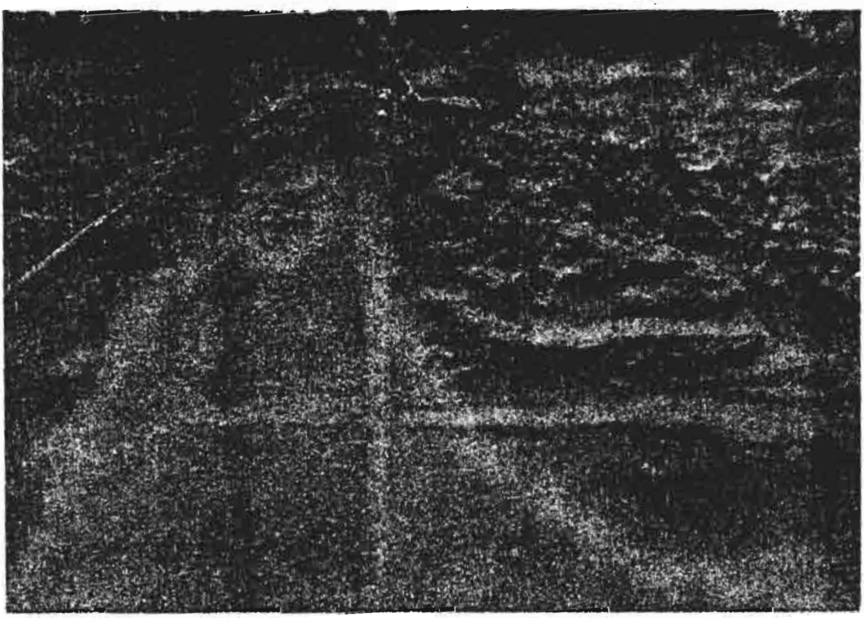

Photo 7. Cultivation profile in a ridged cotton field. Note the buried erosion crusts within and below the ridge; they correspond to ancient surfaces before hand-ridging and weeding. Such discontinuities restrict water infiltration and can impede rooting when conditions are not sufficiently moist (Thysse Kaymor, central Senegal).

Physical properties

Infiltration

So far, there is no fully satisfactory field method for measuring the infiltration ability of crusted soils. A method proposed by Boiffin and Monnier

(1986) for loamy soils under temperate conditions can be of some help. It consists of providing water to the soil surface without kinetic energy by means of capillary tubes. Small shining spots form under these droppers and their diameter stabilizes if the initial moisture is close to saturation. The infiltration rate at saturation can be determined from the capillary flow and the area of the saturated spot. These measurements can be performed only in wet, clayey or loamy soils in an even terrain (for complementary information, see Valentin, 1989a).

Bulk density

Due to the vertical and lateral heterogeneity induced by rows or ridges, it may be difficult to assess the bulk density of the tilled layers. One solution is proposed in the appendix of this volume: the measurements must be doubled (one core on the top of the ridge, one in the interrow).

If a shallow pit is dug, core or excavation methods can be used to determine the bulk density of the various structures identified during the description of the cultivation profile (de Blic, 1976, see Valentin, 1989b).

Another method (Håkanson, 1990) can benefit from the pin-point device which is applied for monitoring surface features'. In this case, the pins are used to assess the volume of the layers of interest. First, the height of the soil surface is measured, taking the upper edge of the frame as a reference plane. The layer is then removed and weighed (samples for moisture-content determination are collected). Finally, the lower boundary surface, for example the harrowing or the ploughing surface, is measured. This author considers that with 196 pins evenly distributed on 0.5 m^2, less replicates are required as compared to the core method. In addition, the core method is dubious when the compaction it induces in loose-cultivated soils is a result.

Penetration resistance

Soil compaction can be a severe problem, particularly in soils submitted to heavy machinery. For monitoring purposes, penetrometer profiles, coupled with soil moisture profiles should be performed. The mass penetrometer measures the energy which is created when a weight is dropped from a given height to make a rod with a cone-shaped head penetrate the ground to a given depth. This method is not adequate for gravelly soils (for further information, see Valentin, 1989b). A personal computer programme is proposed to compute the data and to design the diagrams (see Appendix).

Conclusion

When characterizing a site, as well as monitoring an agricultural experiment, field physical parameters should not be neglected, even in a network dedicated to acid soils. Due to repeated heavy showers, surface crusts develop readily in Oxisols and Ultisols left insufficiently covered. As a result, even on gently undulating slopes, accelerated erosion often occurs. Likewise, these often moist soils are vulnerable to severe compaction, which impedes water storage and suitable crop rooting.

The surface features' map is essential for correctly locating the experimental plots since it can unveil interactions among land factors. In particular, surface crusting can indicate unsuspected harmful environmental conditions.

Monitoring both morphological features and physical associated parameters provides qualitative and quantitative data on the degradation processes - their factors and their intensity. It is thus a relevant approach for making not only diagnoses but also prognoses, and for suggesting more appropriate soil management systems.

Appendix

"Tips" user's guide

E. Perrier, G. Pichon and C. Mullon*

Getting started with "tips"

◊ Type "tips" to start the programme.
◊ Run tips with the option "/c" if your printer doesn't support a complete set of ASCII characters.

Creating a new file

◊ Choose a file name for the storage of your data.
◊ The extension ".tip" will automatically be added.
◊ You must then specify:
- the number of layers,
- the number of rows; it will be possible to modify this number when updating the file.

Entering the values

h : height from which the weight is dropped (in cm),
m : weight of the rod axis and cone (in kg),
S : cross section of the head (in cm^2),
M : weight of the hammer (in kg).

All these values can be modified.

Editing a file

The editor is a "spreadsheet" editor, and it is very easy to use.

Three columns are displayed on the current screen: the depth, the number of blows (Nblows), and the resistance *R*. Moreover, the spreadsheet extends beyond the current screen so that you have to use the cursor-control keys to move and display other columns: the *h*, *m*, *S*, *M* columns or other rows.

The variable *R* (resistance) is automatically updated at any modification.

At any moment, press the "home" key to go back to the cursor's initial position.

While editing a file, press F2 to repreat the previous line's value without typing it.

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```
File name: trial

h (cm):  95.00          m (kg):  2.09          ------------------------
S (cm2): 2.50           M (kg):  1.00             F1 to toggle histogram
                                               ------------------------
                                                      RESISTANCE
Layer    Depth    Nblows    R                  0                      27.1
                                               depth
--------------------------------------         5  ---------------
_ 1  _  5.00    13.00   15.99                  10  ----------------
_ 2  _ 10.00    14.00   17.22                  15  ----------------
_ 3  _ 15.00    13.00   15.99                  20  -------------
_ 4  _ 20.00    10.00   12.30                  25  -------------
_ 5  _ 25.00    10.00   12.30                  30  -------------
_ 6  _ 30.00    10.00   12.30                  35  ------------------
_ 7  _ 35.00    14.00   17.22                  40  ---------------------
_ 8  _ 40.00    22.00   27.06
--------------------------------------



--------------------------------------         ------------------------
      ESC key to end                                  F3 to PRINT
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