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CHAPTER 6
Criteria for Observing and Measuring Changes Associated with Land Transformations

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6.1 INTRODUCTION

Previous chapters have examined the factors and conditions present when land transformation processes were engendered by agricultural development. These land transformations affect the environment through changes in a number of parameters, which naturally constitute criteria for appraising the transformations themselves if it is possible to observe, measure and interpret variations in the parameters.

Parameters are to be found at various levels in the terrestrial environment. They may concern the edaphic environment itself, relating either to its constituent elements (chemical elements, ions, molecules) or to the internal organization of these constituents. But the consequence of a land transformation may also affect the environment through the behaviour of fluids (including gases) that circulate above or in the soil, or through the behaviour of plant and animal populations supported or nourished by the area in question. This change of behaviour then constitutes a criterion for judgement.

Land transformations may also affect the environment in a more comprehensive manner, notably in terms of climate or the form of the landscape. These, too, are criteria for assessing and evaluating the transformations.

One aim of this chapter is to illustrate criteria that are useful for evaluating and monitoring land transformations, with the aid of a number of specific examples taken from chapters of this report and case studies prepared by SCOPE national committees (especially the French committee) as part of the SCOPE project on land transformation. It should be noted at the outset that these criteria do not all possess the same value. Some draw attention to a transformation while it is actually taking place or to the dangers it will eventually lead to: these are 'warning signal' criteria. Others provide immediate and better information about the mechanisms involved (they have a diagnostic value) and thereby possess a superior operational value (they have a prognostic value).

The second aim of the chapter is to provide a list of available criteria; the list cannot be exhaustive but it will have a definite indicative value. Stress will be laid on the methodological problems involved in using these criteria: analytical problems, problems of sampling in time and space, for example.

Finally, an attempt will be made to determine to what extent the proposed criteria may be used to forecast possible controls over transformations, and consequently over environmental change.

6.2 CRITERIA RELATED TO THE CONSTITUENTS OF SOILS AND WATER

Four examples will illustrate the use and advantages of this type of criterion. A listing will then be given of the main constituents, the variations of which in space and time may serve as a reference. Points will also be made regarding the precautions to be taken when using this type of criterion.

6.2.1 Examples

6.2.1.1 Rapid Increases in Copper and Zinc Content of Soils (Coppenet and Golven, 1984)

In the last 20 years or so there has been an intensification of pig farming in Brittany, the corollary of which is that large amounts of liquid manure are spread on the land. One consequence is a marked increase in the 'assimilable' copper and zinc content (extraction through EDTA) of the upper soil horizons. Table 6.1 shows the results of monitoring (between 1973 and 1982) of 64 farms in Finistère on which large amounts (higher than 100 m^3/ha per year) of liquid pig manure were spread. The results refer to the ploughed horizon (0–30 cm).

There is a manifest increase in copper and zinc content. If this rate of

Table 6.1 Recorded Cu and Zn concentrations (mg per kg of earth) in Finistère

	1973	1979	1982
Assimilable Cu	3.8	5.1	5.9
Assimilable Zn	3.2	6.2	7.4

increase is maintained, it is possible that, within a century or two, certain soils in the region may become toxic for plants because they contain excessive amounts of these elements.

The same phenomenon can be observed in several regions of Europe.

This change in the contents of the two elements may exist, from the chemical point of view, either in an 'exchangeable' state on the clays, or in association with organic products (chelation), or in the form of saline combinations of varying degrees of solubility. The change is linked to a profound transformation in Breton agriculture, the main characteristics of which are as follows.

In the past Breton farmers practised a diversified and not very intensive form of normal husbandry. The bulk of the animal fodder came from the farm. Since 1960 animal husbandry has become more intensive and specialized, notably owing to the construction of units housing hundreds of pigs. Some of the fodder is now brought from outside the region and includes mineral additives enriched with copper and zinc, for these elements have a favourable effect on the physiology of the animals. But the pigs only retain a small proportion (5%) of the copper and zinc they ingest; the rest is eliminated in their urine. The urine is collected with the faeces and stocked in the form of liquid manure, i.e. not mixed with straw as it was in the past. The manure produced in this way is spread on the soil but often on surfaces that are too restricted, thus causing a gradual concentration of copper and zinc in the upper part of the soils where these elements are fixed.

In this example, the 'change in the copper and zinc content of the soil' criterion is both a symptom of the effects of the transformation (a 'warning signal' criterion), and a factor in diagnosis, since the source of the dangerous elements and the mechanism whereby they are accumulated are in this case fairly well known. This criterion is a signpost to prognosis ('the accumulation of copper and zinc in the soil may become toxic over a century') and to forms of treatment: among the latter, it will be advisable to reduce concentrations of the incriminated chemical elements in the animal feed, and to improve the organization of spreading (choice of dates, dosage, land).

6.2.1.2 Increases in Nitrate Content in the Highest Level of Groundwater

Analyses of water from wells in the Platte River Valley, Nebraska (USA) have revealed a recent rapid increase in nitrate content. The average concentration of $N(NO_3^-)$ in surface water rose from 3 mg/l in 1950 to 18 mg/l in 1980 (Schepers *et al.*, 1984). This increase is a criterion to indicate the consequences of a growing use of irrigation and mineral fertilization in order to intensify corn (maize) farming. The soils in this valley are in many cases shallow, light in texture, sandy, or sandy and loamy. The highest groundwater level is near to the surface.

Inadequately controlled irrigation of corn (maize) feeds this groundwater and boosts the lixiviation of the dissolvable elements near the base of the profiles, beyond the zone of root implantation.n. The level of mineral fertilization has risen considerably (see Chapter 5.V). During 1981, for example, an average of 189 kg/ha of mineral nitrogen was added annually on most of the 17 000 ha in the area concerned. Some of this nitrogen reaches the groundwater in the form of nitrate ions, in addition to the organic nitrogen in the soil which has been mineralized during the same period.

The increase in the $N(NO_3^-)$ content of the water thus constitutes a criterion that is symptomatic of the consequences of a certain form of intensification of agriculture, focusing on:

(1) the rate of increase (from 3 to 18 mg/l of $N(NO_3^-)$ in 30 years);
(2) a comparison of the concentrations that have been attained with a reference value—in this case 10 mg of N per litre—beyond which the water is judged to be unsuitable for human consumption.

This criterion is also useful for making a prognosis since it makes possible the observation that 'water in a given area, at the present rate of increase, is already, or in *x* years will be, unsuitable for consumption'. But this $N(NO_3^-)$ criterion is not an explanatory criterion, since in this case it does not allow either the origin of the incriminated nitrogen or the reasons why it is leached to be identified. Several sources are possible: nitrogen from mineral fertilizers, of course, but also nitrogen from the mineralization of organic matter, as well as nitrogen from rainwater, or nitrogen re-injected by the irrigation water itself.

A research of the respective importance of these different sources can only be effected using high-precision chemical methods, and especially a study of the stable isotope ^{15}N. These methods of isotopic geochemistry require not only expensive apparatus, but also the ability to interpret their results; interpretation is a highly sensitive process because of the isotopic fractioning that occurs during the nitrogen cycle (Hauck, 1982; Mariotti, 1982).

An excellent 'warning signal' criterion, 'change in $N(NO_3^-)$ content' is thus not really an operational criterion since it is not sufficiently explanatory. To reduce the risks involved in this land transformation, the Nebraska authorities (Hall County Water Quality Special Project) used a series of additional observations and measurements. These measurements, carried out with the help of farmers in the region and a technical support team, ensured regular monitoring of soil water content, of soil nitrate content over a sufficient depth, and of the rooting depth of the corn. Coupled to the use of soil cartography and a simulation model, these measurements made it possible to effectively improve irrigation and fertilization management and gave grounds for hope that the concentrations of $N(NO_3^-)$ in the water could be stabilized.

This and the previous example concerned elements in the chemical sense of the term; other criteria involve combinations of elements or ions.

6.2.1.3 Increase in the Electrical Conductivity and SAR of Extracts of Water Taken from the Soil and of the Highest Level of Groundwater

This third illustration concerns what happens, unfortunately, in many arid or semi-arid regions when irrigation is practised, even using water that is only slightly salty. In this particular instance the land transformation is the result of a desire to improve agricultural production in regions where there is insufficient precipitation. Poorly controlled drainage often causes gradual salinization of soils and water. This transformation has often left its mark on the landscape after the irrigation network has been operating for a few years, but changes in the electrical conductivity of the soil or the water constitute a better criterion for making a more accurate judgement of the land transformation in terms of salinization.

This conductivity is measured using either water extracted from soil samples (including the well-known 'saturated paste extract') or the groundwater itself. The ions in the water reduce the resistance of the water when an electric current is passed through it, and hence change its electrical conductivity. This is a criterion relating to a combination of elements.

The criterion is often used as a 'warning signal'. In Pakistan, for instance, the electrical conductivity of soils and water increased considerably in the late 1950s as a result of the intensification of irrigation in the Indus valley and the poor quality of the drainage associated with it. A government project, revealed the consequences of the appearance of this symptom (see Chapter 5.I).

This symptom may also appear a long way downstream of the transformed system (the off-site effect). The Colorado river in the United States provides an example of this. The electrical conductivity of the water in the river was increasing and appeared likely to continue to do so if appropriate measures had not been taken (observations made at Imperial Dam). This was a consequence of an apparently successful transformation upstream; the drainage system established in the cultivated and irrigated areas successfully protects the soil against becoming too saline for plants. But in the course of time the drainage water has salted the waters of the Colorado river itself. The negative consequences of the land transformation have simply been transferred downstream. Because of its simplicity and flexibility, the 'change in the electrical conductivity of water' criterion here makes it possible not only to draw attention to the phenomenon but also to follow spatially, with the water vector, the downstream advance of the system's negative consequences.

Another criterion of the same type is often associated with the above. This has to do with the sodifying capacity of water, or the SAR (sodium absorption ratio). An example from France, a non-arid region, illustrates the usefulness of this criterion in diagnosing, and even providing a prognosis of, the consequences in the course of a land transformation (Conesa and Schenck, 1982).

In the Alsatian part of the Rhineland plain, there has been an increased use of irrigation, using groundwater from the plain. The irrigated soils are starting to show signs of structural degradation: blocking of porosity and a reduction in permeability.

A survey was carried out of water from 43 wells stretched along a 100 km SSW–NNE axis, a disposition which corresponds to the direction of the groundwater flow in this part of the Rhine plain. From measurements of concentrations of Na^{+}, Ca^{++} and Mg^{++}, it was possible to calculate the SAR level of the water in each well. Four conclusions emerged from this survey:

(1) The SAR levels of the 43 samples were relatively high (3.6 on average, with a maximum of 7.4) in comparison with data found in the international literature.
(2) Soils irrigated with water with a high SAR showed signs of structural degradation.
(3) The application of Hénin tests confirmed a reduction in structural stability and permeability (Hénin and Monnier, 1960).
(4) The SAR values fell quite regularly from SSW to NNE. A large-scale sylvinite (Na, K, Cl) mining area is active upstream along the flow axis. The KCl is separated from the NaCl, then sold as fertilizer. The NaCl subsists in a residual form, capable of causing sodic pollution.

The 'change in time and space of water SAR' criterion is thus a 'warning signal' in this case. But it also has an explanatory value, making it possible to trace the origins of sodic pollution spatially: this pollution originates upstream of the region under consideration and is propagated longitudinally by the groundwater. It is thus possible to explain the phenomenon itself: the sodium from the irrigation water encourages the dispersal of the clay colloids in the soil, and thus their structural degradation.

6.2.1.4 Reduction of the Proportion of Organic Matter in Soils

Molecules constitute another, structural, mode of combination of chemical elements. Organic molecules of the soils, which result both from plant and animal activity (humic acids) and from specifically human activity (pesticides) play an all-important role in the various physical, chemical and biological properties of the soil, both as regards water dynamics, resistance to erosion, and the dynamics of metallic elements (chelation phenomena), or of elements necessary for plant nutrition. Changes in the soil's organic molecule content will thus in many cases provide a criterion for assessing the consequences of land transformation under the influence of agriculture. One such case, relating to the physical properties of soils, will illustrate this point.

In many world regions, à reduction in organic-matter content is observed following intensification of agriculture: clearing of forests, ploughing of former permanent meadow, less frequent use of organic manures, etc. In some cases the result is a degradation of the physical properties of the soils. Especially in the case of soils with a loamy texture, this degradation seems to take the form of local manifestations of compaction either through pressure exercised by animals (trampling) or by farm machinery (ruts). The reduction in a soil's organic-matter content is a noteworthy criterion for assessing the negative consequences of a land transformation; but in practice it is an extremely sensitive criterion to use, as is shown by the example of a long-term test carried out in eastern France (Boiffin *et al*., 1982).

The test was carried out on undrained loamy soils in a climate of intensive and fairly abundant rain (900 mm/year). The soils were previously covered by meadow. Three crop rotations were established and compared, with care being taken to maintain a constant ploughing depth (23 cm):

Rotation A: corn (maize)—wheat—rape seed—wheat (all straw removed)
Rotation B: corn (maize)—wheat—rape seed—wheat (straw ploughed in)
Rotation C: corn (maize)—wheat—rape seed—wheat (straw removed)—followed by four years of temporary meadow (fescue, clover) at two levels of fertilization (level 1:110 units of nitrogen per hectare per year; level 2:165 units).

At the beginning of the test, the organic matter content in the plough horizon was 10.5, expressed as C‰. Table 6.2 shows the values recorded in the ploughed horizon after 14 years.

The change in the percentage of organic matter is pronounced and, after 14 years, varies significantly depending on the treatment:

(1) It proved to be impossible to maintain the initial organic level, whatever the treatment.

Table 6.2 Results of test described in section 6.2.1.4

Level of fertilization	Rotations		
	A	B	C
1	8.3	8.8	9.5
2	8.6	9.1	9.5

(2) Periodic cycles of temporary meadow (4 years) nevertheless make it possible to maintain an organic level only slightly lower than the original level.
(3) Ploughing in straw slows down the impoverishment in humus.

During this test the influence of treatments on the structural stability of the ploughed horizon was also monitored. These soils are highly sensitive to beating, which compromises the success of sprouting from seed. Table 6.3 shows the evolution of structural stability registered by Hénin tests: the structural instability index (I_s) increases and the percolation index (K) diminishes when the percentage of organic matter diminishes in the order of treatments C—B—A. Statistically the values are significant, but the differences are nevertheless not great.

The reduction in organic matter content is thus in this case the criterion of the consequences of an agriculture in which circumstances have led to the development of specialized holdings and to the disappearance of certain traditional sources of organic restitutions (manure, long-term meadows). But the differences in values, which are not pronounced even after 14 years, are only significant as a result of the special precautions taken during the test.

A similar illustration of the use of the 'evolution of proportion of organic matter' criterion is provided by the test carried out since 1976 in Illinois (USA) on 'mollisols' ('Morrow Plots', cf. Daniels, 1982).

The percentage of organic matter has fallen everywhere since 1976, but at rates which differ according to the crop rotation chosen. This drop is accompanied by greater sensitivity to erosion and a tendency to produce lower yields. But many interactions must be considered. In certain conditions (addition of $CaCO_3$, N, P_2O_5, K) the organic-matter content on the Morrow Plots has even risen recently.

More generally, the role of organic matter seems difficult to assess without an in-depth analysis of the climatic and technical context within which the variations of the properties of land are revealed, induced by variations in the amounts of these forms of organic matter which they contain (Boiffin *et al.*, 1982). This type of criterion is thus a 'warning signal' criterion of an 'explanatory' kind, but one which can only be used after considerable

Table 6.3 The evolution of structural stability (see section 6.2.1.4)

Level of fertilization	$\log_{10} I_s$			$\log_{10} K$		
	A	B	C	A	B	C
1	1.90	1.82	1.72	1.55	1.73	1.81
2	1.87	1.80	1.73	1.63	1.75	1.92

precautions have been taken; and to take account of the transformations described here (structural degradation) it will sometimes be advisable to use criteria relating to the morphological characteristics of the soils themselves ('organizational' criteria—see later).

6.2.2 Other Criteria Related to the Constituent Elements of Soils

The aim here is not to draw up an exhaustive list of all the chemical elements, ions and molecules present in soils and soil water, whose variations in space and time could be taken as criteria. We wish simply to draw attention to a number of criteria that have not yet been described—especially pH, heavy metals, phosphorus, and the exchangeable elements in the soil.

6.2.2.1 pH-Value

Variations in pH may be the criterion of a poorly controlled land transformation. The drop in a soil's pH-value following an intensification of nitrogenous and phosphate manuring, without the simultaneous addition of lime amendments, is an example of this (see Chapter 5.V). Most mineral nitrogenous fertilizers are acidifying, especially ammonium sulphate. If there is no correction by liming, acidity will gradually reach deep into the soil and will eventually create risks of aluminic or manganic toxicity. The lowering of pH here appears as a 'warning signal' criterion.

6.2.2.2 Heavy Metals

Copper and zinc have already been used to illustrate the role of monitoring heavy metals as a criterion for evaluating the consequences of land transformation. Other metals may also be usefully taken into account:

(1) those indispensable for plant growth and development, but which soon become toxic when their concentrations in the soil rise: Cu and Zn (already discussed), Co, Mn, Mo;
(2) those not indispensable for plant production and to varying degrees toxic to living organisms: Cd, Hg, Pb, Ni, Se, Cr, Sn.

The total content of these elements is used to evaluate the evolution of land, for their increase often reveals the consequences of intensified agriculture, involving a greater use of fertilizer and other products, which leads to the dissemination of heavy metals in the environment.

6.2.2.3 Phosphorus

The soil survey in Finistère cited in section 6.2.1.1 shows a pronounced enrichment over a 10-year period of the soil's 'assimilable' phosphorus content in the surface horizons. The 'assimilable' P^2O^5‰ content in the 0–30 cm horizon (Dyer method) rose (average of 64 holdings) from 0.44 in 1973 to 0.69 in 1982.

This enrichment is linked to the intensification of animal husbandry and to the increase in restitution to the soil through spreading. A content of 0.35‰ is already considered optimal in the loamy soils of this region. Enrichment beyond this level thus constitutes the criterion of a transformation increasing the risks of a zinc deficiency (if the soil has a non-acid pH; see Chapter 5.V) or of the transfer downstream, through erosion, of earthy particles particularly rich in phosphorus (eutrophication of the water).

6.2.2.4 The Soil's Exchangeable Elements

Cationic exchange capacity (CEC) is a good indicator of a soil's ability to fix cations, some of which play a favourable role in plant nutrition (K^+, NH_4^+) or in the physical behaviour of soil (the flocculent role of Ca^{++}, Mg^{++}).

The diminution of a soil's CEC expressed in me/100 g of soil may thus be considered as a criterion of the lowering of fertility; it is often linked to a land transformation involving a drop in the percentage of organic matter.

For the sake of completeness, the four cations that influence the saturation rate may also be used as criteria in so far as a variation in their content reflects the results of farming operations (especially calcium, potassium and magnesium) or affects the physical properties of the soil (sodium). Proof of this may be found in Chapter 5.V or elsewhere in this chapter. It is significant that at Grimari Station in the Central African Republic the levels of calcium and magnesium fell, in the first 15 cm of soil, 40% below that observed under the pre-existing savannah, when the latter was cleared and turned to agricultural use. This is a 'warning signal' criterion; the transformation of the organic matter and its reduction constitute the explanatory criterion.

6.2.3 Precautions to be Taken When Criteria Related to the Constituent Elements of Soils are Used

The determination by analysis of the chemical element and molecule content of soil or soil water does not, *a priori*, seem to present insuperable difficulties. Further consideration shows, however, that the application of this type of criterion is less simple than it appears.

6.2.3.1 Sampling Problems

Whatever the end in view, the results of analyses of soil samples carried out in laboratory conditions are only fully significant if the samples are representative. A simple example will illustrate the inaccuracies that may occur as a result of carelessness. A comparative analysis of areas of ploughed land may reveal a variation in the amount of a given element contained in it. This positive or negative variation may depend on an enrichment or an impoverishment of the milieu in the element concerned, but it may also be due to a variation in the depth to which the areas of land were ploughed. If additional determinations made in the layers beneath the arable land also show changes in amounts of the same element, it is no longer possible to establish a balance by taking account of the surface layers alone.

It is thus necessary to pay attention to the points where samples are taken and to relate the analytical data to what is known of the volumes of earth in question in order to form a better judgement of the overall evolution of the environment.

6.2.3.2 Problems of Analytical Determination

Monitoring concentrations of chemical elements may concern either the 'total reserve' or the 'mobile' (or assimilable') reserve, i.e. the quantity of elements capable of being absorbed or put in solution, even by agents with a low dissolvent capacity (cf. the case of Cu and Zn described earlier). It is interesting to establish whether the state in which the chemical elements are found makes them immobile or, to a greater or lesser degree mobile. The problem here is to understand the mechanisms whereby an element passes from one state to another, since the different elements which may serve as criteria change state in different ways.

6.2.3.3 Problems Arising from Concentrations and Flows

Contents or concentrations are static data which reveal deficiencies or excesses of a given element. Flows of these substances through a given volume of soil are, on the other hand, dynamic data which involve quantities in relation to time. Flows and concentrations thus make it possible to identify the elements in the 'entrance–exit' balance and to define the stationary or non-stationary nature of the system concerned (permanent or variable regime). *A priori* the problem appears simple, but here too we are faced with the question of the immobility or mobility of the elements and of the evaluation of assimilable elements, discussed above.

6.2.3.4 Problems with the Determination of Organic-matter Content

Particular attention must be paid to this problem, firstly because it is not the organic-matter content but the carbon content that is being measured directly, the former being derived from the latter using a coefficient; and secondly because a distinction must be made between several forms of organic matter. Agronomists usually distinguish two forms: those consisting of the residues of living creatures, easily separated from the mineral fraction by a rapid analysis method such as density or mechanical sorting, and molecules resulting from microbial activity and stemming from the more or less direct transformation of so-called free organic matter.

Methods of dosing do exist. They are used to a greater or lesser degree, but agronomists are able to calculate balances from them and have been able to formulate equations representing the speed and order of magnitude of the change and the transformation of these two types of substance.

Many more problems could be discussed here. Thus in spite of the apparent simplicity of their application, the criteria relating to elements, to ions, and *a fortiori* to molecules, should be used with care both in reasoning and in calculations.

6.3 CRITERIA RELATED TO THE ARRANGEMENT OF THE SOIL'S CONSTITUENTS

The structure and the porosity of a soil are examples of parameters that depend on the organization of the soil's constituents (mineral or organic). The evolution of these parameters is often used as a criterion, as G. Monnier points out:

> The evolution of the conditions of land use in most agricultural regions in the last few decades reveals a number of dominant characteristics. They include land transfers in connexion with reallocation procedures, simplification of farming methods, increasing use of heavier and more powerful farming equipment, and an increase in drained surfaces. Either directly or indirectly, these developments are liable to lead to transformations of the physical properties of cultivated land, some of which correspond to degradation: beating, compacting.

Three specific examples will be taken to illustrate the criteria relating to the organization of the constituents of soils, and then a list will be made of the criteria of this type that are available for application to changes linked to land transformation. The diversity and wealth of possibilities for using the criteria relating to the arrangement of the constituents of the soil will be shown.

6.3.1 Examples

6.3.1.1 Formation of Ruts and Reduction in Porosity (Monnier and Fies, 1982)

Several hundred kilometres of electricity transmission lines are installed each year in France. The cost of this equipment is such that those responsible systematically take the shortest route, without attaching to much importance to the effects on the land crossed. The case of the implantation of large pylons for high-tension lines illustrates this approach.

Heavy equipment must be brought to each site on many occasions throughout the year, whatever the hydric state of the soil. The passage of these machines causes the soil to become compacted, revealed by two symptoms:

(1) ruts, the shape of which is recorded by asperimetric measurements:
(2) a diminution in the porosity of the soil under the ruts, recorded by measurements of bulk density.

This compaction caused by rolling initially lowers the 'structural' porosity linked to the existence of fissures and galleries of biological origin (Table 6.4). However, it may also reduce the 'textural' porosity which corresponds to the gaps left by the arrangement of the granulometric constituents. The extent of these compactions varies with the textural type of the soil: loamy soils are particularly sensitive to it. It also varies with the hydric conditions of the soil when rolling takes place: for a given material there is a 'range' of water content within which the soil shows itself to be particularly sensitive to compacting. Each time a machine passes such effects may be created.

The criteria for assessing these transformations are the appearance of ruts and the reduction in the soil's porosity. These are 'warning signal' criteria, but they are only partially explanatory. A more precise diagnosis must be based on a better understanding of the specific role of the texture, humidity, organic-matter content and other parameters. This diagnosis requires the use of additional experimentation, especially dynamic (Proctor) or static (oedometry) compaction tests. Here, only more thorough diagnosis of this kind can make it possible to attempt a prognosis, and above all to advise on effective preventive or curative treatments.

Table 6.4 Comparison of the aeration porosity ('structural' porosity) beneath the ruts and between two ruts (Monnier and Fies, 1982)

	Under one rut	Between two ruts[a]
Not rolled	20%	21%
One passage of the roller[b]	11.8%	15.2%
Four passages	4.2%	5.4%

[a]The two ruts are 1.80 m apart. The measurement is thus made at 90 cm from the axis of each rut.
[b]Pressure on the soil is 5.2 kg/cm^2.

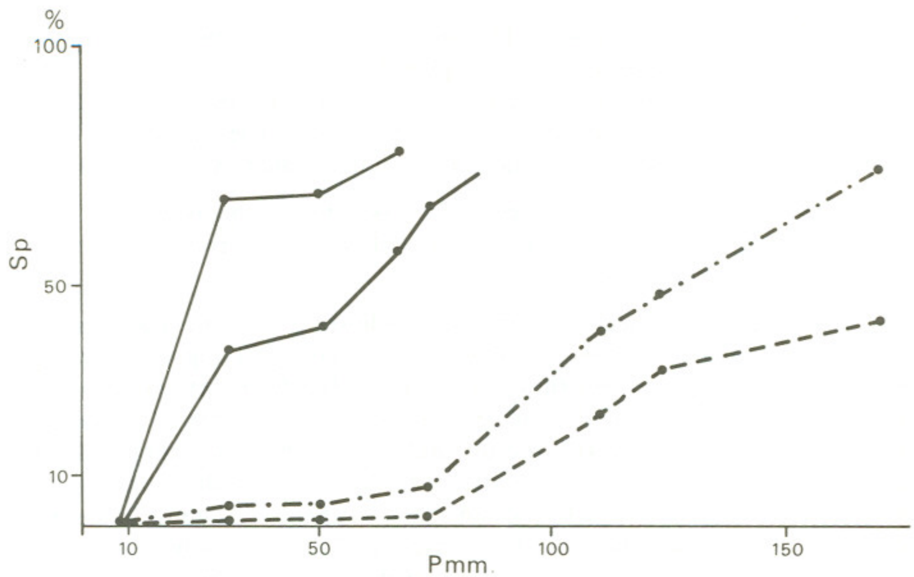

Figure 6.1 Evolution of the percentage of soil covered by continuous crusts (first indicator of beating), S_p, as a function of the cumulative depth of rainfall from the moment of the soil's exposure to the rain, P

——— Evolution of the unintercepted rate of the energy of drops

·—·—· Evolution when the energy is intercepted to 30%

——— Evolution when the energy is intercepted to 70%

6.3.1.2 The Appearance of a Beaten Crust (Boiffin, 1984)

A beaten crust is often observed on the surface of loamy soils. This structural degradation is linked to the action of rain (Figure 6.1).

This criterion reveals an increased sensitivity in the milieu to rainfall action as a cause of disaggregation of soil structure, notably by bursting processes. This is a warning signal that draws attention to a phenomenon which may have serious consequences: increased runoff, return to a massive state from the fragmentary states created by working the soil, and bad crop implantation.

6.3.1.3 Structural Degradation (Centre Technique Forestier Tropical, 1969)

When mechanized groundnut farming began at Sefa in Casamance, Senegal, around the 1950s, the structural stability and permeability of the tropical ferruginous soils under dry forest cover were satisfactory. In the soil's upper horizon and beneath the forest, the Hénin instability index ($\log_{10} I_s$)[1] was much lower than 1 (between 0.43 and 0.57 for five samples), and the permeability (evaluated by the K coefficient of Darcy's law) varied between 30.7 and 47.0 mm/hour.

Deforestation, then mechanized groundnut farming, increased the value of $\log_{10}I_s$ to 1.21 after two years' farming, then to between 1.42 and 1.77 (the effect of six years' farming). Parallel to this, permeability suddenly became slight—20–30 mm/hour at the end of the first year's farming—and subsequently did not return to its former level.

Further examination of the 'clay and loam' fraction revealed that beneath forest cover, only from 7–9% of this fraction was dispersed, whereas six years later, after cultivation, from 13.5–20% had become dispersed. As granulometric analysis indicated that elements smaller than 20 μm made up 15–20% of the soil's surface horizon, this meant that almost all the fine elements were dispersed.

Thus we have here a criterion which is both a 'warning signal' since it changed with the land transformation (deforestation and bringing into cultivation), and 'explanatory' when combined with other data from the physical analysis of the soil.

6.3.2 Criteria Related to the Arrangement of the Soil's Constituents

Criteria related to the arrangement of constituents usually concern changes in this form of arrangement: the formation of a rut, the appearance of a beaten crust. But they may also concern the properties of the soil particles themselves, determining the behaviour of a given soil in response to actions tending to cause change. In this case the criterion is the sensitivity of a soil to a given action, a sensitivity which will be assessed using a scale of reference. We shall, for example, speak of sensitivity to compaction or of structural stability. The criterion here will be a soil's change of position on the reference grid. A soil will, for example, have become more sensitive to compaction after transformations that have brought about a marked diminution of the percentage of organic matter. Consequently a distinction will be made here between these two cases.

6.3.2.1 Changes in Forms of Arrangement of the Soil's Constituents

These transformations can be attributed to three main categories of phenomena:[2]

(1) *Disaggregation phenomena under the action of water, inducing structural changes*. Their criteria may be (i) the appearance on the surface of the soil, following a series of downpours, of sheeted structures which harden when they dry (these are the beaten layers analysed above); (ii) the return to a massive state of fragmentary layers through the action of tools used when the soil is too wet, and the appearance of a continuous structure; or (iii) the appearance of continuous structures in the subsoil, due, for example, to inadequate drainage of these layers.

(2) *Compaction phenomena*. Here the criterion may be the appearance of ruts (an example cited above) or the appearance of deformations as a result of trampling by animals' hooves. These are morphological criteria, but they may also be evaluated by physical analysis, especially of an increase in bulk density.
(3) *Fragmentation phenomena.* The appearance of a broad network of shrinkage cracks in clayey ground may be the consequence of sodification of the milieu, since the exchangeable sodium encourages the clays to disperse in the presence of water, and then to fragment in this way when they dry out.

For each of these categories the list could be made longer. Among the criteria linked to disaggregation through the action of water, the appearance of rills or even of new arrangements might be mentioned, as in a case cited by Daniels (1982) in the USA. Ill-adapted farming practices caused considerable erosion which entirely removed the ploughed horizon. A new surface horizon was reconstituted, the organization of which (size of aggregates, porosity, etc.) was new and thus revealed the unfolding consequences of the land transformation.

6.3.2.2 Changes of Behaviour of Soils and their Sensitivity to an External Action

Monnier distinguishes three main groups of properties:

(1) *Structural stability*. This denotes the resistance of aggregates to disaggregation through the action of water. The problem is how to standardize evaluation methods. The French school (Hénin and Monnier, 1960) attaches considerable importance to the intrinsic properties of the soil (its mineral and organic constitution), particularly considering that a change in the organic status of land plays a major role in the evolution of its structural stability.
(2) *The behaviour of soils in relation to mechanical actions*. This involves the assessment of consistency limits, notably by Atterberg tests; and behaviour under compacting, assessed either by dynamic compacting tests (the Proctor test) or by static compacting tests (oedometry).
(3) *The tendency of soils to fissure*. The tests used reveal first of all the role of texture, and notably that of clay. But the organic matter and the cations attached to the clays (through the flocculating or dispersing properties of the cations) also play a role which makes it possible to use these tests as criteria in certain cases of land transformation.

The expressions of these properties may be shown on texture diagrams for given soils.

6.3.3 Conditions Under Which it is Possible to Make Better Use of Criteria Related to the Arrangement of the Soil's Constituents

6.3.3.1 The Diversity of this Type of Criterion

The number of illustrations and the list of criteria concerning the arrangement of constituents could have been considerably longer. Here one last example, revealing the diversity of these criteria, will be presented.

A team of research workers from south-western France chose as a criterion the notation of clods of soil after ploughing (Hutter *et al*., 1982), according to a pre-established code. These authors were particularly interested in the smoothing and crumbling phenomena manifested in the clods, smoothing being an indicator of land wastage. The processing of these notations through factor analysis of the correspondences enabled the team to point out the influence of irrigation and previous cultivation on the stability of ploughing. Thus it appears that in irrigated conditions, maize–sorghum as previous crops cause considerable smoothing, unlike cereals. This difference disappears if there is no irrigation.

Here the notation of an organizational feature (clods produced by ploughing) and processing through calculation of the marks given constitute the criterion of consequences of a land transformation (introduction of irrigation, modification of rotations).

6.3.3.2 Use of these Criteria Through a Spatio-temporal Process

Boiffin (1984) adopted this approach in his study of the formation of beaten crusts in loamy French soils. After making a careful typology of the various morphological stages of these crusts, Boiffin carried out large-scale mapping (several square metres) of their spatial distribution and then monitored them over a period of several months, punctuated by rainy periods. The association of these three processes—typology, cartography and monitoring—over a period of time enabled him to understand more clearly how beaten crusts are formed, and thus to use the 'appearance of a beaten crust' not only as a symptomatic criterion, but also as a criterion that could be used in making a diagnosis.

6.3.3.3 A Synthetic Criterion: Examination of the Cultural Profile

The concept of cultural profile, defined by Hénin and Monnier in 1956, meets the need to pay attention to *the overall physical state of the soil* when judging the effects of a change in farming practices, techniques or systems. Within the soil profile attention is focused on the entity formed by the superposition of differentiated layers of earth through the action of farm implements, of root systems, and that of factors reacting to the two previous actions. This examination is an extremely reliable synthetic criterion for an experienced observer.

Finally it should be pointed out that in the case of land transformations involving physical modifications to the soil, criteria related to the arrangement of the soil's constituents are, because of their diversity and wide range of applications, often more operational than criteria related to a single constituent element of the soil, especially organic matter.

6.4 CRITERIA RELATED TO THE WATER AND GAS COMPONENTS OF THE ECOSYSTEM

The behaviour of water and gas in soils and on land may constitute a highly reliable criterion for assessing a land transformation and its consequences. The four examples chosen here relate either to *regime* characteristics or to *balance* characteristics and are significant in this respect. The very nature of the criterion means that it is unnecessary to draw up a list of parameters or to indulge in methodological considerations.

6.4.1 Examples

6.4.1.1 Increase in the Water Runoff Coefficient

In Madagascar, during storms or cyclones, the annual runoff coefficients may exceed 60% and the instantaneous flows reach 1350 l/s/ha (during a decennial flood) under secondary vegetation after burning and in undulating areas. Under natural or artificial forest (after reforestation with eucalyptus), on the other hand, the same coefficients and flows are far lower: 20–30% and 500 l/s/ha) (Bailly, 1982).

Results of the same order have been obtained in Guyana in similar relief conditions in a study area of ten catchment basins, where the total measured flow varies from 11% to 50% of annual rainfall depending on the use to which the basins have been put (reforestation, natural new growth, pasture, orchard).

This criterion related to the behaviour of water reveals the consequences of an extremely widespread form of land transformation: the destruction of dense tropical forests. 140 million hectares will have been affected between 1975 and the years 2000, in addition to which it is foreseen that 70 million hectares of open forest will also have been destroyed. Reforestation during the same period will only amount to an estimated 15 million hectares. Unfortunately the use of this criterion is thus highly topical.

6.4.1.2 Rise in the Level of Superficial Groundwater (Shannan, Chapter 5.I)

A rise in the water level of the root area signals an unfavourable environment for the roots of most cultivated plants, notably because of lack of oxygen. In semi-arid or arid regions, it also points to a secondary salinization of the land.[3]

The example of Pakistan is highly revealing from this point of view. Over a large part of 15 million irrigated hectares, the originally deeper-lying groundwater has risen rapidly—by 30 cm annually. As a consequence, in 1978, over 54% of the total irrigated surface, the groundwater was at a depth of less than 3 m.

This depth has been considered as the threshold above which risks of waterlogging and salinity become very acute. This 'rise in groundwater level' criterion has led the Pakistan government to launch a large-scale drainage programme (the SCARP programme) without which 50% of the irrigated surfaces would now be unfit for cultivation.

6.4.1.3 Modification of the Flood Régime

In the west of France, rural land was until 1960 structured by a network of hedges consisting of wooded banks skirted by ditches: the *bocage*. Socio-economic considerations induced the farmers in this region to regroup their land-holdings, extend plots, construct access roads, etc. Consequently there has been a massive levelling of the wooded banks. A change in the flood and low-water régime in the elementary catchment basins (several dozen hectares) is one of the criteria which reveals the consequences of this profound transformation of the landscape.

A comparative study of two elementary basins, one subject to reallocation, the other not (Mérot, 1978; Carnet, 1978), has made it possible to describe these modifications. Flood hydrograms (Figure 6.2) show that at this spatial scale at least the destruction of the *bocage* leads to a greater rate of discharge during flooding and smaller flow rates at low water.

6.4.1.4 Reduction of the Water Drainage Coefficient

The same type of criterion was used by Gachon *et al.* (1982) in medium-altitude mountain areas of the Massif Central (France), during experiments carried out on lysimetric plots. The water balance, and notably the drainage coefficient, revealed the consequences of changes in agricultural systems and changes in the conception and intensity of mineral manuring. Gachon and his co-workers have thus shown that in cultivated meadowland subject to crop rotation, drainage fell by between 5% and 10% when the level of nitrogenous manuring was raised. Under permanent meadow, on the other hand, drainage is almost constant and independent of the level of nitrogenous mineral manuring. A high compensatory production of white clover compensates for the absence of this fertilization, and helps to maintain the level of water consumption.

Changes in the behaviour of water in soils may thus constitute a criterion, as indicated by the four cases chosen as examples. The same applies to another

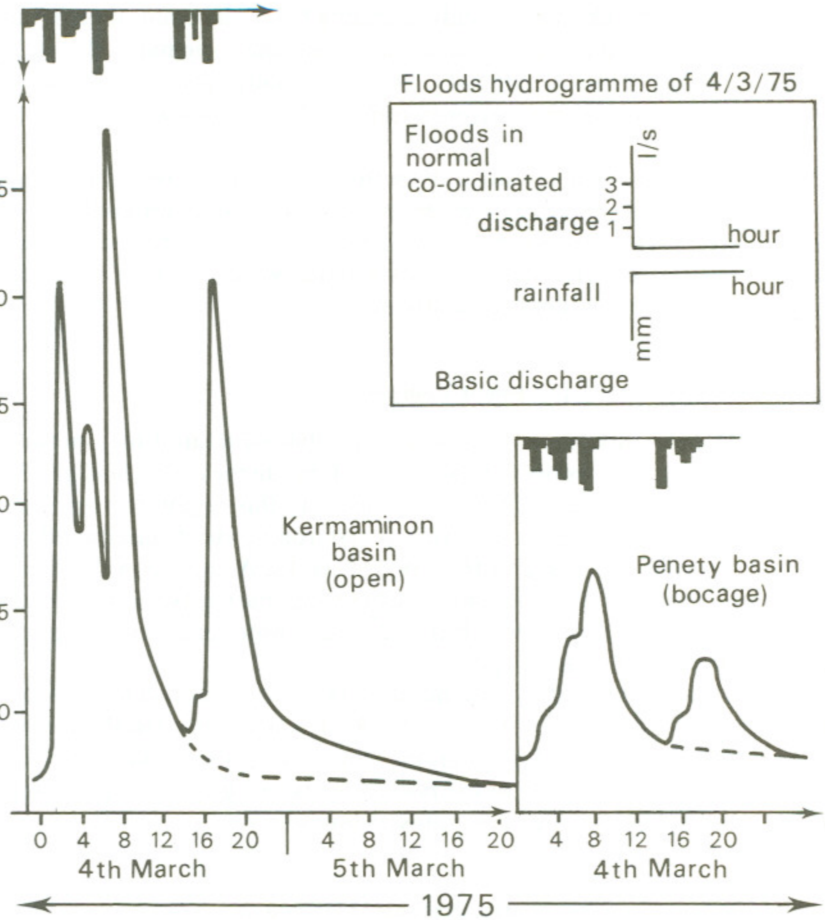

Figure 6.2 Comparison of the behaviours of a *bocage* catchment basin and an open catchment basin. The two basins have the same area (32 ha) and their geological and geomorphological characteristics are closely comparable. They are less than 4 km apart and are subject to virtually the same precipitation (Mérot, 1977)

environmental fluid, gas. The appearance of a specific gas such as hydrogen sulphide may reveal a milieu that has become extremely reducing subsequent to a transformation which has increased waterlogging.

However, the criteria related to water and to gases are usually only of symptomatic value, and possess little explanatory value. In the last example, the Massif Central in France, the drainage coefficient criterion nevertheless makes it possible to analyse the favourable role of nitrogenous fertilization using the water consumption of meadow plants. As a rule, however, the criteria relating to fluids are not very useful for making diagnoses, nor consequently for making prognoses, unless they are compared with climatic data recorded at frequent intervals.

6.5 CRITERIA RELATED TO THE BEHAVIOUR OF PLANT AND ANIMAL SPECIES

The behaviour of plant and animal species often provides information about the consequences of a land transformation of agricultural origin. The criteria may be:

(1) the disappearance or appearance of species;
(2) the modification of the respective share of various species in a given ecosystem (impoverishment, diversification);
(3) the modification, within a given species, of certain behaviour characteristics: the localization of roots in the case of a plant species, the sensitivity of a species to environmental changes.

Three examples have been selected to illustrate the application of these criteria.

6.5.1 Examples

6.5.1.1 Impoverishment of Forest Flora and Fauna (Bonneau, 1982)

In many forests, economic imperatives have made it necessary to attach great importance to productivity. The result has been a trend towards uniformity and increasing density: forests are created by plantation; there are no clearings; they consist of a single type of tree; all the saplings are regularly spaced and of approximately the same height.

Under dense plantations of resinous trees, the natural flora is impoverished. The litter, consisting of plant matter of a single origin, may decompose less well: the range of species of microflora (bacteria, fungi) and microfauna (microarthropods, earthworms, insect larvae) which cooperated to fragment, alter and mix the fallen leaves in the soil, is reduced in size and variety and becomes less efficient. Animal life in the forest diminishes—notably the bird population, which prefers a mixed forest of irregular structure. The forest is more exposed to attacks from parasites. The lack of diversity in the herbaceous and ligneous flora and in the plant structures reduces the number and variety of potential pest-destroying predators.

Thus the impoverishment both of the natural flora beneath the forest canopy and of the ground-level fauna are here the criteria of the consequences of a profound change in forest management.

6.5.1.2 Diversification of Flora and an Increase in the Value of Plant Species as Animal Food (Loiseau, 1982)

This criterion is closely related to the previous one, but in a sense converse to it. In the pastureland of the Monts Dore in central France, a diversification of the flora has been observed on parts of the common land used for pasturing ewes, with the appearance of red fescue and white clover which constitute nutritious forage. This corresponds to the organic manuring of the commons by local sheep farmers. In places where the farmers have not applied this new strategy, i.e. have continued to spread organic manure outside the commons, the vegetation remains relatively undiversified, with spreading of spikenard, followed by heather; this has led to the abandonment of this land and a consequent regression in the quality of the pasture.

An improvement in the potential of pastureland is here the criterion of the consequences of a change in the organization of pasturing.

6.5.1.3 Disappearance or Appearance of Plant and Animal Species

The flora of the Netherlands has declined sharply since 1950, as shown in Table 6.5. The forms and mechanisms of this change in the number of species have been identified in two regions of the Netherlands which have undergone profound transformations:

(1) In the region of the dunes, the exploitation of fresh water from the groundwater has led to a marked drop in the water level. The number of species of phreatophytes and birds has fallen considerably. Some are unable to survive the desiccation.
(2) In the region of the polders, intensive land use has led to transformations of the same type, notably the decline of certain species of birds as shown in Table 6.6.

Many more illustrations could be given of the ways in which plant or animal

Table 6.5 Decline of the Dutch flora (de Molenaar, 1980)

	Number of species	%
Total number of species	1502	100
Number of species that have diminished	824	55
Diminution:		
50%	108	7
51–70%	423	28
71–90%	182	12
91–100%	111	7

Table 6.6 Decline of a bird species in the polder region (Eyerman, 1975)

Species	Extensive land use	Intensive land use	Decline (%)
Oystercatcher	33	0	100
Lapwing	133	4	97
Black-tailed Godwit	120	2	98
Redshank	53	4	92

species can be used as a criterion. Nor are such criteria invariably based on the number (appearance, disappearance, diversification, impoverishment) of species or on their 'quality' (as fodder, for example). They may also be based on the behaviour of a given part of a plant. The 'foliar diagnosis' approach is a well-known illustration of this. But the localization and state of roots are also reliable criteria.

Thus in the marshes of western France, examination of cultural profiles carried out in meadowland showed the existence of a mat 7 cm thick consisting essentially of root debris (from fodder plants) and a little earth. This mat represents a system almost independent of the subsoil, from which it can be separated as if it were placed on a substratum. This criterion enabled Hénin and Fournier (1982) to make a diagnosis of the consequences of developing these clayey lands won from the sea by a network of embankments and drained by ditches. Improvement of this land was carried out by eliminating obstacles to deep root development (asphyxia, excessive chloride content). The first step in the treatment is to lower the water table. Thus the 'appearance of a rooty mat' criterion is in this case a symptom but, since it has some explanatory value, it also points towards diagnosis, prognosis and forms of treatment.

6.6 CRITERIA RELATED TO GENERAL CHANGES IN THE ENVIRONMENT

The parameters that can be used as criteria for assessing and evaluating land transformation are largely related to components of the terrestrial environment: soil, water, plant and animal populations, etc. In some circumstances, however, a land transformation has consequences that may make a more comprehensive impact on the environment; in this situation some of the general characteristics of the environment may be affected, such as the form of the landscape or climatic behaviour. These changes may be included among the criteria for assessing and evaluating land transformations, as the following examples reveal.

6.6.1 Examples Related to the Shape of the Landscape

6.6.1.1 The Appearance of Sinkholes (Unesco, Land Subsidence, to be published)

Since the 1950s, large numbers of sinkholes have appeared in Alabama as a result of land subsidence due to the lowering of the groundwater level, a phenomenon which is itself the result of excessive pumping of underground water for various reasons (agriculture, human consumption, etc.). Over 4000 sinkholes have appeared in the insufficiently consolidated clayey deposits surmounting carbonated rocks. Most notable of all are 1700 holes spread over 36 km^2, an average of almost 50 holes per km^2. Their size varies greatly: from 1 m to 90 m in diameter and 0.30 m to 30 m in depth.

Because of their shape and density, these sinkholes create a landscape that is both a 'warning signal' criterion and a 'diagnostic' criterion, for it is easy to connect the pumping of the water and the appearance of fields of sinkholes.

6.6.1.2 The Appearance of Salt 'Lunettes' (Unesco, Land Subsidence, to be published)

Small hillocks of earth formed by the wind are sometimes found on the edges of depressions in North Africa. Analysis reveals that they are composed of pseudo-sand formed by the aggregation of particles of clay and salt crystals. Clumps of grassy vegetation support the first stages of accumulation of these pseudo-sands. The growth and multiplication of the 'lunettes' creates a distinctive landscape.

This 'landscape' criterion reveals the very high degree of salinity of the soils in the region. The salts bring distinctive structural properties to the soil's surface crust, and pseudo-sands are created. The movement and accumulation of the latter takes the form of a landscape of salt 'lunettes'.

6.6.2 Examples Related to the Climate

6.6.2.1 Evapo-transpiration (Choisnel and Payen, Document prepared for the SCOPE Project to be published by the French Ministry of Environment)

Evapotranspiration may act as a criterion for judging the effects of transformations in agriculture. The oasis effect (an increase in evapo-transpiration) is an illustration of this. In Mediterranean areas, when irrigation is introduced on to small and scattered plots of land, evapo-transpiration becomes abnormally strong. The mechanism of this phenomenon is well-known: in the non-irrigated zones, the surface temperature of the soil remains higher than the temperature of the air for most of the day. The temperature of an irrigated plot, on the other hand, is always lower than that of the air temperature: the convection flow is then directed towards the soil and evapo-transpiration increases.

Focusing on this oasis effect by monitoring evapo-transpiration constitutes a 'warning signal' criterion since it draws attention to a certain waste of water. It also makes it possible to define an irrigation strategy: in the dry Mediterranean region the irrigation of these small plots should aim to bring water to the soil in sufficient quantities to maintain a level of evapo-transpiration at most equal to the net radiation. The oasis effect is thus also an explanatory criterion which leads to a proposal for a solution.

More generally, a modification of the surface energy balance may reveal the consequences of transformations linked to agriculture which bring about changes in the hydric state of the surface of the soil, in the phenological state of the vegetation, in the albedo of the soil–vegetation system, or specific modifications of the wind régime.

The destruction of the *bocage* in western France is relevant here (see section 6.4.1.3). Land reallocation led to the disappearance of the hedges which surrounded the fields; climatic measurements were carried out simultaneously on areas that remained as *bocage* and on the reallocated areas, using batteries of apparatus posted at different heights. The comparison of climatic balances (Missonnier *et al*., 1982) shows that the *bocage* acted as an energy trap and increased the continentality of the climate; this had diminished in the redistributed areas. Furthermore, the potential evapo-transpiration of the open (reallocated) plots has not changed in relation to that of the closed plots of the *bocage*.

Here too the usefulness of certain climatic parameters is apparent as criteria for evaluating the consequences of land transformation in agriculture.

6.7 CONCLUSIONS

This chapter does not claim to be an exhaustive presentation of all the environmental parameters that may be used as criteria for judging the evolution of land. It seeks above all to highlight the types of parameter and criteria which may be useful in environmental monitoring.

For this reason, a number of concluding remarks are called for, the first of which is that parameters relating to the soil are more widely taken into account than other environmental parameters. This is because the consequences of land transformation in agriculture primarily affect soils, by causing their properties to vary.

It appears that monitoring is not simply a question of recording changes in the properties of soils. It may be carried out not only by focusing on modifications in the cycles of chemical elements and the structural properties of soils, but also by taking account of modifications in elements external to soils, such as water, or supported by soils, such as animals and plants. Finally, such general characteristics of the environment as climate and landscape may also be affected.

Today there is a tendency to wish to monitor the evolution of the earth's surface on a global scale. Teledetection, which is used for this purpose, takes account of the two general criteria, climate and landscape, among others. But if teledetection now makes it possible to draw up periodic land-occupation balances and to record surfaces seen from satellites with a certain precision, it cannot provide a complete explanation of environmental mechanisms, nor of the cause-and-effect relationships between the phenomena that exist in the environment. However, analyses are essential for decision-makers, and it is to further this work of analysis that a series of parameters have been discussed which emerge from the preceding chapters (especially those that evaluate knowledge of agricultural practices which cause changes in land use).

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6.9 NOTES IN THE TEXT

(1) The factors in the Hénin stability index (I_s) are: (i) the average percentage of stable aggregates (this percentage is the arithmetical average of three percentages of aggregates stable in water: without pre-treatment, after pre-treatment with alcohol, after pre-treatment with benzene); (ii) the dispersed 'clay and loam' fraction; and (iii) the 'rough sand' fraction. Then

$$I_s = \frac{\text{(ii)}}{\text{(i)} - 0.9 \times \text{(iii)}}$$

Stability is considered good when $\log_{10}(I_s)$ is less than 1.

(2) After Monnier: Document prepared for the SCOPE Project and to be published by the French Ministry of the Environment.

(3) Shanan uses the expression 'the twin menaces: waterlogging and salinity'—see Chapter 5.I.