Causes of Soil Degradation and Development Approaches to Sustainable Soil Management

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Pilot Project
Sustainable Soil Management

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Foreword

Soil is being degraded and its productivity is diminishing at an alarming pace worldwide. Higher input may offset lower productivity in the industrial countries, but most developing countries lack the capabilities for this. The impressive achievements of the "green revolution" are therefore in danger of being lost also because they cannot be sustained. Increasingly, too, soils have been irreparably damaged in the tropics and subtropics, so agricultural land is disappearing.

The challenge now facing us is to ensure the sustainable use of the resources, soil, water and nutrients (sustainable soil, water and nutrient management) to secure food supply, conserve the environment and alleviate poverty. German development cooperation is taking up this challenge by placing particular emphasis on implementing the programme of action (Agenda 21) adopted by the United Nations Conference on Environment and Development (UNCED) in Rio in 1992, which accords high priority to the preservation and sustainable use of the soil.

The Federal Ministry for Economic Cooperation and Development (BMZ) has responded by stepping up assistance to resource conservation in both bilateral and sectoral projects. Via sectoral projects the aim is to develop concepts, methods, strategies and innovations for application in bilateral development cooperation. The pilot project, Sustainable Soil Management, which has prepared this publication, is an example of this commitment.

This report pinpoints the basic bio-physical and socio-economic causes of soil degradation and suggests approaches to remedying them. These approaches should be tailored to the special needs of land users in individual ecological regions; they should be closely geared to the specific situation and the interventions must address different levels in both production technology and in the social sphere. This calls for new initiatives in development cooperation. The partner countries must be given more assistance in drafting soil policy and soil conservation strategies as well as in developing production techniques to conserve soil. Land users will only adopt new, sustainable cropping techniques, if these result in economic gains. To ensure this, the legal and economic parameters need to be reformed.

This report is the outcome of cooperation amongst the staff of different university institutes and organizations, particularly the Lehrstuhl für Bodenkunde (Professorship for Soil Sciences) at Bayreuth University, the Lehrstuhl für Bodenkunde (Professorship for Soil Sciences) at Munich Technical University, the Institut für Pflanzenproduktion in den Tropen und Subtropen, für Agrar- und Sozialökonomie in den Tropen und Subtropen and the Institut für Agrarsoziologie, Landwirtschaftliche Beratung und angewandte Psychologie (Institutes for Plant Production in the Tropics and Subtropics, for Agronomy and Socioeconomics in the Tropics and Subtropics, for Agro-sociology, Agricultural Extension and Applied Psychology) at the University of Hohenheim, the German Development Institute, Berlin, LUSO Consult, Hamburg, ATSAF, Bonn and the ETC Foundation, Leusden (The Netherlands). We have received suggestions from the Geographisches Institut

(Geographic Institute) at Bern University and the Direktion für Entwicklungszusammenarbeit und Humanitäre Hilfe (Directorate for Development Cooperation and Humanitarian Aid), Bern. We thank all the above for their contributions to this state of the art report.

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Page

Appendix

List of Figures

List of Tables

Summary

Extent and causes of soil degradation

The challenge facing international agricultural development in the next decades is not just to halt progressive soil degradation, but to reverse the process and double food production at the same time.

The degradation and irreversible destruction of soil have reached alarming proportions. Every year **worldwide 5-7 million ha** of **agricultural land are lost,** and the productivity of even more land is steadily decreasing. A quarter of agricultural land is badly damaged, i.e. its productivity is significantly impaired.

Soil degradation is taking place worldwide. Under p**articular threat are tropical soils,** however, as these are less stable than those in temperate climates because of their properties and the climatic conditions.

Ongoing soil degradation is not just endangering food security for the world's population, it is accelerating global climatic change. **Soil organic matter** is an **important sink of CO_2**. Under unsustainable soil management organic matter is depleted and CO_2 released. At the same time, less CO_2 is assimilated because less biomass is produced.

Throughout history there have only been three examples of sustainable agricultural production systems. All three are based on restoring soil fertility after each cycle of production:

- Shifting cultivation
- Mixed farming with integrated livestock farming
- Irrigated rice growing

Each of these systems can only remain stable when sufficient suitable land is available. The land can only carry a higher population density if nutrient loss due to the harvest is not just compensated by inorganic fertilizers, but if the **nutrient status** of the soil is actually improved. Otherwise, it will deteriorate because of nutrient depletion and the decomposition of organic matter. In semi-arid regions **the water retention capacity** must also be improved and water use controlled. Lower productivity will be partly compensated by extending agricultural production increasingly to marginal regions with unstable soils. This engenders **a downward spiral of unsustainability,** which ends in poverty. The aim must be to reverse this trend, not just to halt it, and to do this the causes must be thoroughly analyzed in each particular case and approaches developed to remedy the problems based on the findings.

Soil degradation means a significant deterioration in the physical, chemical and biological properties of the soil, particularly:

- Depletion of nutrient reserves (soil impoverishment)
- Depletion of organic matter and associated deterioration of soil structure, water retention capacity and sorption and release of nutrients

- Soil acidification combined with aluminium phytotoxicity and phosphate fixation
- Salinization due to inadequate irrigation and drainage (destruction of relatively small but highly productive surfaces)
- Soil erosion (mostly selective, i.e. fine nutrient-rich particles) due to water and wind

The **causes of soil degradation** are bio-physical and socio-economic and frequently one problem causes another. According to GLASOD (Global Assessment of Human-Induced Soil Degradation), the main reasons for soil erosion and chemical soil degradation are agricultural mismanagement, overgrazing and deforestation. Erosion is exacerbated in the tropics by heavy rainfall and prolonged and intensive dry seasons. Heavy rainfall in the humid tropics combined with low nutrient sorption by kaolinic soil are promote nutrient leaching. Many soils, especially in the savanna regions, tend to phosphate fixation. Organic matter is depleted five times faster in the tropics than in temperate climates.

A number of **socio-economic factors** deter land users from investing enough in conserving soil productivity:

Rapid **population growth** over the last decades has caused land shortage resulting in shorter fallow periods and the extension of cropping to marginal land. Traditional cropping systems have been destabilized and land users have failed to adapt their systems fast enough to changing conditions. High population density and land shortage can also raise land prices and induce investments in soil conservation if the production and marketing prospects are good for more lucrative products (vegetables, fruits, ornamental plants, milk).

Ill-defined rights of ownership and use result in disputes and soil mining in many countries. Traditional land rights for all the people in a village have been undermined by social change. Land reforms and granting personal rights have often exacerbated the situation and more land is concentrated in the hands of the better off. In densely populated regions there has been a rapid increase in short-term land tenure. Traditional rights prohibit the planting of trees or perennial crops on this land, which again destabilizes the soil.

Livestock farmers are ousted by the advance of cropland, which results in overgrazing and the destruction of fragile eco-systems.

Price, fiscal and subsidies policies in many countries act as incentives to extend arable land, continued cultivation of profitable crops, e.g. soya, and farm cattle on large expanses of rainforest, thus exacerbating soil degradation.

Investing in production methods that conserve soil only results in higher output after a delay. Erosion control measures simply maintain the production potential, apart from arid areas where improved water retention directly raises output. Lower **labour income** in the first years and uncertainty about when and how much output can be raised deter many low-resource land users from investing in soil conservation and sustainable production methods. This is particularly true if there are alternative sources of income and **opportunity costs** for labour play a role.

A **key factor** in soil degradation or sustainability is **time**. Soil degradation is a gradual process that mainly affects following generations. As a result, many farmers do not view erosion as a problem. Planners and land users differ greatly in their assessment of soil erosion.

The **off-site effects** of soil erosion are often more pronounced than the **on-site effects**. Sanded up reservoirs, destroyed roads, rain rills and sand and boulder masses in low-lying fields cause greater damage than soil run-off on the fields of individual farmers. Individual land users are generally less concerned about soil conservation than society as a whole.

Product prices are low in many countries and are deliberately kept low by governments, who give precedence to satisfying the needs of the urban population over those of farmers who have a weaker lobby. Another reason is the poor **market access** of many farms, particularly for lack of infrastructure (roads, markets, warehouses).

Inputs to raise output (like mineral fertilizer) are only worth purchasing for a few lucrative crops (like export crops, vegetables).

Government agricultural services, including extension services, place more stress on promoting certain crops than disseminating sustainable production techniques. There is a lack of qualified staff in agricultural services and **agricultural research**. Due to **insufficient involvement of target groups** in technological advances and **inadequate collaboration** between research and extension the acceptance of extension messages is low.

Promoting agriculture and especially sustainable soil management are accorded low priority in most of these countries. **Agricultural policy** lacks coherence and is frequently amended. High output regions and large-scale farms receive more assistance while endangered marginal zones are neglected.

Structural adjustment programmes curb public investment, including subsidies for inputs or producer prices. Combined with lower prices for export crops (e.g. coffee) this means drastic cutbacks in incomes, which in turn curtails investment particularly in sustainable soil management methods.

Lifting **import restrictions** and **deregulating trade** (GATT) also bring down producer prices with a direct effect on sustainable soil use.

Causes of failed projects in sustainable soil management

Many bilateral or multilateral development projects aim at promoting sustainable soil management. Compared with the input, achievements so far tend to be modest. The main causes are:

- Projects too short to achieve objectives
- No sectoral approach in many projects
- Projects not tailored to existing structures

- Shortage of appropriate technologies; no satisfactory technical options available as yet
- Uneconomic technologies
- Inaccurate or inadequate distinction between or definition of target groups
- Insufficient participation of target groups in problem analysis and technology development

Development approaches for sustainable soil management to conserve resources

Sustainable soil management entails the sustainable management of the resources soil, water and nutrients. This calls for a departure from a policy of simply raising output to aiming for sustainable production as well, and this, especially in the Sub-Saharan regions, at a significantly higher level. This policy shift necessitates interventions at different levels, ranging from plots and farms up to the global level. The problem is that action at the different intervention levels needs to be synchronized and coordinated.

Conducive policies and structures in agriculture

Reforming agricultural policy to actively promote sustainable soil management means providing policymakers with facts and figures and long-term data on the ratio between erosion and yield reduction and cost-benefit analyses for measures to conserve soil as a basis for decision-making. However, in most countries this data is lacking.

More sustainable soil management can be achieved by altering the determinants: cropland area, cropping pattern and cropping techniques. Planting seasonal crops like maize, soya or cotton exacerbates soil erosion far more than multi-seasonal forage or permanent crops. Through pricing and the active promotion of crops that help conserve soil, it should be possible to shape cropping patterns by planting more crops that conserve soil and planting fewer that deplete resources.

By internalizing the external effects of soil degradation, price policy can bridge the gap between the social and business costs of soil degradation. This is particularly significant for the impacts of soil erosion, because in the short term off-site (external) effects are frequently more severe than on-site (internal) effects. Via appropriate product pricing, productivity per land unit can be raised and pressure on marginal regions reduced accordingly. Though it is not possible to make generalizations on the impacts of price changes, pricing is commonly considered a tool of agricultural policy.

If land users are averse to sustainable soil management and especially erosion control for reasons of cost, another option for changing production methods might be subsidies or other incentives, particularly where government and society are intent on preventing off-site damage or securing national food supply. Adverse experience with these kinds of subsidies calls for caution: they should be for a limited term and stand in reasonable relation to farm income.

The land user must be sure that he will benefit from investing in the soil. This calls for long-term guaranteed rights of ownership and use. Land reform is not necessarily the best way. It is better to adapt traditional land use conventions to social change and technical developments and the best approach here is target-group participation at village or regional level. Major elements when reorganizing land use are guaranteed usage rights for women and permission to plant trees on leasehold.

Sustainable soil management measures often require a collective approach. Farmers' associations, village committees or user associations can better represent the collective interests of land users and facilitate decision-making for specific measures and their implementation.

Approaches at farm level

Production systems for soil conservation are often unprofitable since investments do not result in higher yield or income. Only in some cases, e.g. minimum tillage, has it been possible to reduce production costs directly by input savings. Generally, they incur opportunity costs due to greater labour needs. The only way to solve this dilemma is to cater for farmers' short-term economic interests by using by-products like forage in alley cropping, planting more lucrative crops, such as fruit, or producing fuelwood on planted fallowland. When choosing a technology, precedence should be given to a high cost-benefit effect over technical efficiency and another yardstick should be easy handling. This will take account of farmers' strategy of minimizing risk.

Research and extension

Preconditions for a high acceptance rate are an exact identification or definition of the target-group(s) in the intervention zone and suitable participatory methods in technology development.

Scientists and extension staff should not just apply their own decision-making yardsticks; more than hitherto, they must also cater for the reasoning behind decisions taken by farmers. Minimizing risk comes before maximizing yield; farm income is measured against labour input. Farmers frequently assume higher opportunity costs than scientists.

Today, target-group participation in technology development is seen as key to the successful adoption of innovations, but this holds only if innovations are economically viable and to ensure this research and development need reorganizing. Participatory approaches demand a high standard of research and extension. Extension services must cooperate closely with the land users to help them solve their problems. The participatory approach also entails a new definition of roles and better staff training. Non-governmental organizations are more amenable to participatory approaches but a strongpoint of official institutions, their continuity, should not be overlooked. Participatory approaches need more time than others. This poses a problem for short projects and donor organisations are accordingly more reticent. However, greater sustainability warrants longer projects.

Developing technologies for different ecological conditions

Research and development has produced a number of technical options that go a long way towards conserving soil productivity. These options, e.g. green manuring, alley cropping, buffer strips or terraces, must be adapted to the local agro-ecological and socio-economic conditions of the farm enterprises. Very disparate ecological conditions due to topography, parent rock, climate and human activities pose problems. This localized diversity calls for specific trial and evaluation methods that can be extrapolated for other locations. Models can be very useful, but they need a large database. Drawing on local farmer know-how and endogenous techniques can be a considerable help in developing appropriate technologies.

National agricultural research is understaffed and underequipped in most developing countries and is not organized efficiently enough to produce viable findings in sustainable soil management.

Only massive assistance by international agricultural research and bilateral donor organisations can ensure a breakthrough in soil conservation in the foreseeable future. Though creating suitable political and economic parameters is important, there are still no technical solutions for many problems and changing ecological and economic conditions give rise to new problems that call for new solutions. To develop these, we need sound agricultural research facilities.

Escalating problems

Without question, the prime challenge for research and development in the coming years is nutrient depletion of the soils and loss of organic matter. The nutrient balance is negative in nearly all regions and types of farm enterprise. A priority task for research and development is to raise the efficiency of mineral as well as organic fertilizer.

Identifying appropriate solutions for hoe farming is most difficult. Assuming farmers use their inputs rationally, little can be achieved by reallocating resources. Only by introducing animal or motor traction and appropriate tillage implements and means of transport can production methods be substantially improved, e.g. transport of manure and compost to remote plots, incorporating harvest residues, timely ploughing to make better use of early rains, inter-row cropping or underseed, minimum tillage and direct sowing.

Underutilization of capacity

A relative equilibrium of the N balance at least can be achieved through a consistent use of biological nitrogen fixation. Cropping systems should be developed for optimum N fixation while reducing N loss due to leaching and volatilization. N fixation itself could be enhanced by using more efficient rhizobium strains, variety x rhizobium combinations and controlled use of non-symbiotic N fixation. There is a great need for research here.

The best way to conserve soil is good ground cover, all year round if possible combined with less soil tillage. Perennial crops, cover crops, cropping systems (mixed cropping) for rapid ground cover, underseed and direct sowing will reduce soil erosion substantially, foster soil biology, improve soil structure and bring about an ideal carbon balance. Applied research must tailor these techniques to different local needs.

Conclusion

Only by improving the general agro-political and socio-economic conditions and developing technical options can a sustainable use of soil, water and nutrients be achieved. Many variables need changing and account must be taken of the interests of different groups. Developing national strategies for sustainable soil management to conserve resources could help avert conflicts of interest. This would achieve the aim more quickly.

Sustainable soil management – introduction 1.

Aims of the report 1.1

To meet growing needs, the world food supply must be raised by about 40% in the next 15 years. Three-quarters must be produced in the developing countries. This will place even heavier demands on natural resources and increase the danger of a massive destruction of these resources, especially soil.

So, the job of development cooperation is not just to help secure food supply, but also to increasingly conserve production resources. Sustainable agricultural development in general and the sustainable management of agricultural soils in particular are key.

This state of the art report aims to highlight the magnitude and causes of soil degradation and indicate options for sustainable soil management and interventions in development cooperation. The extensive international literature has been evaluated and reports of German research institutes collected. The report also draws on the many years of experience gained by German and international development cooperation and this material has been largely used to outline the options and define the research needs. This report is intended as the groundwork for guidelines in designing projects in sustainable soil management.

The report is primarily addressed to the agriculture and environment divisions in the Federal Ministry for Economic Cooperation and Development, but also the regional divisions in charge of rural development projects in developing countries. The intended readership also includes the staff of organisations playing a major role in designing new projects and planning/adapting ongoing projects.

Scope of topic 1.2

The term "sustainable soil management" stems from "sustainable soil and water management" or the more comprehensive "soil, water and nutrient management" (SWNM). To avoid vagueness and overgeneralizaton, the topic has been confined to **sustainable management of agricultural soils.**

Sustainability means using the natural resources soil, water and nutrients in such a way as to conserve them for future generations. Sustainable soil management is therefore the prerequisite to sustainable agriculture (GTZ 1994) and agricultural development.

"Sustainable soil management conserves the soil of a region for future generations as a whole to guarantee undiminished utility at the least."

HURNI 1993

Sustainable agricultural development was defined by FAO (FAO 1990a) in 1988:

"Sustainable development is the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non degrading, technically appropriate, economically viable and socially acceptable."

The FAO/Netherlands Conference on Agriculture and Environment (FAO 1991) revised this definition and translated it into several basic criteria and objectives to measure the sustainability of present agriculture and future trends. These include the following:

- Meeting the (basic) food needs of present and future generations in terms of quantity and quality and the demand for other agricultural products
- Providing enough jobs, securing income and creating humane living and working conditions for all those engaged in agricultural production
- Maintaining and, where possible, enhancing the productive capacity of the natural resource base as a whole and the regenerative capacity of renewable resources without impairing the function of basic natural cycles and ecological balance, destroying the socio-cultural identity of rural communities or contaminating the environment
- Making the agricultural sector more resilient against adverse natural and socio-economic factors and other risks and strengthening the self-confidence of rural populations

The sustainable management of agricultural soil calls for production systems that meet the increasing needs of a growing population while safeguarding or even raising soil productivity. The Consultative Group on International Agricultural Research (CGIAR 1989) therefore defined the main goal of agricultural research as maintaining soil productivity for future generations in an ecologically, economically and culturally sustainable system of soil management.

It needs stressing, however, that even in the short run sustainable soil management or soil management to conserve resources must be economically viable and must achieve the production targets of rural households. Many development projects have miscarried because they failed to account for this basic premise (see Chapter 3).

Multidisciplinary dimension of sustainable soil management 1.3

Sustainable soil management is a multidisciplinary approach and is not limited to soil science aspects. The bio-physical concern is to maintain and improve the physical environment (soil) and hence the basis for plant and animal production and from the biological standpoint the aim is to preserve bio-diversity. The socio-cultural goal is the satisfaction of human needs in a socially and culturally acceptable manner. In economic terms, all costs to individual land users and to society must be covered, and the capital resource soil must not be allowed to diminish in value through agricultural use. Another factor is time: immediate, short-term profits should not be made at the expense of the medium-term and long-term production base.

"To be sustainable, agricultural farming-systems must be productive in the short term i.e. enable the farm family to meet the immediate production goals of providing the family members with sufficient food to meet their needs and/or produce a cash surplus (FAO 1990)"

The report only touches on soil science and production details so as to devote adequate attention to socio-economic issues, including general economic and agricultural policy.

Development policy status of sustainable soil management 1.4

To cope with the annual population growth of 100 million in the developing countries, food production will have to be doubled in only 35 years. At the same time, millions of hectares of agricultural land are being lost every year. Most of the developing countries are agrarian and agricultural development is a key factor in development generally (GTZ 1994). Under these circumstances, conserving soil productivity is a basic precondition for steady, peaceful development. Lasting success in development cooperation is inconceivable without safeguarding soil fertility in partner countries.

Relevance to Agenda 21 1.5

The resolutions adopted at the Conference of the United Nations on Environment and Development in Rio de Janeiro 1992 (UNCED) and listed in AGENDA 21 (BMZ 1992) oblige the German Government to gear development cooperation more toward sustainable agriculture and rural development (Chapter 14). The following statement is made in Subchapter 14.1.3:

Conserving soil productivity poses the same challenge for tomorrow as the avoidance of war today and the fight against epidemics yesterday.

"A systematic procedure is necessary to identify sustainable land use and production systems for different land and climatic zones while taking into consideration social, economic and institutional aspects."

Subchapter 14.1.5 advocates well planned long-term national and regional measures to conserve soil. For the first time, soil conservation and productivity has been recognized by the international community as a priority in development policy.

This report will show how these pledges can be translated into practical development cooperation measures.

First, the problem of soil degradation will be outlined, causes then analyzed and options presented. Finally, guidelines will be specified for development cooperation measures in sustainable soil management.

2. Sustainable soil management – the problems

2.1 What is agricultural soil?

This report deals with the sustainable management of actual or potential agricultural soil to conserve resources. Agriculture comprises cropping, livestock farming, horticulture and forestry. Agricultural soil is thus defined as that part of the earth's surface that produces or can produce useful plants (food crops, forage and fibrous plants, fuelwood).

2.2 Soil – a renewable resource within limits

Only 11% (1500 million ha) of the earth's land surface can be used to grow useful plants. 28% is too arid, 23% lacks a balanced nutrient status, 22% is too shallow, 10% is too wet and 6% has permafrost. Soil is effectively a non-renewable resource. Soil destruction is irremediable. Soil formation is a very long process. Under normal conditions it takes 100-500 years to form one centimetre of soil. Altogether, agricultural soil takes 3000 to 12000 years to develop.

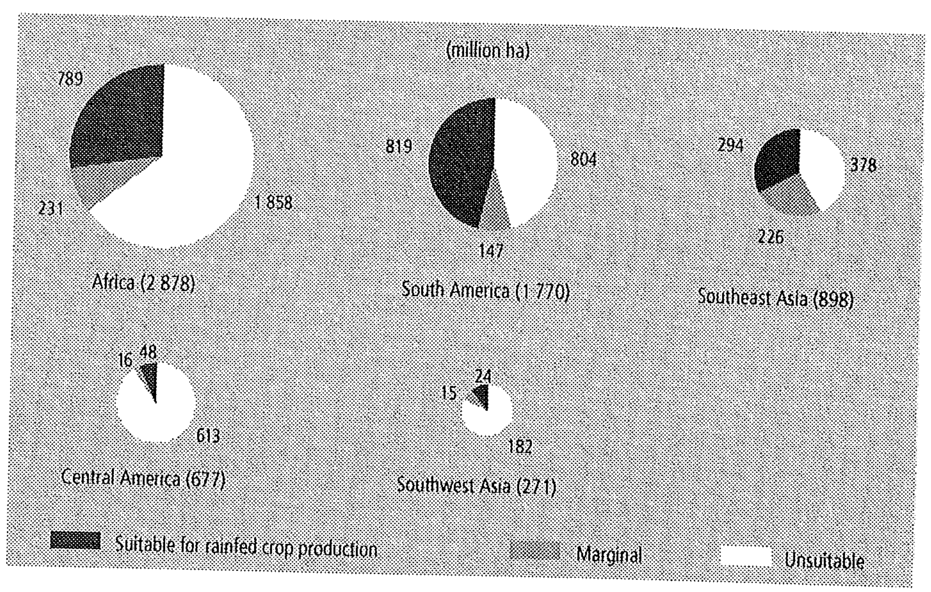


Figure 2.1
Potential land surface for rainfed agriculture
Source: FAO 1984, p.10

Unlike soil formation the destruction of fertile soil is proceeding very fast. The FAO estimates a worldwide loss every year of 5-7 million ha of agricultural soil (FAO 1994, UNDP 1992), including 2.7 million ha through erosion and 1.6 million ha due to salinization (Al-SWAIFY 1991), far more than could be offset by new land. Annual loss is forecast to rise by the year 2000 to 10 million ha (FAO 1991).

In the recently published world map, Status of human-induced soil degradation (GLASOD 1990), one quarter of agricultural land is estimated to be seriously damaged by soil degradation. Estimates for the African continent are even more alarming. Out of a

total of 1020 million ha of potential agricultural land, 124 million ha (12%) have been seriously damaged and 5 million ha (0.5%) utterly destroyed, i.e. now unusable for agriculture. Productivity on 190 million ha (19%) has diminished substantially.

At present, 5-7 million ha of arable land (0.3-0.5% of agricultural land in current use) a year are lost due to cropping.

Table 2.1
Major terrain divisions of the GLASOD map (in million ha)

	non-degraded terrain				
	none-used wasteland	stable land	other terrain	human induced soil degradation	Total Land surface
Africa	732	441	1299	494	2966
Asia	485	1426	1597	748	4256
South America	28	368	1129	243	1768
Central America	53	27	163	63	306
North America	75	1043	672	95	1885
Europe	1	116	614	219	950
Australasia	95	250	434	103	882
World	1469	3671	5909	1964	13013

Source: OLDEMAN et al. 1990

So productivity per ha needs to be raised drastically but the spread of non-productive land needs halting also. Of increasing importance too is how to regenerate the destroyed soil partly because the land is needed for production, partly because the continuing erosion is jeopardizing adjacent fertile land (run-off, coverage by rubble, boulders and wind erosion).

Definition of soil degradation 2.3

The term soil degradation means reduction to a lower level (BLAIKIE & BROOKFIELD 1987). If soil is degraded, its productivity is reduced and may be further reduced until steps are taken to stop further degradation and restore productivity.

The unhindered degradation of soil can completely ruin its production capacity for human purposes (DOUGLAS 1994). Generally, though, we have to cope with different stages of the same process of diminishing production capacity. This becomes clear in the following definition:

"Land degradation is the reduction in the capacity of the land to produce benefits from a particular land use under a specified form of land management" (BLAIKIE & BROOKFIELD, 1987 cited from DOUGLAS 1994).

This definition embraces not only the bio-physical factors of land use, but also socio-economic aspects such as how the land is managed and the expected yield from a plot of land.

2.4 Nature and extent of soil degradation

Every kind of soil use partly destroys soil structure and reduces soil fertility. Long-term soil use must therefore be accompanied by measures to conserve the soil.

Soil degradation is reaching alaming proportions. In the last 50 years alone 20% of the world's agricultural land has been irreversibly damaged. If the process of destruction continues at the same pace, agriculture will lose 15-30% of its present productivity in the next 25 years.

Rapid population growth in the tropical and subtropical countries and the concomitant intensification of land use is one of the main reasons for increasing soil degradation in these areas. Also, a high percentage of tropical soils are unstable and have low inherent fertility (see Chapter 2.5). So 64% of agricultural land in Africa is classed as low potential land (FAO 1984).

Table 2.2

Human-induced soil degradation between 1945 and 1990

Continent/Region	Degraded Land in millions of hectares	Percentage of Land (total area producing biomass)
World	1965	17
Europe	219	23
Africa	494	22
Asia	747	20
Oceanea	103	13
North America	96	5
Central America	63	25
South America	243	14

Source: UNEP-ISRIC 1991

Soil degradation makes land completely unproductive, but this also means higher inputs to maintain output. In the USA today, 50% of fertilizer is used to compensate loss due to soil degradation. In Zimbabwe pure nutrient loss due to soil erosion is three times higher than fertilizer input (STOCKING 1986).

The processes and causes of soil degradation are described in detail in Chapter 3.

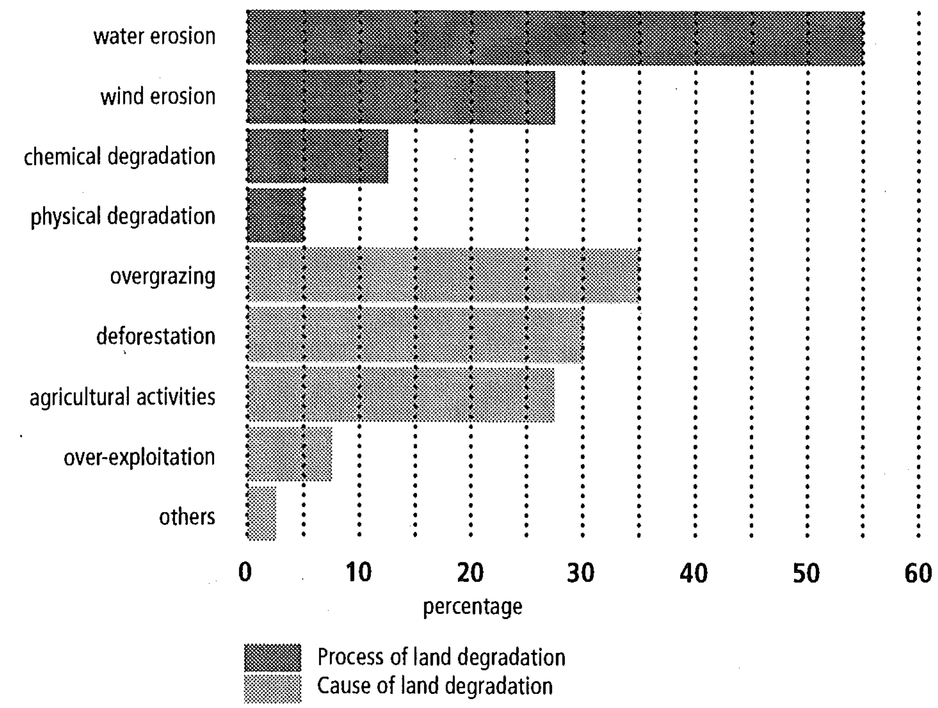


Figure 2.2
Processes and causes of soil erosion
Source: FAO 1984.

2.5 Impact of soil degradation on the global climate

Progressive soil degradation is not only jeopardizing the world's food supply; it is also influencing global climatic change

The vegetative ground cover and the soil organic matter are a major CO_2 sink. Soil degradation causes a reduction in vegetative cover frequently combined with an impoverishment of bio-diversity. In regions with high rainfall, erosion is much faster giving rise to badland. In non-sustainable soil management the contents of organic matter is also depleted relatively fast. Within a few years the carbon (C) contents may decrease by 20-50%. In the humid tropics this process is proceeding faster than in the arid areas, where it is interrupted during the 6-9 month dry period. Nevertheless, in the humid tropics, unlike the dry areas, C content may be increasing more rapidly thanks to the faster regeneration of vegetation. Estimating a C content of 100 t/ha/20 cm depth and a depletion of 1% and 10% respectively, the release is 3.7 and 37 t/ha CO_2 respectively. Less vegetative cover is conducive to C mineralisation of the soils which continues until a new balance is reestablished at a lower level. At the same time less CO_2 is fixed in the biomass.

Additional quantities of CO_2 are released by burning weeds, stubble or fallowland vegetation. In terms of global emissions, this burning by farmers plays a greater role than the burning of forests. In 1990, 2,047 million t CO_2 were released alone by burning grassland and savannas but "only" 98 million by slash and burn deforestation (Bundestag Commission of Enquiry 1992). It would of course be misleading to infer from these figures that no CO_2 would be released from biomass without burning. For the CO_2

balance it makes no difference whether CO_2 stems from mineralisation or burning. In a balanced system, practically the same quantity of C is released into the atmosphere as removed. Only until this equilibrium is achieved, e.g. after a change in land use, can a system act as a C sink or C source. A permanent C accumulation can only occur in unbalanced systems, e.g. where decomposition is inhibited. Inhibited decomposition, however, furthers nutrient fixation and this in turn hinders plant development and CO_2 uptake. On the other hand, the incomplete combustion of some biomass produces carbonized residues which can result in a substantial C sink (SEILER & CRUTZEN 1980; CRUTZEN & ANDREAE 1990). Altogether, what we are describing here is a complex interaction of different factors, most of which still need quantifying.

Table 2.3

Biomass of the major types of global vegetation

	tropical forests	temperate forests	northern forests	tropical grasslands	temperate grasslands	Tundra
surface (millions of km²)	24,5	12,5	12,0	15,0	9,0	8,0
living biomass (g C/m²)	18 000	14 000	9 000	1 800	1 440	250
litter (g C/m²) 710	368	250	360	667	75	
soils (g C/m²)	13 000	9 000	15 000	5 400	23 000	22 000
soils (g N/m²)	816	640	1 100	333	2 100	1 125
microbial biomass (g C/m²)	50	110	35	60	215	20
microbial biomass (g N/m²)	2	14	2,5	8,7	51	1

Source: Scharpenseel, cited from Bundestag Commission of Enquiry 1992

In forest clearance, not only does burning produce CO_2, but the organic matter stored in the soil also decomposes rapidly. During the first 5 years C content can easily be reduced by 20-50%.

During the last 100 years forest clearance for agricultural land use has produced about one half of total CO_2 emissions, but today the combustion of fossil fuels plays a far greater role (1980: 0.4-2.6 Pg C/year through changing land use as compared with 5.0-5.5 Pg through burning fossil fuels (Commission of Enquiry 1992).

Sustainable soil management can help minimize the pressure on the forests and, by stabilizing the content of organic matter in the soil, substantially reduce global CO_2 emissions. Increasing annual consumption of fossil fuels, however, will more than offset this reduction.

2.6 Specifics of tropical soils

Tropical soils differ in many respects from those in temperate climates – especially in terms of stability and resistance to human activities. Most tropical soils have also undergone a longer period of development and more intensive weathering. The individual

fertility properties of tropical soils are distributed very disparately amongst the various ecological zones, which is why the term tropical soils should not be applied in a generalized sense.

Owing to the wide variety of chemical and physical soil properties due to climate, rock and topography, there are localized, but highly significant agricultural soil types within these zones, e.g. argillaceous vertisols, soils from young volcanic substrates (andisols) and hydromorphic alluvial soils.

Properties of soils in the humid tropics

A special problem in the humid tropics is the low nutrient level because of the very short nutrient cycle involving only the upper layers. The slash and burn agriculture, very common in these areas, permits the accumulated nutrients in the organic matter to be used but also causes significant losses in nitrogen and sulphur. The chemical stability of these soils, i.e. nutrient buffering and subsequent delivery capacity is poor. Removed nutrients cannot normally be compensated from geogenetic sources because most of the alkali and alkali earth elements are leached out by intensive and deep weathering. Most of the inorganic components of the soils are oxides which contain few plant nutrients and release little because of high weathering stability, and two-layer clay minerals (kaolinite), which are also very resistant to weathering with a low cation exchange capacity. Anionic plant nutrients, however, such as phosphate and sulphate, are permanently fixed by these oxides. Altogether, on an estimated one third of the soils the nutrients reserves limit plant growth, on another third aluminium phytotoxicity occurs, while one fifth of the soil reveals pronounced phosphate fixation (SANCHEZ & LOGAN, 1992). Particularly in soils of the humid tropics chemical weathering has progressed to a great depth (40-60 m). That is the reason why the subsoil is very poor in nutrients and acidic (high concentrations of aluminium), so that even plants (trees) with deep roots do not have access to a higher nutrient concentration. This reduces the anticipated effects of agroforestry ("nutrient pump").

Thanks to their medium organic matter content and mostly high clay and oxide content, the topsoils are well to very well structured and highly permeable. Nevertheless, their organic matter is depleted very fast through agricultural use after fallowing, reducing yields greatly and increasing their susceptibility to erosion.

Properties of soils in the sub-humid and semi-arid tropics

In sub-humid to semi-arid regions soil formation has also taken place under tropical-humid paleoclimatic conditions, so highly weathered soils are also widespread in these regions. The often high iron oxide contents of these soils can result in phosphate fixation and root penetration is often impeded by concretion layers and crusts. However, weathering is usually not as advanced as in humid tropical soils.

In the semi-arid tropics, it tends to be more the physical soil properties such as structural stability and water balance that act as constraints on sustainable soil use. A common feature of soils in the semi-arid tropics is their low level of organic matter and – compared with soils in the humid tropics – a more sandy particle-size distribution.

Hence, in the dry tropics the physical stability of the soils is often particularly poor, while nutrient reserves can be quite high. The main reason for this low organic matter content is the low subsequent biomass delivery of the sparse vegetative cover, which is limited to once a year because of the seasonal climate. Due to the negative water balance in the arid tropics, salt frequently accumulates in the soils, reducing soil fertility and impairing soil structure (dispersion capacity). Because of the fast development of surface crusts, up to 70% of any single rainfall incident is lost as run-off (NILL 1993; ROOSE & PIOT 1984).

Soils in tropical uplands

In the tropical uplands, soils can be very rich in organic matter, depending on initial substratum, temperature and rainfall; these soils have a high capacity for nutrient accumulation and release and a stable structure. Peaty humus frequently accumulates in these areas. Special techniques, such as carbonization are needed to cultivate these soils. The subsoils are often acidic with high, in part phytotoxic, concentrations of aluminium (Al ions).

Valley soils

The quality of alluvial soils of inland valleys, which are in intensive use in many places, varies greatly due to the diversity of the initial substratum and the conditions of sedimentation, but they are generally superior to weathered soils. Alluvial soils also include the clay-rich vertisols of the largely semi-arid areas. Agricultural problems are caused by pronounced swelling and shrinking which make for highly variable infiltration capacity. Vertisols are difficult to cultivate, but they have a high nutrient status in spite of their low organic matter content. Loamy alluvial soils on flood plains, in contrast, have problems due to salinity, alkalinity, and very low pH values in the sulphate-rich clays of the more humid regions (e.g. mangrove swamps).

Because of azonal soil formation and microspatial climatic variation, there are substantial local deviations from these general tendencies in the distribution of soil fertility determinants in all tropical areas. Of special interest for example are the high-nutrient cenotypal soils that are intensively used because of their high fertility. However, they tend to fix phosphate and are highly prone to erosion.

2.7 Ecological problem zones

Erosion is a particular problem in areas of accentuated relief, high annual rainfall and/or heavy single rains, sparse vegetation cover and physically unstable soils – in particular all tropical mountainous regions and arid zones. Tropical highlands are particularly densely populated because of the favourable production conditions and the healthy climate, which is frequently the reason for the overexploitation of the soils and the higher risk of erosion.

The rainforests of the humid tropics, whose dense vegetation cover makes them highly resistant to erosion in their natural state, become problem areas when put to agricultural use because of the rapid decline of organic matter in the topsoil after forest clearance. The soil loses its physical stability and is exposed to rainfall. The erosion then spreads rapidly into the unstable, low-nutrient subsoil and weathering zones.

2.8 The role of land in the national economy

In economic theory, land is classed as a factor of production. As such it takes on the function of a location for agricultural and industrial production and thus furnishes the basis for supplying the population with food, fuelwood and other products. It is fixed, immovable and cannot be reproduced, but its quality and productivity is very much subject to human influence.

In a national economy land also performs additional functions:

- Site for business, industry, buildings and infrastructure
- Habitat for flora and fauna
- Major medium for sustaining ecological cycles and balance
- Living and recreation area for people
- CO_2 sink (organic matter in the soil is a major storage location of CO_2, and in unsustainable soil management much of this CO_2 is released).

The function of land has altered continuously with economic development:

- In economies where agriculture accounts for a high percentage of net value added, land performs an important function as a factor of production in agriculture.
- As industrialisation advances, this function of land plays a smaller role, while its value for business and industry increases.
- In economies with large industrial and service sectors and higher incomes, land increasingly performs a leisure and recreational function. Thus agriculture is increasingly seen as part of the cultural environment, and farmers are paid to tend the landscape.

These functions of the scarce and non-reproducible factor land partly clash and partly complement each other. Land and the different systems of land use are partly allocated by the market. Land prices are determined by supply and demand.

A particular problem is to valuate total costs of land use as a basis for a market allocation of resources. For lack of full costing, land is often overexploited. So there is a difference between the microeconomic and macroeconomic costs of land use, generally termed "external effects". Similar to other more or less free goods, such as water and air, part of the costs are passed on to the next generations.

The overexploitation of land – and hence external effects – manifests itself in different ways. Examples are leaching of nitrate into groundwater, e.g. impairing its use as drinking water, or the on-site effects of soil erosion, which limit the utility of land for the next generations, and the off-site effects which reduce the quality of the surface water and impair the operation of infrastructure.

2.9 Land as a production factor in farming enterprises

Access to land and its exploitation are a precondition of agricultural production. Together with the factor labour, largely family manpower in small-holder farming systems, land is the most important production factor in farm enterprises.

In the first place, agricultural land is used to satisfy basic needs and then to earn income. In addition to short-term subsistence (food supply), the ownership of land safeguards the long-term economic and social survival of the farming family.

In traditional societies land can have a religious significance in addition to economic and social functions. It is the link between past and present generations, who bequeath it to future generations. The current generation is the trustee for the next one, hence the religious precept to preserve the land as a basic source of livelihood for future generations. Traditional land use rights are, however, being superseded due to demographic pressure, modern land law and the decline of traditional village society. In many places today there is a complex mix of traditional, colonial and modern land use rights.

In Black Africa, for example, land is primarily communal, in other regions it is taking on a more private character. This private system means:

- Power of disposal, i.e. the right to sell, lease, bequeath, give away and pledge
- Right of use, i.e. kind, scope and intensity of exploitation

In the communal land system rights are confined to use.

To develop sustainable soil management, it is important to account for basic land law (see Chapter 4).

2.10 Raising output with sustainable methods – a challenge of our time

Throughout history there have only been three examples of sustainable agriculture. All three systems are based on restoring soil fertility after every cycle of production. These are:

- Shifting cultivation
- Mixed farming (integrated livestock farming)
- Irrigated rice growing

Each system worked as long as the demands on it were low and enough land was available. A higher population density was only possible after the discovery of inorganic fertilizers and ways of compensating nutrient loss through harvests as well as improving nutrient status.

In some regions (e.g. Southeast Asia), yield was also significantly raised by improving water retention and its controlled distribution together with the use of inorganic fertilizer. While in some countries yield continues to rise, in others (e.g. India) there are doubts about the sustainability of cropping systems e.g. rice-wheat-systems.

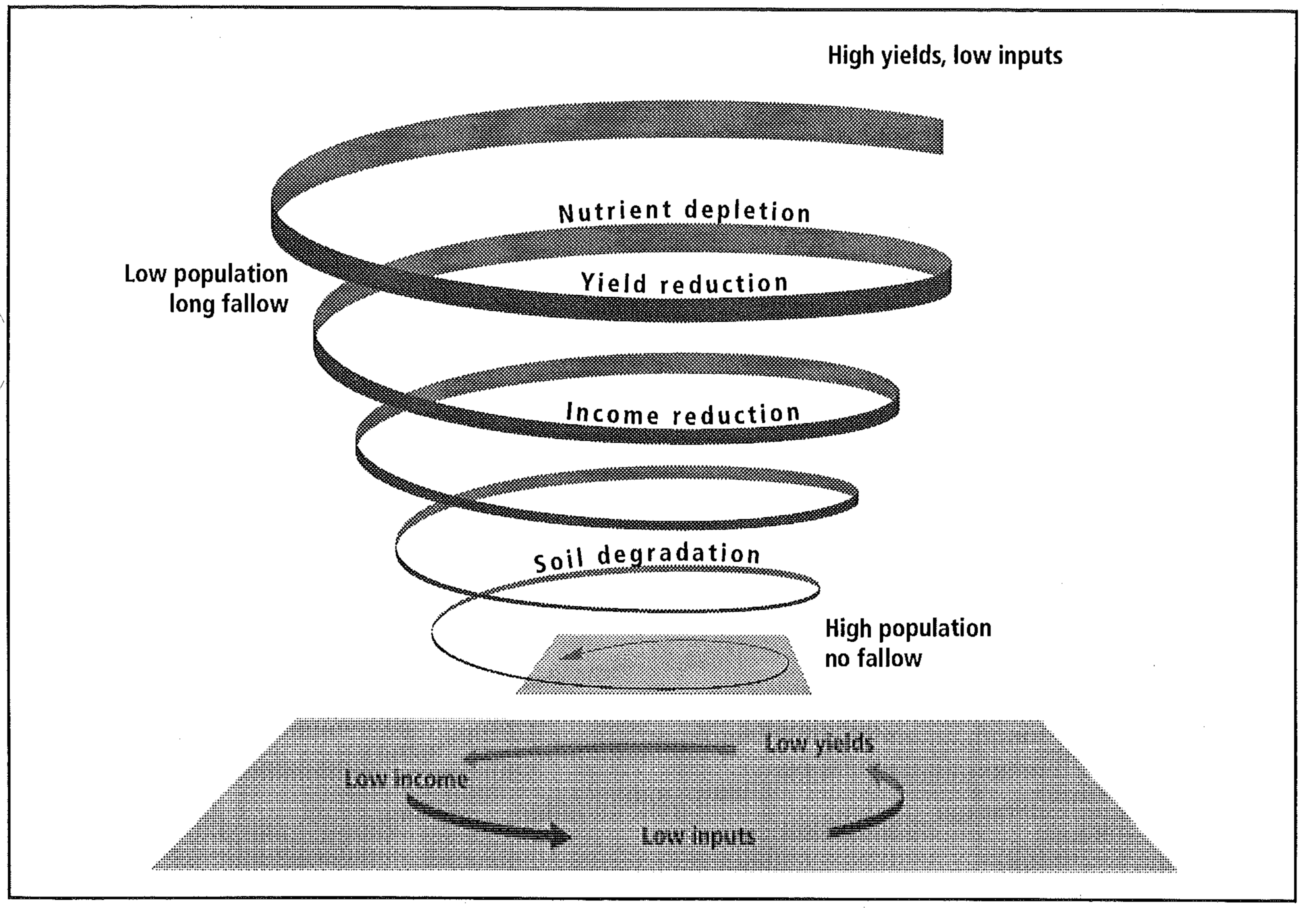
In regions with fallow farming or integrated livestock farming, in forest and savannah areas in Africa for example, growing population pressure compels farmers to replant fallowland before soil fertility has been restored or to work marginal land only suitable for pasture or forestry. (This low-fertility marginal land is particularly threatened by soil degradation.) The outcome is a downwad spiral of instability – unsustainability.

The spiral ends in a vicious circle of "low input – low yield – low income". It is impossible for smallholders to escape the "poverty trap" without outside help.

It is vital to prevent more farms or even whole regions from descending down this spiral. More than this, the decline must be reversed, i.e. output must be raised and kept at a higher level. This calls for farming systems that conserve, but also improve resources. This cannot, however, be achieved by the "low-input" system often propagated in development cooperation in the past.

So future agricultural development faces an enormous challenge to find a balance between the need to raise agricultural output and to conserve resources. This is not just a scientific-technical problem it also a socio-economic issue. Only a thorough analysis of the multiple cause-effect chains in soil degradation and an evaluation of options can help meet this challenge in a purposive way.

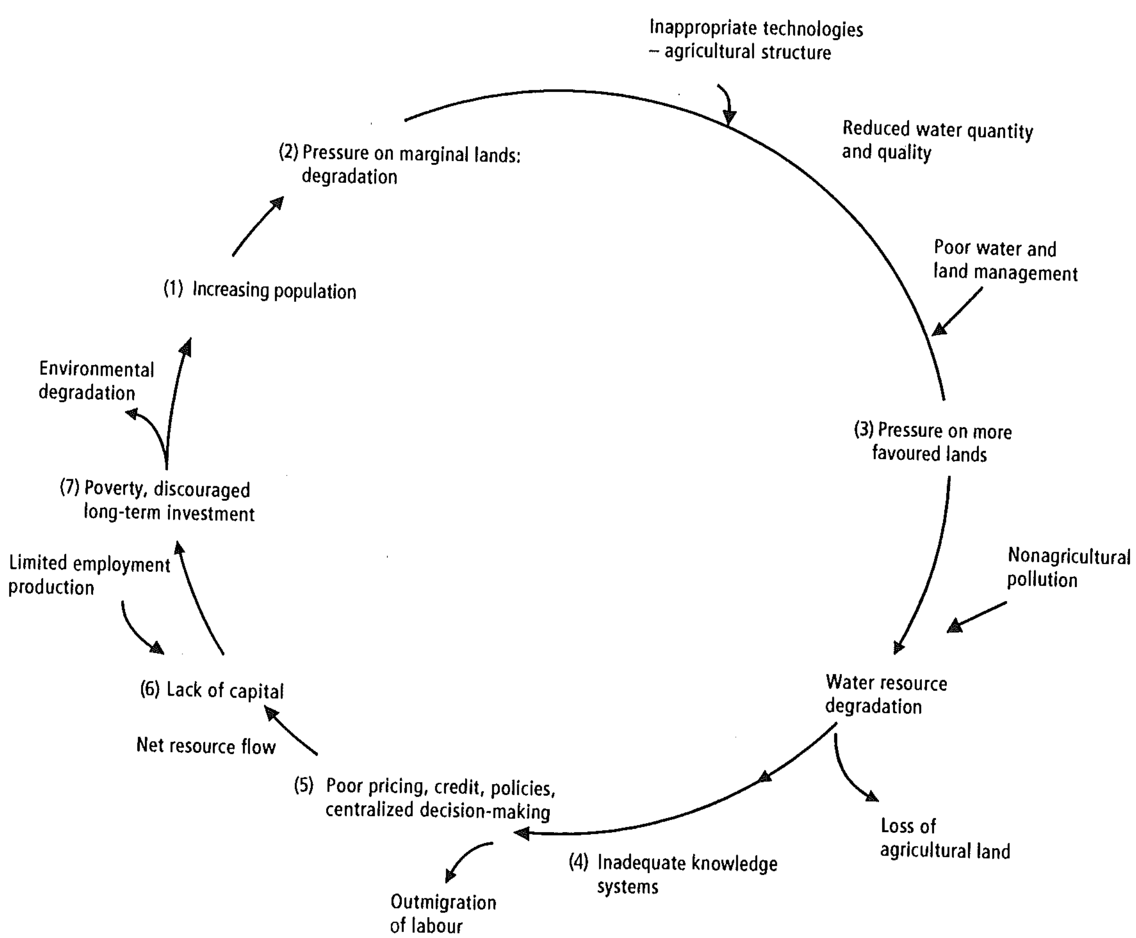
Figure 2.3
The downward spiral of the poverty trap
(McCOWN & JONES 1992)
Source: IBSRAM 1994, p.10



3. Biological, physical and socio-economic causes of soil degradation

Agricultural use degrades soil in the long term and reduces its fertility if it is not accompanied by soil conservation measures. Only suitable cropping methods and more or less labour-intensive or capital-intensive measures can sustain soil fertility. There are enough examples in different climatic zones and cultures demonstrating that fertility can be preserved or even established in spite of intensive land use. So-called anthropogenic soils have emerged over generations from sands of the northern German regions of end-moraene, or from acid, humus-rich soils in the East African highlands. Soil formation is not just a physical and biological process; it has a socio-economic aspect. As a corollary, we may infer that there are socio-economic and political reasons why land users are unwilling to do or invest enough for soil upkeep. Just as conducive economic and political parameters have induced farmers to develop and maintain soil fertility over generations, more adverse circumstances can cause a depletion of fertility or soil destruction. Frequently soil degradation is due less to a lack of production methods that conserve soil and more to general circumstances that deter farmers from applying them (an example is the failure to apply tried and tested soil management methods in the industrial countries).

Figure 3.1
Cycle of unsustainability
(RHOADES & HARWOOD 1992)
Source: IBSRAM 1994, p.12



Soil degradation is one facet of the destruction of the environment and a final stage in a large-scale process of unsustainability. Many farming systems are caught in a downward spiral impelled by interrelated socio-economic and bio-physical factors. Even though this phenomenon takes various forms depending on the situation, there is a discernible general "cycle of unsustainability" (Fig. 3.1) with different components. Both bio-physical and socio-economic problems are key factors in the process and influence each other.

The next subchapters look more closely at the major components of this cycle.

Biophysical forms and causes of soil degradation 3.1

The speed and extent of soil degradation depend on different factors, especially soil type (soil stability and subsequent nutrient delivery capacity), relief, climate and farming system (intensity of use). The UNEP (United Nations Environment Programme) Project GLASOD (Global Assessment of Soil Degradation – OLDEMAN 1990) distinguishes four human-induced processes of degradation: water and wind erosion plus chemical and physical degradation. Soil erosion caused by water and wind is the most important form of degradation:

- Soil loss due to wind erosion (28%)
- Soil loss due to water erosion (56%)
- Nutrient depletion due to inadequate fertilizer application
- Soil acidification
- Salinization due to inadequate irrigation and drainage (12%)
- Depletion of organic matter due to faster decomposition and insufficient organic fertilizer
- Compaction, aggravated by the use of heavy machinery (4%)

Soil loss due to erosion is 20-60 t/ha/year, 20 to 40 times higher than the rate of soil formation. There is no hope of restoring destroyed soils within a timespan that bears any relation to human history.

GLASOD estimates soil erosion to be the most important form of soil degradation, because water erosion affects 56% and wind erosion 28% of all land used by man (OLDEMAN 1993). The most important causes of water erosion are deforestation (43%), overgrazing (29%), agricultural mismanagement (24%) and of wind erosion, overgrazing (60%), agricultural mismanagement (16%), overexploitation of natural vegetation (16%) and deforestation (8%).

The most important forms of chemical soil degradation are loss of nutrients and organic matter (South America, Africa) and salinization (Asia) (OLDEMAN 1993). The main reasons for chemical soil degradation are agricultural mismanagement (56%), and deforestation (28%). The GLASOD maps show physical degradation particularly in the temperate zones, probably due mostly to compaction as a result of using agricultural equipment.

Table 3.1

Causes of soil degradation (in million ha of affected areas)

	deforestation	overgrazing	agricultural mismanagement	overexploitation	bio industrial activities
Africa	67	243	121	63	+
Asia	298	197	204	46	1
South America	100	68	64	12	-
North and Central America	18	38	91	11	+
Europe	84	50	64	1	21
Australasia	12	83	8	-	+
World	579	679	552	133	23

Source: OLDEMAN et al. 1990

3.1.1 Displacement of soil material – wind and water erosion

3.1.1.1 Definition of soil erosion

Soil erosion is defined as the detachment and the lateral transport of solid particles on the soil surface by water and wind. In the long term, this process leads to stable land-forms with low erosion rates. In natural eco-systems undisturbed by man, soil erosion is triggered by natural disasters or tectonic events alter the relief or destroy the vegetation cover. Determinants of erosion are rainfall (erosivity), vegetation (ground cover), topography (surface forms), soil properties (erodibility), slope inclination and exposure (sun, shadow) (DE GRAAF 1993). Soil use changes three of these factors from their natural state: vegetation, topography and soil properties. So it disturbs the balance and the process of soil erosion begins.

Particularly important is the selectivity of soil erosion: the particles removed contain higher percentages of clay minerals, organic matter and nutrients than the soil itself. Therefore even a seemingly minor loss of soil per year can reduce soil productivity significantly.

3.1.1.2 Water erosion

Worldwide 25 billion tonnes of soil are washed away every year.

Tropical rainfall is heavy, ranging between 120 and 160 mm/h (KOWAL & KASSAM 1977), sometimes attaining as much as 800 mm/h for brief periods (AL-SWAIFY & DANGLER 1982). Average drop diameter of tropical rains exceeds that in temperate zones, at least in some areas (KOWAL & KASSEM 1977). The high kinetic energy of raindrops destroys the soil aggregates resulting in crusting, which increases the soil's erodibility. In tropical uplands, however, the energy of raindrops is lower (NILL 1993; RYUMUGABE & BERDING 1992). (Crustification only increases erodibility at the beginning of the erosion process. Later, after the loose particles on the surface have been removed, less soil is lost but run-off increases.)

Erosion through water occurs as splash erosion, sheet erosion, rill and gully erosion and mass movement, which can also be seen as stages of a process.

Water erosion usually starts with splash erosion. It occurs when raindrops fall onto the bare topsoil. The energy of the raindrops breaks up the surface soil aggregates and splashes the particles. On slopes more of these will fall down the slope resulting in a downhill movement of soil. Some of the soil particles enter the soil pores reducing the amount of rainwater that can infiltrate into the soil. This results in increasing run-off.

Table 3.2

Soil erosion in selected developing countries

Country	Location and extent	Land and landuse conditions	Erosion (t/ha/a)	Year of estimate
Burkina Faso	Mossi plateau	Crops/grazing	5-35	1975
Kenya	Tugen plateau		72	1985
Lesotho	Whole country	Grazing/crops	7	-
	(scattered)	intensive cropland	> 250	1974
Nigeria	Imo state			
	(0,9 million ha)		14	1974
	(scattered)	Cassava; 15% slope	221	1984
Yemen	Serat Mountains	Abandoned terraces	150-400	1984
China	Loess plateau		11-251	1980
	(60 million ha)			
Indonesia	Upper Solo Wsd1	Crops ; <5% slope	30	1976
	Upper Solo Wsd	Crops; >50% slope	380	1976
	Konto River Wsd	Maize; bench terraces	4-52	1988
	Konto River Wsd	Onions; forw. slope terraces	> 500	1988
	Konto River Wsd	Coffee plantations & shade	1	1988
	Konto River Wsd	Built up areas	160-215	1988
India	Part of country			
	(80 million ha)	Cropland, seriously affected	75	1975
Nepal	Whole country			
	(13.7 million ha)		35-70	-
	Runoff plot studies	Dense forest	<1	1986
		Protected pasture	1-10	1986
		Various forest/grazing land	8-37	1986
		Overgrazed, gullied forest	200	1986

Country	Location and extent	Land and landuse conditions	Erosion (t/ha/a)	Year of estimate
Brazil	La Plata River Basin		19	
		Annual crops	10-21	
		Perennial crops	1	
Jamaica	Total cropland			
	(0.2 million ha)	Cropland	36	1980
	Blue Mount. Wsd	Natural woodland; >50%	37	1982
	Blue Mount. Wsd	Grassland, ruinate; 50%	120	1982
	Blue Mount. Wsd	Cultivated land (yam); 40%	800	1982
	Blue Mount. Wsd[2]	Overall, including gullies	220	1982

[1] Wsd = Watershed(s); Upper Konto River Wsd is about 24,000 ha.

[2] Among others, Yallahs, Hope River and Wagwater; total about 40,000 ha.

Source: World Resources Institute 1988; RIJSDIJK & BRUIJNZEEL 1990; Project FAO/JAM/78/006; RAMSAY 1986; GREENLAND & LAL 1977, in: DE GRAAF 1993, p. 27

The run-off gains kinetic energy, picking up some of the particles released by splash erosion and also detaching more particles from the soil surface. This may result in sheet erosion where the removal of soil particles from the whole soil surface is fairly uniform. Sheet erosion can occur on soils prone to erosion under heavy rainfall even on very slight slopes of under 5% incline.

When uneven surfaces cause run-off water to flow into small channels this causes rill erosion which can then develop into gully erosion. Rills are relatively small depressions that can be crossed easily with farm machinery. Gullies are much deeper (often several metres deep and wide) and impede farm machinery.

When soil is saturated on slopes, it can dislodge under its own weight, which causes mass movement in the form of landslides or mudflows. On steep slopes mass movement can be very rapid displacing large amounts of soil. In relatively recent and unstable geological formations, such as the Himalayas, the Andes or the Central African Rift landslides are natural events. However, their frequency and size can be increased by inappropriate land use, as in Rwanda, for example.

3.1.1.3 Wind erosion

Wind erosion entails the removal and deposition of soil particles by wind action and the abrasive effects of moving particles during displacement. It is particularly common in arid and semi-arid regions and occurs when the soil is left bare of vegetation as a result of tillage or overgrazing due to overstocking. It causes damage through topsoil loss on good cropland and through burying land, buildings, fences and machinery under unwanted earth masses.

Effects of soil erosion 3.1.1.4

On-site damage

Soil erosion causes loss of nutrients, organic matter and utility water and structural deterioration, which results in lower yield and soil fertility. How much productivity declines depends on the crop planted; high input crops such as maize or beans are more sensitive than low input crops such as cassava or cowpeas. The space for root penetration narrows, seeds and plants are washed away or covered up depending on their position. Fertilizer and ash are displaced.

Decline in productivity depends of the quality of the soil and the different properties that curtail yield. Topsoil loss has a greater effect the less conducive the subsoil is to plant growth and the more nutrients and organic matter are concentrated near the surface. This is why soils in the humid tropics (oxisols, ultisols), with their poor nutrient status and frequent high subsoil aluminium saturation suffer far greater yield loss than less intensively weathered soils (alfisols, inceptisols). Inimical subsoil properties can be caused by compact horizons limiting root penetration or water retention capacity (iron crusts, accumulation of concretions). Because of the deterioration in soil structure, water run-off increases, reducing groundwater recharge and resulting in a lower groundwater table. All this is attended by pronounced fluctuations in surface water run-off. In the long term, arable land can be devastated by the formation of rills, thus generally reducing land suitable for production.

Table 3.3
Soil erosion in different farming systems as compared with bare soil

system	relative erosion [-]
bare soil	1
bush fallow	0,004
grass fallow (poorly developed)	0,09
mulch cover 20%	0,2
40%	0,04
60%	0,008
direct sowing without plant residue	0,01 - 0,3
direct sowing with plant residue	0,0001 - 0,0003
maize	0,4 - 0,8
cassava	0,4 - 0,9
groundnut	0,3 - 0,8

Source: NILL 1993

Off-site damage

Downstream, soil particle sedimentation causes damage to developing crops, roads, residential areas, outlet ditches, irrigation and drainage systems, and water reservoirs. In addition water turbidity and nutrient and pesticide entry damage the aquatic ecosystems. This impairment of water quality is more serious in regions where surface water is used for drinking and washing. Because off-site damage often has evident and disastrous impacts, decision-makers respond more readily than to on-site damage.

Soil erosion need not, however, have adverse consequences for everyone. The annual sedimentation of nutrient-rich and clay-rich particles enhances the fertility of valley soils (e.g. Nile Valley).

3.1.1.5 Tolerance thresholds of soil erosion

The ideal tolerance threshold is where the rate of erosion does not exceed the rate of new soil formation. Setting these limits, however, raises many different problems and issues. Some are listed below:

Scientific

- How high is the soil formation rate/rock weathering rate?
- How are soil fertility criteria accounted for (topsoil, profile depth, subsoil quality?
- Can fertility loss be compensated and are appropriate inputs available (fertilizers etc.)?

Social

- For how many generations must productivity be maintained?
- Which damage is more severe – on-site or off-site?
- Who is liable for the damage (farmers/society)?
- How should programmes be implemented (educational/direct implementation)?
- Who pays for conservation measures?

Technical

- Are suitable cropping systems and techniques available?
- How can we cater for the different erosion effects of various crops?

Currently, the tolerance thresholds set are modelled on standards from temperate climates or based on the personal assessment of experts – usually without clearly defined criteria. A major factor is soil depth, e.g. the tolerance thresholds for shallow soils are lower than for deep soils. Another reason for the lack of objective tolerance thresholds is the difficulty of correlating erosion and yield development. Examples of tolerance thresholds from the available literature are summarized in Table 3.4.

Table 3.4

Tolerance thresholds of soil erosion for tropical soils (Ex. from the literature)

reference	year	tolerance threshold [$t\ ha^{-1}a^{-1}$]	applied to
HURNI	1980	2	Ethopia
LAL	1980	2,5	shallow upland soils
LAL	1983	0,2 - 2	
NYAGUMBO	1992	5	sandy soils in Zimbabwe
HUDSON	1986	9	sandy soils
		11,2	clay soils of the Central African Republic
HUDSON	1971	2 - 5	shallow, erodible soils
CHIN ET TAN	1974	15 - 25	deep loose soils
CONTILL		1 - 5	Zimbabwe

3.1.2 Chemical degradation

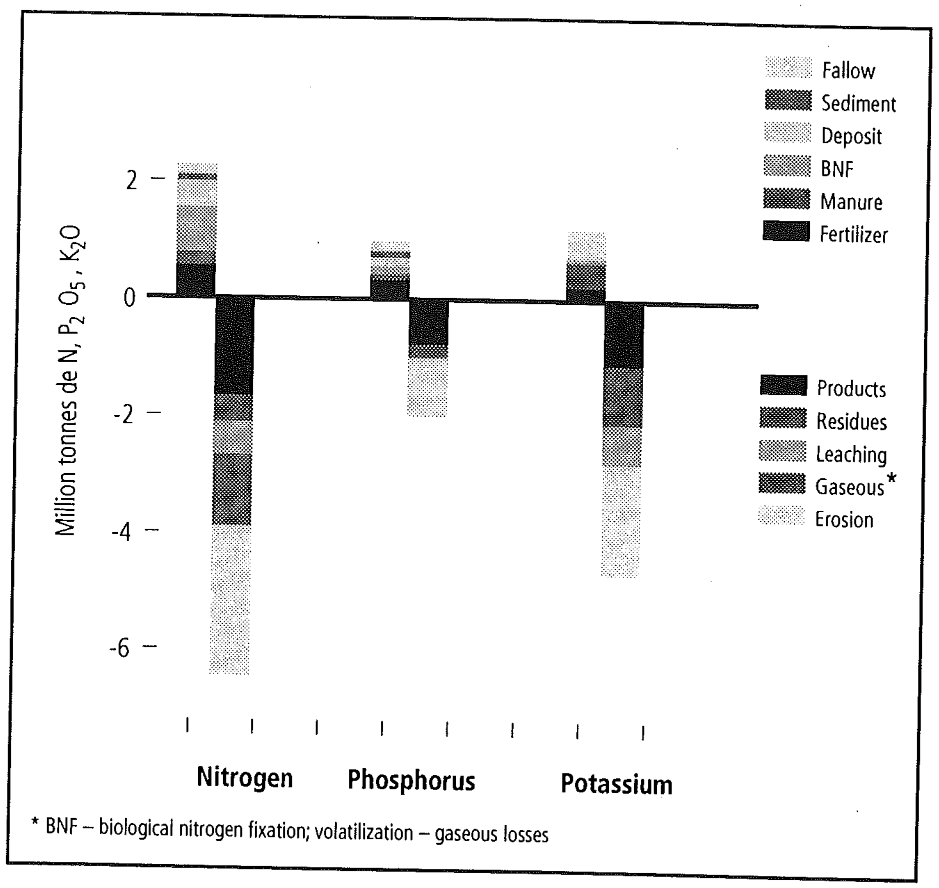
A number of chemical processes impair soil fertility. Of particular relevance to sustainable soil management is the depletion of plant nutrient reserves.

Nutrient impoverishment

About 36% (1.7 billion ha) of tropical soils are low in nutrient reserves (SANCHEZ & LOGAN 1992), i.e. contain under 10% weatherable minerals in the sand and silt fraction. These intensively weathered soils can supply only a limited amount of the nutrients phosphorus, potassium, calcium, magnesium and sulphur. They are particularly common in the humid tropics (66% of the surface) and savannas (55%).

Because of leaching, particularly in humid areas, soluble nutrients from the root zone can be transported into deeper soil layers. Acidification produces aluminium and ferrous oxides leading to phosphorus fixation (P fixation) which is no longer available for plants. A ferrous oxide/clay ratio of > 0.2 is considered to be the threshold for P fixation and affects 22% of all tropical soils (SANCHEZ & LOGAN 1992). P fixation is more frequent in the humid tropics, but it also occurs to a significant degree in savannas and steep highlands. Most sandy and loamy ultisols and loamy oxisols hardly fix any significant quantities of P (LOPEZ & COX 1979). In andisols, P fixation is a major problem because of allophane. Volcanic soils in the humid tropics and tropical highlands are particularly affected.

Figure 3.2
Soil impoverishment due to poor compensation of nutrient loss: NPK balance for Sub-Saharan Africa
Source: STANGEL et al. 1994, p. 186



Substantial quantities of nutrients are exported from agricultural soils during harvest. With the grain and straw of a maize harvest of 2 t/ha the soil loses about about 40 kg N, 30 kg P2O5 and 50 kg K2O. If the exported nutrients are not compensated by mineral fertilizers, manures, compost, biological N fixation or subsequent delivery through weathering soil minerals, the nutrient content of the soil will decline rapidly.

Soil acidification and aluminium toxicity

Soil acidification occurs during the agricultural use of land. The direct causes are leaching and nutrient export, decomposition of organic matter or root exudation. The use of acid reacting mineral fertilizers such as urea or ammonium sulfate can speed up the process.

On about one third (1.5 billion ha) of tropical land problems occur with highly acidic soils, which contain phytotoxical Al in solution (SANCHEZ & LOGAN 1992). Aluminium saturation in these soils, i.e. the Al percentage of total cation exchange capacity exceeds 60% in the upper 50 cm. The aluminium ions directly damage the roots and thus reduce water and nutrient uptake. In many tropical soils (e.g. in oxisols, ultisols or inceptisols) the Al concentrations in the subsoils increase significantly (SANCHEZ & LOGAN 1992). This could be another explanation for declining soil fertility resulting from the denudation of topsoils by erosion.

A quarter of tropical soils (1.1 billion ha) are acidic soils with pH values below 5.5 in the upper horizons but with no aluminium phytotoxicity (SANCHEZ & LOGAN 1992). These soils exist in all agro-ecological zones. They require higher fertilizer rates than soils with higher pH values. In addition, manganese phytotoxicity may occur in acidic soils with a tendency to waterlogging.

Salinization

In the tropics salinization poses a problem on 66 million ha. 50 million ha of alkaline soils contain in the upper 50 cm a sodium saturation of more than 15%. These problems affect less than 1% of total land area, but they have a major local impact, because the land concerned is often high potential and capable of irrigation.

Salinization can be classed as a specific form of chemical degradation. Human-induced salinization is either the result of improper irrigation, higher evapo-transpiration or changed hydrological conditions due to human activities. Due to high osmotic potential of the saline soil solution, salinization reduces the amount of water available for plants. It also results in phytotoxicity and high soil alkalinity and under certain conditions it damages soil structure and impairs infiltration capacity.

Decomposition of organic matter

Organic matter ensures favourable physical soil conditions, including water retention capacity. It furnishes a balanced and slow-flowing source of nutrients and a basis for cation exchange. Particularly in soils with low-sorption clay minerals, organic matter plays an even greater role in cation exchange capacity (CEC).

In cropping involving tillage organic matter diminishes rapidly, often within a few cyles. JANSSEN 1983 (cited in BUDELMAN & VAN DER POL 1992) estimates that even if additional fertilizer is purchased cropping ceases to be economically viable when the potential CEC (CEC_{pot}) drops below 30-40 mmolc per kg soil. Nutrient retention declines below the necessary minimum and nutrient leaching increases by a large margin. Very low CEC_{pot} is therefore gauged to be far more detrimental than a deficiency in particular nutrients.

Many processes affect the delivery and decomposition rate of organic matter, which is why equilibrium collates with different levels of C content depending on the site. In the tropics organic matter decomposes about five times faster than in the temperate climates (SANCHEZ & LOGAN 1992).

YOUNG (1989) estimates the supply of plant biomass necessary to maintain the organic matter level as follows:

	plant biomass necessary to maintain humus level (in kg dry matter/ha/year)	
climatic zone	above ground	below ground (roots)
humid	8400	5800
sub-humid	4200	2900
semi-arid	2100	1400

In different tropical land use systems, dispensing with tillage altogether or restriction to minimum tillage have proved conducive to raising organic matter content or keeping it at a high level (DUXBURY et al. 1989). On the other hand it reduces availability of plant nutrients.

3.1.3 Physical degradation

3.1.3.1 Compaction

Soil compaction is an increase in bulk density due to external load leading to the degradation of physical soil properties such as root penetration, hydraulic conductivity and aeration. Compaction usually only occurs in mechanized farming systems where the soil has to support regular heavy loads. In the tropics damage due to compaction is thus a particular problem with forest clearance machinery and in agroindustry. Compaction can also occur through grazing even with low stock. In agricultural engineering there are many methods to reduce soil compaction. These either aim to loosen existing compactions mechanically or biologically, to reduce the load on the soil (wide tyres, combined tillage, minimum tillage) or to limit the load to small parts of the cropland by controlled traffic. Similar techniques are applied in forestry.

3.1.3.2 Hardsetting

Hardsetting affects soils with an extremely low structural stability which decompose into their primary particles when moistened and during drying harden to a compact, very hard, dense, impermeable mass without structure. Unlike soil compaction, no external load is necessary so hardsetting also occurs in traditional farming systems with predominantly manual labour (BREUER 1994). Infiltration and water retention are very limited on hardsetting soils and plants cannot germinate or are seriously hampered. Tillage by hand or animal traction is often impossible and the land degenerates to badland.

Hardsetting soils occur especially in alluvial plains of semi-arid areas with relatively high rainfall and monomodal rainfall pattern. They can probably be found on all continents, but they have only been specifically mapped in Australia, where they take up 12-13% of land area. In the provinces of northern and northernmost Cameroon 900,000 ha, about 11% of the total area, are hardsetting (BREUER 1994).

Crusting 3.1.3.3

Crusting is due to the destruction of aggregates in the topsoil by rain and it is closely linked to soil erosion. Crusting reduces infiltration and promotes water run-off. It inhibits germination and emergence. Lower infiltration rates reduce water retention capacity and aggravate drought stress. Surface crusting is exacerbated by a lack of organic fertilizer and/or insufficient recycling of harvest residues.

Increased harvest shortfalls during droughts are not necessarily the result of long-term climatic change; they can be due to the lower water retention capacity of degraded soil.

Biological degradation 3.1.4

Biological degradation is frequently equated with the depletion of vegetation cover and organic matter in the soil, but it also denotes the reduction of beneficial soil organisms, soil fauna. It is the direct consequence of inappropriate soil management. Physical and chemical soil degradation have been thoroughly studied by researchers, but relatively little is known about biological degradation. It is known that soil fauna is an important indicator of fertility. Soil organisms can influence and improve the physical structure of the soil. The best example are some species of termites, which transport large amounts of soil through the soil profile every year (LEE & WOOD 1971), mixing mineral and organic components and changing micro- and macro-pore volume. This enhances rainwater infiltration, thus curbing run-off and erosion. As well as improving soil aeration termite activity also helps raise soil fertility (SWIFT & SANCHEZ 1984). Earthworms play a key role in temperate soils and they can perform a similar function to termites in some tropical soils, but they are not comparable in terms of number and biomass (YOUNG 1976).

Soil organisms themselves, though, depend on a good soil structure. Most methods of soil tillage have a very marked impact on the quantity and composition of soil fauna. Any soil perturbance disturbs soil fauna, because many organisms prefer certain profile depths. The destruction of soil structure, e.g. by compaction, waterlogging or crusting, impedes aeration and thus the supply of oxygen to the aerobic soil organisms; conversely, this is conducive to anaerobic organisms. Another component in this interaction is organic matter, which is itself beneficial to soil structure, while at the same time furnishing the basic food source for most soil organisms.

Minimum tillage is conducive to the development of soil fauna and thus helps considerably in improving soil structure.

Human-induced degradation 3.1.5

Deforestation and unsuitable land use are according to GLASOD (Table 3.1) the major anthropogenic factors in soil degradation. In all areas of the tropics the dominant process is loss of organic matter due to burning, rapid oxidation after aeration and lack of subsequent delivery. In most farming systems the harvest residues do not remain on the land but are burned on the surface or used as forage, household fuelwood or construction material. Only a small part of the biomass produced returns to the fields as manure or compost. Most organic fertilizer is used on fields near the household or village and as a rule it is not used on fields in more remote bush farms because of transport problems. Green manure and mulching are seldom. By producing large amounts of biomass, agro-forestry systems can improve organic fertilization, but large-scale use is often hampered by management problems and unprofitability (Subchapter 3.2).

The second major degradation process is the removal of nutrients without compensation with fertilizer on low-nutrient soil, which compels land users to clear more forest after exhausting soils. Where used at all, the quantity and quality of organic fertilizer applied does not usually suffice to offset nutrient loss. Plant malnutrition, e.g. on soils with phosphate deficiency, results in persistence of nutrient deficiencies even with optimum recycling of organic matter.

Mechanisation in developing countries is only a minor reason for physical degradation. The main local causes (crusting and compaction) are continuous cultivation of seasonal crops that consume high amounts of carbon, burning or removal of harvest residues and lack of ground cover.

Cropping

Perennial cropping is becoming the dominant form in all tropical areas because there is less land for fallowing. Cropping undergoes different phases of stability, from slash and burn and shifting cultivation to perennial cropping. The most unstable stage is semi-permanent cropping with insufficient fallowing. Here soil mining predominates with a high risk of erosion. Perennial cropping is, in contrast, relatively stable, because the development is attended by intensification and farmers invest more labour in conserving the scarce land. In densely populated regions trees are again on the increase. Trees and other perennial crops, such as bananas, are planted to earn cash income or for food (fruits, fats), fuelwood and timber. Perennial crops help substantially to stabilize soils.

Instability recurs, however, when the land area shrinks too far to feed the family, when non-agricultural activities predominate, if marginal, unsuitable land is cropped and farmers are unfamiliar with local conditions after migration. With high population density and land shortage, leasehold increases. Tenant farmers are rarely interested in sustainable soil management and are not allowed to plant perennial crops (including trees) as a rule. Because of this, the number of trees may decrease again in densely populated areas.

Cropping systems are often very inefficient, especially in their use of available plant nutrients. About one third of the nutrients, available to crops during a cycle, are lost due to erosion and leaching or escape into the air as ammonium (BEETS 1990). Improving plant nutrient utilization is thus a major task of sustainable soil management.

The risk of soil erosion and nutrient leaching is highest on bare unprotected soil, as occurs after tillage at the beginning of the vegetation period which is accompanied in many tropical regions by storms and heavy rainfall. 4-6 weeks after the start of the vegetation period, when ground cover is complete and the soil has been stabilized by root systems, nutrient loss due to erosion or leaching decreases markedly even under heavy

rainfall. The aim of all efforts in sustainable soil management must therefore be to minimize soil tillage and keep soil covered all the year round. While in highly mechanized large-scale agriculture, inter-row cropping is increasing and minimum tillage or strip cropping are applied, these methods are not practised in non-mechanized smallholder farming.

Pasture farming

Pasture farming is the best way to use many areas where cropping is unsuitable because of insufficient rainfall (arid zones) or risk of erosion (slopes, heavy rainfall). Pasture farming is a productive way of using land to conserve resources.

Nevertheless, overgrazing destroys the protective ground cover and wind and water erosion endangers adjacent arable land in certain climatic zones. Pastureland is traditionally common land with clearly defined rights of use. For lack of control mechanisms, a change in property relations, assigning land to the state, for example, converts this land in practice into "open access areas". This results in uncontrolled use and overgrazing, which frequently culminates in an irreversible destruction of the land.

Another threat to traditional rangeland is its use as arable land under increasing population pressure. Even a few cycles suffice to render productive pastureland useless. Damage can also occur outside the arable land itself on lower lying land due to runoff and soil erosion. Loss of land reserves may force pasturalists to overstock the remaining pastureland and thus degrade it irreversibly (e.g. Kenya). There is a similar development when pasturalists are cut off from traditional migration routes (e.g. by national frontiers), or when access to certain waterplaces is barred and vegetation cover around the remaining ones is damaged.

Forestry

Forestry is a productive and sustainable way to use slopes seriously threatened by erosion or stony shallow soils. Permanent soil cover and the root systems of trees protect these fragile surfaces effectively against adverse climatic influences.

Forestry can only have a beneficial effect when management and species selection cater for site conditions. There are unfortunately plenty of examples, even in development projects, where eucalyptus planting has aggravated erosion or planting pines has completely degraded naturally acidic soils.

Forestry is frequently beset with conflicting goals. Society is concerned to maintain forests in the long term, but there is also an urgent need to earn (foreign exchange) income from their use. Many governments thus often allow felling for export purposes with a view to short-term profits. The usual outcome is a total destruction of the soil (e.g. Canada, Brazil, Indonesia), which is also partly due to settlers and livestock farmers following in the wake of the logging companies.

Another dilemma is to safeguard the interests of both the present and future generations. If forest administrations prohibit savanna forest grazing to protect forestland for example, this can result in repeated forest fires ("conversion" of forest into savanna) if the local population needs to use this land. The result is the opposite of that intended: degradation of extensive stretches of forest (e.g. Burkina Faso).

3.2 Socio-economic factors in sustainable soil management

3.2.1 Sustainability – investing in the future

Soil degradation is a gradual process which particularly affects subsequent generations. Because investments in soil conservation only pay in the long term, sustainable soil management means planning generations ahead. This was understood by earlier farming generations in Central Europe and was also a religious tenet in many traditional cultures.

The timespan involved in sustainability explains why soil conservation is not discussed until there is not much left to be conserved. It would however be much less costly and more rational to conserve the production base of not yet degraded soils. With young people moving to the towns and leaving agriculture to the older generation, investments in soil conservation are unlikely. The same applies to poor farmers, who cannot afford the "luxury" of long-term investments.

3.2.2 Socio-demographic factors

A well-known problem in most developing countries is high population growth, which places increasing demands on natural resources, which in turn results in increasing shortage of agricultural land. In the early 50s in the developing countries 0.45 ha arable land was available per capita; by the year 2000 this figure will have dropped to 0.2 ha per capita. (FAO 1984).

Where land can no longer be extended to raise production, food needs can only be met by raising productivity. This has, however, not been done in many parts of Sub-Saharan Africa, for example. Per capita food production has declined with impoverishment and hunger as a consequence. Land shortage and decreasing productivity are the reasons why more needy people in particular migrate to less densely populated and often marginal areas or to remote regions (e.g. virgin forest), in the hope of higher farming incomes and better living conditions.

The main effect of high population growth is the overexploitation of soil as a resource, which takes different forms. Land scarcity need not necessarily mean using land in a way that depletes resources, i.e. there is no fixed correlation between population growth and soil degradation. As explained in Subchapter 3.2.4.2 land scarcity can raise the value of land and therefore raise the propensity to invest in soil conservation. This nevertheless presupposes conducive economic parameters (Subchapters 3.2.5, 3.2.6).

3.2.3 Land law and sustainable soil management

The allocation of the production factor land is a major determinant of soil degradation. In many countries population growth exerts increasing pressure on land access. Added to this, land is increasingly concentrated in the hands of commercial farmers and capital investors (not only in Latin America, but also in Sub-Saharan Africa now that traditional land rights have been undermined). Poor farmers are obliged to sell their property after yield loss due to drought or natural disasters or loss of additional income. Where the land can no longer be farmed and farms/households have to close down, all that remains is migration to the town or to ecologically fragile regions.

A precondition for investment in soil conservation is institutional or legislative change, since long-term measures will only be viable for land users when ownership and user rights or long-term leasehold are assured. Even planting trees or other permanent crops calls for land ownership or at least long-term usage rights. In many societies women have no inheritance rights and they possess no land, so they cannot plant trees or perennial crops. This rules out the most important target group in sustainable agricultural for innovations in sustainable soil and water management.

Though assured ownership and use rights are a key factor, land reform and private property relations are no panacea, but in societies with very inequitable property distribution and a high percentage of landless, they can bring about improvements.

On the other hand, a World Bank study (FALLOUX 1987) comes to the conclusion that the benefits of land reforms do not in most countries warrant the high costs. Establishing state farms and cooperatives for example has often resulted in mismanagement leaving the soil infertile. In addition some land is quite unused, while in the surrounding villages land is scarce and overexploited (Peru, Benin). New settlers in the wake of land reform are often unfamiliar with the local conditions and ignorant about sustainable soil management. Experience in commercial farms set up by whites in Zimbabwe and other African states show that parcelling up these farms often speeds up soil degradation.

Though land reform and granting land rights is imperative, it should be remembered that in many regions of Africa traditional common land rights have long changed in practice to private land ownership in response to land shortage. So far, common land rights have also ensured poor households and immigrants access to land and limited concentration in the hands of a few landowners. Nevertheless, the World Bank is trying to do away with the traditional system of common land ownership in Africa as part of its structural adjustment programmes. PLATTEAU (1992) shows in his study that rural property relations are undergoing radical change. Allotting certain plots to individual members of the community has engendered social distinctions that have produced exactly the same problems of landless people and unequal land ownership as the reform was intended to eliminate. Issuing land titles in regions with land shortage cannot prevent that land being rented or sold as before, with all the adverse repercussions on sustainable farming.

In Africa there is often a great deal of uncertainty in law due to different overlapping and intersecting legal systems and dwindling traditional local authority to enforce rights. The government is also seldom able to exert enough control, particularly over the often extensive public-owned land (especially forest). Increasing privatisation often displaces the socially disadvantaged (pasturalists, the landless) and these overexploit the remaining land and come into conflict with the other local land users. Disputes often arise over forestland that the government has placed under its protection without catering for the needs of the local population (Subchapter 3.1.5).

3.2.4 Microeconomic factors

Microeconomic yardsticks are crucial determinants of sustainable soil management, not only for semi-commercialized family farms but also for large-scale commercial enterprises. The aim is maximum return on the production factors land, labour and capital. However, large enterprises are more prepared to take risks than smaller ones. Sustainable soil management is not a prime target for any type of farm enterprise: it is always subordinate to a common goal – maximizing profits.

3.2.4.1 Financial criteria of farming households

With increasing commercialisation, monetary income is playing a growing decision-making role in smallholder households. Income from selling agricultural produce and other sources raise living standards. It is not uncommon for non-agricultural income to predominate. Young men frequently migrate to other regions or countries, while the women and older men remain. The women live mainly from the money earned by the men working elsewhere and the farm is only a place to live and a source of basic food and fuelwood.

Alongside land, labour is the constraining factor of production in smallholder farms. Particularly densely populated areas with small farms create the impression of latent underemployment. This impression can however be misleading. Frequently there is no surplus manpower, and there is even a shortage and high wages are paid in the seasonal peak labour demand periods of planting/sowing and harvesting. Labour incurs opportunity costs resulting from the option of employment on or off the farm.

Nearly all sustainable soil management measures require additional labour input, but it takes several years before innovations raise farm income, so the income from labour diminishes at first. As a rule, the farmer is unsure whether and how much income will increase later on. Low-income farmers are seldom willing to take this risk. Lower labour income and unprofitability are the main obstacles to adopting sustainable soil management measures.

Table 3.5

Impacts of an agroforestry system (Grevillea contour lines) on land and labour productivity in Nyabisindu, Rwanda

cropping system and demand	without trees	with trees 1st year	2nd year	3rd year	7th year	10th year
Productivity in percent	100	90	90	90	113	130
labour input in percent	100	103	100	103	109	113
labour productivity in percent	100	87	90	87	102	114

Source: SPERLING & STEINER 1992

As a general rule, innovations are only adopted if they promise a significant rise in yield and income in the next cropping cycles. The smaller the farm and yield the higher the rise in yield must be to warrant changing cropping methods. A rule of thumb is 30-50% more yield. Thus, measures to conserve soil must be accompanied by measures to enable a short-term rise in income, cropping forage or fruits on protective strips, for example.

3.2.4.2 Farm enterprises and the market economy

Food security and satisfying basic needs are priority aims of rural housholds/farms. Once these have been achieved, the more consumer goods available and closer links between rural areas and urban centres encourage farmers to gear cropping more to the market and extend cropland. Land develops increasingly into a factor of production to earn maximum income as quickly as possible. Sustainability remains of minor importance as long as other land is available. The prime goal for the farmer is no longer family subsistence; he now aims at maximizing income.

When land is short the incentive to invest in soil conservation is greater provided market access is good and lucrative cash crops can be planted, which raise the value of the land. If this is the case, soil degradation need not occur in spite of demographic pressure and indeed productivity can be enhanced. An example of this is Machakos District in Kenya where soil degradation is actually less a problem now than some decades ago (TIFFEN, MORTIMORE & GICHUKI 1994). Despite land shortage in other parts of East Africa, though, insufficient investment is made in effectively preventing soil degradation for lack of markets (no purchasing power, no market access) and of lucrative crops. The soil is overexploited intentionally or inadvertently to raise farm income. The result is the depletion of the capital resource soil.

In part, lucrative markets (and tax incentives) can also induce large-scale farm enterprises to degrade the soil through unbridled overexploitation, for example soya production in Brazil.

3.2.4.3 Risk assessment and uncertain yield

A decision-making criterion for smallholders is minimizing risks. Safeguarding subsistence even in bad years takes precedence over average income. Changes in farming systems are only accepted if there is no risk of lower yield. With incomes low and yield very unpredictable, especially in the sub-humid and semi-arid areas, all planning is short term. This means that the following years and generations are ignored or subordinated in decisions, so there is a tendency to overexploit ecological resources.

Even though the point of introducing methods of sustainable soil management is long-term soil stability and higher yield, the strategy of minimizing risks makes for reluctance in adopting these innovations.

3.2.4.4 Input level of farming systems

Whereas the inherent production capacity of soil largely depends on bio-physical conditions, the actual production capacity is essentially the result of management and inputs. Despite low bio-physical production capacity, with good management and high inputs, yield can be higher than in regions with a higher production potential but with a lower rate of input. The input level (to raise yield) is therefore a crucial factor in the sustainable use of agricultural soils.

Low and medium input systems (FAO definition, 1982, 1984) are still the norm in Africa, while in the more advanced economies of Asia and Latin America a growing number of farmers operate at a medium-input and some even at a high-input level. A low-input system can, however, be quite sustainable. These systems only become less sustainable when land gets short. Shorter fallow periods can no longer compensate for losses in organic matter and nutrients (due to leaching, harvesting, burning). Soil mining occurs, and the capital resource soil, needed to earn income, is depleted. Based on nutrient loss in South Mali, for example, 40% of farmers' income is estimated to stem from soil-mining. On the other hand, only 11% of gross income is invested in agricultural production (VAN DER POL 1992). With certain provisos, these findings can be applied to many countries of West Africa. Their magnitude underlines how difficult sustainable soil management is under these conditions.

A low level of mechanisation means transport problems and less flexibility and power in tillage. Where the hoe is the only tool used, there is little chance of improving soil and water management (e.g. early ploughing, tied ridges).

High-input systems, though, are not necessarily sustainable and they can cause their own environmental problems (for example agriculture in industrial countries). Improper use of fertilizers can result in acidic soil, mechanical tillage can aggravate run-off and erosion and irrigation farming often produces saline soil. There are a host of examples of misinvestments and the irreparable destruction of soil, but there is no doubt that poverty is still the most important cause of soil degradation in the tropics.

However, mechanisation, fertilizers and herbicides enable the application of new techniques to conserve soil, such as inter-row cropping, minimum tillage, incorporating harvest residues or transporting manure and compost.

3.2.4.5 Technological progress

There are two types of technological progress:

[1] Progress in biological engineering, such as high-yield varieties, input to enhance yield (e.g. fertilizers, plant growth regulators), input and methods to secure output (e.g. pesticides, veterinary services). This kind of progress raises the productivity of all factors allocated.

[2] Progress in mechanical engineering to raise labour productivity. Certain mechanical engineering advancements in soil cultivation and irrigation also raise land productivity.

Technological progress also alters costing. While progress in bio-engineering raises variable costs, mechanical engineering innovations incur higher fixed operating costs. This furthers specialization or streamlining in farm organization and means a larger optimum scale of enterprise. Certain kinds of technological progress stabilize yield and thus mitigate the "direct" supply risk. On the other hand, dependency on prior inputs and hence the "indirect" supply risk is greater.

Due to the introduction of technological innovations – and the resulting higher output – farmers have come to disregard sustainable soil management as a priority in decision-making. Even where the soil is being deliberately overexploited, it is assumed that technological progress will make good the lower production potential for the next generation.

Government must therefore provide the parameters to achieve a balance between the economic interests of the individual farmer and the ecological interests of society as a whole. Within these parameters farmers should and must take decisions based on economic principles in order to put the natural resources entrusted to them to proper use.

3.2.5 Role of agricultural policy

In most countries, both industrial and developing, these parameters are lacking and natural resources are used to satisfy short-term economic interests. Even in the agrarian economies of developing countries, policymakers seldom promote sustainable soil management. As the environmental effects of agriculture are largely due to the economic parameters set by agricultural policy, this is one place the search for the causes of soil degradation should start.

"Sustainable soil management calls for social, economic and political parameters that accord precedence to the long-term conservation of resources for future generations over short-term material benefits to the present generation."

HURNI 1993

Major goals of agricultural policy in developing countries are:

- Securing a high degree of self-reliance in food
- Ensuring an adequate supply of agricultural raw materials to agroindustry
- Creating jobs for the growing pool of manpower
- Earning foreign exchange by planting export crops
- Raising government revenue (e.g. export duties, producer price fixing)

If resources are short, food security and earning foreign exchange through export crops in particular entail methods of land use that deplete resources and the extension of cropping to marginal, ecologically vulnerable land.

Keeping product prices low to secure supply to the urban population has fostered resource-depleting soil use due to pressure for higher yield, but it has also prevented soil reclamation. Lower producer prices for agricultural products as against industrially manufactured inputs, deteriorating international terms of trade at the expense of agrarian countries exporting agricultural raw materials, overvalued foreign currencies can be expected to have the same effects. Where general agricultural policy means lower farm incomes neither semi-commercial smallholders nor larger commercial farms are willing to adopt methods of sustainable soil management.

Because of increasing land shortage and declining income, agriculture can no longer provide enough employment for the growing rural population. Agricultural policy must therefore also aim to create additional jobs in rural areas by promoting downstream and upstream sectors. As agriculture is likely to remain the major economic sector in most developing countries, the foundation for sustainable development must be laid by the purposive promotion of soil management to conserve resources throughout.

3.2.6 Institutional setting

3.2.6.1 Organizations and institutions

The sustainable use of agricultural soils entails a multi-sectoral approach, comprising both natural science and socio-economics. This necessitates cooperation amongst different interest groups and specialisms in planning and implementing measures to conserve soil. In practice, however, such cooperation seldom occurs.

Many public agricultural services – research, extension, seed production or marketing boards – are inadequately organized and staff are often underqualified. The experience and aims of producers, the mass of smallholders in particular, are therefore not properly accounted for. The main reason is the form of organization which rarely considers institutional cooperation when planning measures. Research and extension still focus on improving varieties and using mineral fertilizers. Most agricultural scientists are plant breeders. Soil scientists and socio-economists are rare and have little say. Farming systems research has been assisted for some years by donor organisations, but has not always succeeded in firmly establishing a systemic approach in agricultural research.

In many countries the **government extension service** is modelled on the training and visit approach of the World Bank. The higher efficiency aimed for, i.e. improving extension to raise the living standards of the population, has not materialized in many cases (ALBRECHT 1992). Many extension services have a pronounced hierarchic organisational and therefore rigid structure and they allocate available resources inefficiently. The extension messages, disseminated in a top down approach using unsuitable extension methods, often fail to offer solutions that fit the highly complex local conditions for resource protection and are dismissed by the target population as irrelevant. They are frequently the outcome of national targets and of insufficiently verified research findings. The experience and knowledge of the target population is often ignored. They have no say either in defining the problem or in selecting suitable options; they are simply permitted to implement prescribed solutions. Extension staff are unmotivated because of poor training and pay and additional workloads that have nothing to do with their advisory duties.

The growing number of **non-governmental organizations** which support local development efforts in self-help, extension and marketing try to compensate for these deficits. They are more adaptable and tend to cooperate more closely with the target population, but their scope of activity is very narrow, their spread effect low and their long term finance uncertain.

Bilateral and multilateral donors have been generous in their support for developing extension services, plant-breeding stations and marketing boards, but **national agricultural research** has found few sponsors. Weighing up their interests, national governments and donors in most cases have agreed to accord agricultural research low priority.

Many national agricultural research agencies are in a desolate state: poor infrastructure, underqualified staff often with low motivation due to organizational deficits. Due to this neglect, agricultural research and hence other agricultural services are seldom innovative and little international know-how in sustainable soil management is translated into national know-how. Donors call for long-term sustainable agricultural development, but that they are unwilling to give it long-term and comprehensive support. The donor community is also inconsistent because it assists international agricultural research and national agricultural extension, but neglects national agricultural research as the essential "conveyor belt". The result is efficient international research centres and local extension services with inadequate extension messages.

Lack of participation by local population in decision-making 3.2.6.2

The active involvement of farmers is indispensable to develop systems of sustainable soil management, especially in marginal areas with changeable ecological conditions. Policymakers in a growing number of countries are increasingly coming to appreciate the need to involve the local population in decisions on development.

But even where it is recognized by development agencies, putting this precept into practice is still difficult. First, all actors need to change their attitudes. Farmers, long disparaged as stupid, ignorant, etc., must now be treated seriously as equal partners in development. This redefinition of roles is difficult both for the population and researchers and extension officers. It takes time to overcome mutual distrust and build up confidence, to reconcile disparate points of view and experience and to devise options. This calls for new approaches and methods. Above all, personnel need to acquire the requisite methodological know-how to apply them.

Conserving resources is not a priority for most target groups, because their depletion is not an urgent problem for farmers or because short-term aims (subsistence) accord precedence to other activities.

Because of the multiplicity of institutions and organizations in resource conservation (e.g. ministries of forestry, agriculture, government and non-governmental donors) and a lack of consultation and coordination, there are often a host of interventions in the same region. This confuses the target population: projects are expected to be "competitive" by providing the same inputs as neighbouring projects or it fosters resignation and they leave the implementation of the measures to others.

3.3 Causes of failed projects in sustainable soil management

Sectoral approach

Activities in resource conservation need allround approaches that cater for the family as well as the farm enterprise. Frequently, however, projects are confined to one component only and disregard other major factors of influence or pay less attention to them.

No or weak links with existing structures

Often, new projects do not fit properly or at all into existing structures, which are discarded as inefficient. Separate, efficient facilities are set up to achieve project objectives faster. The repercussions on existing facilities (services, institutions) are ignored and little thought is given to the project's future capabilities, including staff. To achieve sustainable project activities, however, planners also need to account for organisation and personnel (BAUER 1992).

Too short

Developing and introducing sustainable soil management systems require adequate project timespans. Integrating trees or improving crop rotation, particularly on poor ecological sites, take time before the soil has been stabilized and yield raised. However, farming families can only be expected to adopt new methods or change traditional techniques if they are themselves convinced that these innovations are better.

Extension messages, even in renowned projects, are based in part on findings from very short trials (2 years). Overhasty conclusions are drawn, the socio-economic conditions of farm enterprises are not taken into proper account and the resultant cropping recommendations have no chance of being accepted by a significant number of farmers.

Lack of technologies

One outcome of insufficient promotion of agricultural research is a lack of knowledge about soil processes. Satisfactory technical remedies have not yet been found for many problems. Field trials are frequently terminated before verifiable findings have been made on long-term soil fertility and yield. Donors are reluctant to make long-term commitments to research with unpredictable results, preferring to assist extension projects, even if many of these lack sound extension messages.

Extension projects are often flanked by their own research and development, but they are unable to put the experience and knowledge to proper use for lack of time. Extension recommendations are thus frequently based on wishful thinking rather than facts.

Uneconomical technologies, outlay, maintenance costs

In the search for technologically efficient options too little account is taken of the effects on yield, risk to yield and labour input for maintenance.

Ill-defined target groups

Projects often fail to address "poor" target groups in particular because these have not been defined and demarcated precisely enough in the project design. Even if this has been done, inferences are rarely drawn for extension messages.

Lack of target-group participation

Target group participation in technological development is often merely a matter of form. Farmers' experience, observations and objections count less than the "hard facts", such as yield or soil data (collected in research). Findings from questionnaires, meetings and field days are much more difficult to evaluate statistically and present convincingly than facts and figures. In addition, the farmers' statements are often not taken seriously because they are not seen as competent and equal partners. The target population is often classified as lacking in awareness or biased; extension messages are prescribed "top down" and the target group is "made" to implement them.

4. Sustainable soil management – development approaches

Experience has repeatedly shown that soil conservation is not just a scientific or technological problem; the socio-economic and socio-cultural side is equally if not more important. This implies that conditions at the outset differ throughout the world, and there are no easy answers. General conclusions drawn from experience gained in particular projects can only be transferred to other sites under specific conditions. The solutions to the problems have to be geared to local needs and developed on the basis of a detailed familiarity with local conditions.

The technology transfer approach, where research findings were applied and propagated via the extension system has proved inadequate. It became apparent that strictly divorcing research, extension and application precluded the development of localized solutions. The search for approaches has accordingly shifted a lot in recent years towards developing methods, which necessitates dovetailing research, extension and application. This intermeshing requires a change in attitudes and approach on the part of all concerned and will have some considerable repercussions on the organization of the institutions involved and their mode of operation.

The problem is compounded by the frequent need to address several levels at the same time, from the plot to the farming and household system to national agricultural policy and beyond. Rarely are projects efficient enough to initiate a change in soil use systems on their own. Rather, programmes are needed to coordinate activities at different levels. Sustainable soil, water and nutrient management calls for a departure from simply raising output toward more sustainable production, albeit at a much higher level, especially in Sub-Saharan Africa. Sustainable soil management approaches form part of the efforts to achieve sustainable agriculture (see sectoral policy paper, Sustainable Agriculture).

Depending on the problem and potential yield, combined action must be taken at different levels of intervention at the same time. These levels are:

- Plot
- Rural household/farm
  -technical solutions, economically viable
  - participatory approaches
  - accounting for target-group specifics
- Village community or watershed
  - technical solutions
  - participatory approaches
  - organizational options
- Regional level
  - organisational development (e.g. extension services)
  - land-use planning

- National level
  - national strategies for resource conservation
  - agricultural policy (including structures, input supply, marketing)
  - research, training, extension
- Supraregional level
  - collective organisations (research institutions)
  - networks
- Global level
  - donor coordination
  - trade policy (GATT)
  - international research

Creating conducive policies and structures in agriculture 4.1

The influence of agricultural policy and structures on sustainable soil management has been dealt with in Chapters 3.2.3, 3.2.5 and 3.2.6. The prime rationale for government interventions in agriculture is to counter the external effects of land use now and in the future. Today, it is evident that the parameters can only be changed in favour of sustainable soil management, if governments are more interested in assisting the rural population rather than their urban clientele.

The causal links between the global destruction of agricultural resources (soil, water, forest, pasture) and the respective national structural policies are becoming increasingly apparent. It therefore makes little sense to ascribe environmental pollution and destruction solely to agriculture in developing countries, let alone the farming methods of croppers, livestock farmers or forest users. The causes and the different kinds of resource destruction are too complex to be remedied simply by changes in pricing policy, agrotechnology and agricultural services. So cooperation with and between government organisations is crucial for the successful promotion of sustainable soil management.

However, it is also unrealistic to attempt to improve all agricultural and trade policy lines with a view to their environmental impact. This would be impossible even at a national level. It is more sensible to look at key variables that represent both the general economic and ecological parameters of concern to countries intent on stabilizing resources.

These key variables include:

- Regional ratio of arable land to population as an aggregate measure of the margin available for an ecologically feasible development of farm enterprises until the maximum carrying capacity of a farming region has been reached
- Soil fertility as a complex (and measurable) value for yield capacity, regeneration capacity, sustainable yield security and sustainable soil management
- Pricing and costing as a major economic lever for adapting farming operations, gradually changing and developing land use systems and production techniques to earn sustainable ground rent

- Research, training and extension as mechanisms to produce, develop and disseminate know-how and new technologies
- Agricultural legislation as a framework for developing the capabilities of the whole sector and enable the farm enterprises to adjust to economic and social change over generations

These key variables have always been at the centre of sectoral policy in the course of agricultural adjustment processes.

The first variable, the arable land/population ratio, is fundamental: without flanking measures to reduce demographic pressure, all efforts to stabilize agricultural resources will be extremely difficult. Recent studies show that of about 800 million poor people about 60%, i.e. 480 million, live in rural areas where ecological destruction or severe pollution threaten survival. Depending on the context, measures are needed above all here to generate income outside agriculture and redistribute land. Raising living standards could also help curb the birth rate and hence population growth.

Favourable general conditions can generally be created either via a positive policy of incentives (pricing and subsidies) or a negative policy of penalties (taxing adverse external effects such as sand sedimentation in reservoirs or degradation of slopes).

4.1.1 Decision-making criteria for agricultural policy reform

Agricultural researchers, development experts and agricultural consultants expect national governments to reform agricultural policy toward actively promoting sustainable soil management. The rationale for these demands are decreasing yields and risks to self-supply, but there are very few countries where agricultural research can offer policymakers and governments facts and figures, such as long-term records, the ratio between erosion and yield reduction and cost-benefit analyses of soil conservation measures as decision-making aids. Thus it is not surprising that national governments are reticent to promote sustainable soil management through pricing and subsidies. It is however precisely the task of agricultural researchers to use facts and arguments to convince policymakers of the need to reform agricultural policy, to include:

- Soil loss in different agro-ecological zones and farming systems
- Anticipated yield loss and the consequences for food supply if soil conservation measures are not implemented
- Economic cost of nutrient loss (due to erosion, leaching, run-off), calculated in fertilizer equivalent and foreign exchange requirements for importing the necessary amounts of fertilizer
- Regions where investments in soil conservation are most urgent or can be most efficiently made, possibly using GROHS' (1994) decision-making matrix
- Recommendations for regional methods of erosion control and sustainable soil management
- Social costs of soil degradation (e.g. rural exodus)

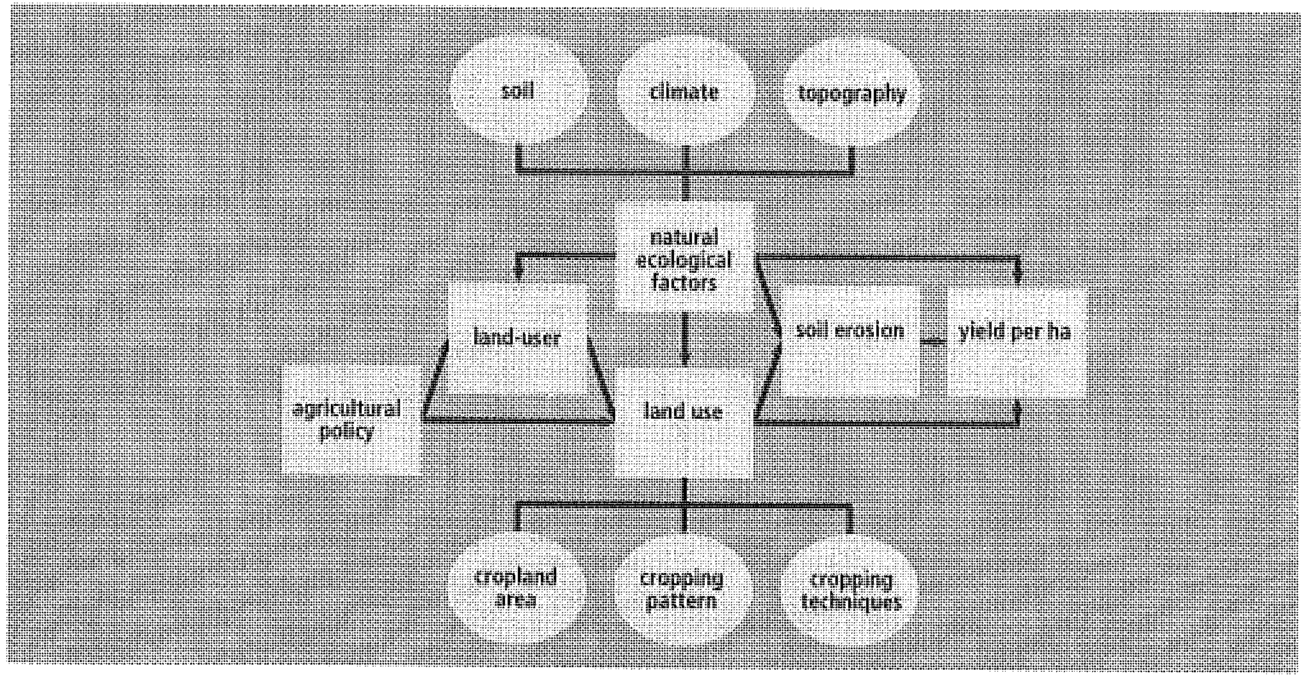
As long as political decision-makers are not (cannot be) furnished with the relevant information, there is little hope of a coherent reform of agricultural policy.

4.1.2 Approaches in agricultural policy

Agricultural policy should accord precedence to promoting land use methods that conserve soil over assisting and subsidizing conservation measures themselves (preventive instead of curative approach). Through prohibitions and directives agricultural policy in developing countries has focussed in the past (especially in the colonial era) on erosion control measures, instead of production systems that conserve or improve soil. However, there was a policy shift a few years ago that deserves donor support. Like all resource conservation measures, soil conservation incurs costs, so it is the job of agricultural policy to improve the trade-off between conserving resources and raising income.

The search for agricultural policy lines to promote sustainable soil management must begin by identifying which aspects should be assisted or can be influenced. The chart below (Figure 4.1) depicts the relationships between soil degradation, land use and agricultural policy. The major factors are without doubt cropland area, cropping pattern and cropping and production techniques (MAYDELL 1994).

Figure 4.1
Relationship between soil erosion, land use and agricultural policy
Source: MAYDELL 1994, p. 56



Land use systems

- **Cropland area:** Low productivity per ha in most developing countries is the main reason why arable land as a whole has been extended so much in the past and is still being extended today. Virtually the only land now left for extension is marginal with low natural soil productivity, unstable soils and high erosion risk. In the past, prices for certain products and subsidies have encouraged more land use. In the Amazons, for example, subsidies for beef production have induced a disastrous increase in land use.

Ways of countering this would be to demarcate and supervise protected areas, cut subsidies and influence prices. In the long term, the most effective way is to raise land productivity by assisting agricultural research, improving agricultural services (including marketing), promoting special crops (fruit, vegetables, ornamental plants) for smallholders and subsidizing inputs to raise output (better seeds, mineral fertilizers, plant protectants, machinery and tools).

- **Cropping pattern:** Some crops and production methods endanger the soil more than others. Seasonal crops like maize, soya or cotton place a far heavier burden on the soil than perennial crops or multiseasonal forage crops. The cropping pattern is therefore important for a whole region. Pricing and the active promotion of certain crops can encourage farmers to plant crops that conserve soil (inter-row cropping and forage) (MAYDELL 1994). This could mitigate the adverse effects of expansive continued cultivation of resource depleting seasonal crops , such as soyabeans in Brazil. However, market demand (e.g. fodder for European dairy farmers, consumer preference for maize) imposes a limit on influencing cropping patterns.

- **Cropping techniques:** Production methods have a decisive influence on soil processes in the individual plot. Most methods that conserve resources (all-year-round ground cover, green manure, incorporating harvest residues) incur higher costs (labour input, opportunity costs of fallowing) or curb output in the short term (foregoing land for protection strips and shrubs, trees and underseed vying for resources). Production methods that conserve soil seldom mean cost reductions (except for minimum tillage), which would encourage their adoption.

Via input pricing and subsidies for certain cropping techniques agricultural policy can promote production methods to conserve soil.

Pricing policy

Where the social and private costs of soil degradation diverge, agricultural policy can help internalize the external effects by means of appropriate pricing policy. This is particularly the case for all consequences of soil erosion, because off-site (external) effects are more important than on-site (internal) ones.

Pricing policy is one way of promoting higher sustainable land productivity. Producer prices geared to production costs act as an incentive for investments in sustainable soil management as well. Reforming the price system may aim at raising or stabilizing producer prices, but deregulating the agricultural market will usually have the same effect.

Because pricing policy can have very different effects on land-user decision-making in different countries, depending on production targets and market organization, it is a controversial issue. Low production prices can make sustainable soil management less attractive. High ones can prompt farmers to extend arable land and encourage monocultures (aggravating soil erosion), but they can also enhance the profitability of soil

conservation measures, enable the use of higher-yield inputs and hence ease pressure to extend arable land.

No general predictions can be made on the consequences of price changes or therefore of liberalizing the agricultural market. Forecasting the effects requires a precise knowledge of the context. Nevertheless, pricing policy and subsidies are not just an instrument of agricultural policy in developing countries; they are also used in the EU.

Price incentives to conserve resources inevitably entail higher consumer prices but as most consumers are town-dwellers, they object to higher prices when these are not offset by higher income, so price increases are difficult to implement. Governments themselves lack the means to offset higher prices through subsidies. This is an area where international donors could provide assistance.

Markets must exist or be created for the products of the soil management systems promoted and/or the by-products such as fodder or wood must be put to economically and ecologically viable use either on-site or off-site. If the production concerned is largely farm-based, the local markets must be protected enough against cheap imports to enable a form of local production that conserves resources.

If the cost advantage of imports is based on subsidies (for production or export), protecting national production against such cheap imports (import restrictions, duties) is warranted. Where the imports have a genuine comparative cost advantage, protective measures are economically justified in so far as the comparative cost advantages exclude environmental costs in the exporting countries. A rationale for protecting local production is that production methods that conserve resources will otherwise be ousted, incurring ecological and hence general social costs in the long term. Then, import duties or charges can be levied on competing cheap imports for ecological reasons.

A satisfactory answer to the problem of valuating environmental damage as a yardstick for protectionist measures or duties, however, has not yet been found. Other problems are how to implement such measures under GATT without risking sanctions and how to raise the necessary funding. As with raising producer prices most countries will need assistance from the industrial countries.

Subsidies

Adopting sustainable soil management systems, particularly erosion control, almost always entails higher costs except for certain high-input systems, where production costs can be curbed by economizing on ploughing and avoiding leaching. It is only logical that the additional costs must be borne by those who have a direct interest in soil conservation measures. It is not correct to presume that this is by definition the land user, as some development projects do. The magnitude of a specific soil degradation process may be assessed differently by the farm/household, society and donor countries/donor organizations/planners.

The farm enterprise is concerned about the size and frequency of the problem only where it jeopardizes its own production targets. Policymakers are concerned to safeguard the interests of society as a whole. They have to cater for the implications of the problem for a whole region and policy goals such as self-sufficiency in food and the long term interests of present and coming generations. The objective of the donor countries and planners is to safeguard the conditions for life in an entire region or a continent, Sub-Saharan Africa for example.

Where unsustainable soil use has adverse external effects on society, such as the severe off-site effects of erosion, rural exodus or a threat to food security, the government has to decide on the incentives needed to balance the interests of farming households with those of society. Applying sustainable soil management methods must be rewarded in keeping with the overall social gain. As with import duties, valuation and financing pose problems here.

If in the estimation of donor countries/organizations not enough is being done by households and governments to ensure the long-term preservation of the conditions for life in a region, they must try to bring the interests of households and governments into line with their own (SHANER et al. 1982, DOUGLAS 1994). Typical examples for interventions are resource conservation projects or more recently integrated approaches in watershed development. These interventions are, however, in danger of remaining patchwork measures, which is why some donors are beginning to assist partner countries in developing national strategies to promote sustainable soil management.

Fiscal policy

Integrated land use systems with a verifiable impact on resource conservation should be granted tax allowances. Conversely, farming systems that degrade resources should be curtailed with fiscal or regulative action, such as prohibitions, charges or compensation payments (taxation of soil erosion for example). Soil management systems that conserve resources will only develop if economic incentives, government assistance schemes and regulative measures mesh effectively. This is the job of an environment-friendly agricultural development policy.

Incentives to apply sustainable soil management methods for households/farms can be very different and depend on the type of farm and the general context. Nevertheless, they will only be effective if changes in farm organization, additional work by family members and capital investment raise output directly and hence raise family earnings. Financial incentives will be dealt with in more detail in Subchapter 4.2.2. Measures to raise awareness may assist acceptance but the motivation of households will wane rapidly if short-term income fails to improve.

4.1.3 Land law

An aim of the state must be to create a long-term economic order that enables land users, tenants and owners alike to maximize yield from resources, while safeguarding their natural regenerative capacity for following generations.

Land rights must provide enough scope to ensure that land users, owners and leaseholders can use land in an economically and ecologically viable way. If not, there is a

danger that the farming system will not allocate scarce resources properly or ignore yield capacity of the soil. The scope and design of land legislation, then, is not just a precondition for the necessary adaptability and development of land use systems as the economy progresses; it is also essential to make sure that land management is sustainable.

The value of land is an essential component of land law, because its value as a production factor generally depends on its sale or use value, which is not necessarily identical with its social value, which in turn depends on its long-term upkeep. To promote sustainable soil management, some agronomists (e.g. OTZEN 1992) advocate taking land value into account for taxation purposes. A fiscal valuation can be a suitable instrument in regions where large-scale commercial farms and estates (e.g. in parts of Brazil) are common. In small-scale farming regions, such as Sub-Saharan Africa, taxation is unfeasible.

Land rights in most countries nowadays contribute to soil degradation because of uncertainty in law, inappropriate government regulations and the dwindling authority of traditional institutions. However, because local conditions vary so much, provisions must be tailored to and made binding for these. Local approaches must be premised on prevailing law.

The aim must be to draft land legislation that is binding and acceptable for everyone and guarantees long-term land use rights. Only when these are assured can land users invest in long-term soil conservation measures. For effective legal provisions it is necessary to ensure that all parties are properly informed about their rights. Adequate information also makes for more reliable planning.

Nationwide measures and rules are rarely appropriate. Because local land rights differ greatly, especially because they are closely bound up with other rights, the legal provisions need to fit the specific conditions to best cater for the needs and knowledge of the local population. Another advantage of proceeding from traditional land rights is that they already contain many elements of sustainable soil management, but most of these are ineffectual because of altered general conditions, such as demographic pressure, economic and technological developments and social change. They need to be improved and supplemented: the ban on tree planting on leasehold or common land, also for women, needs to be revoked for example and greater account taken of land shortage.

The effectiveness of any regulation depends on an institution with the authority to enforce it and abitrate in disputes. This usually overstretches the capabilities of government. A decentralized institution confers greater responsibility on the local population which has a keener interest in its own resources. This applies especially to common property, which is better kept in the hands of a clearly defined group of land users, who exercise control themselves. State-owned land, however, is seen as an "open access area" that should be made use of as quickly as possible before others have an opportunity. Involving the local population in participatory land use planning at village level, where the supervisory authority can also be established or determined, fosters a sense of responsibility as well.

When drafting various rules and regulations different aspects need considering. With greater land shortage and the resultant growth in leasehold, the provisions applied must provide incentives for active resource conservation on leasehold land as well. This includes permitting tenant farmers to plant and use trees and to continue to use them after the term of the lease expires or entitling them to receive compensation after surrendering their right of use.

It is also important to cater for the needs of the socially underprivileged, landless and pasturalists in regional land use planning. Legal provisions that are inimical to resource conservation, such as unbridled forest clearance of land which then becomes private property, as is the case in some Latin American countries, must be abolished.

4.1.4 Institutional approaches

If ecological production methods are to result in sustainable soil management, they must be disseminated. This calls for a reform of agricultural services and projects toward greater participation, coherent functions, well-defined powers, highly motivated, enterprising personnel and a minimum of regulations and control. Reforms needed in research and extension are dealt with in detail in Subchapters 4.4 and 4.5.

Although the availability of and access to lending facilities are important for general agricultural development, loans and investment subsidies (Chapter 4.2.2) are vital for introducing economically viable soil management methods to finance high outlay or bridge the period until output has been raised. Especially for low-income households/farms and women, who have very limited access to credit, measures to promote lending facilities often help a great deal.

Sustainable land and water management measures frequently require a collective approach, particularly when they include watersheds. It helps when individual farmers join together to form farmers' associations, village commitees, user associations or cooperatives. In general, suitable groups are already available for cooperation with projects. Committees and associations also facilitate the exchange of information and experience and play a major psychological role when introducing new production methods.

4.2 Approaches at household and farm level

4.2.1 Catering for the economic interests of farm enterprises

The prime aim of a smallholder farm is to satisfy basic needs – food, shelter, clothing, education, health – and minimize risk. A major aim is also the effective employment of available manpower.

Employing manpower for soil conservation entails opportunity costs, because there is a choice between on-farm and off-farm work and leisure time for social commitments. Labour will be allocated according to opportunity costs where it achieves maximum economic benefit and ensures the satisfaction of basic needs and the performance of social obligations (Chayanov, cited from BRANDT 1994).

A key factor in labour needs is their distribution over the year. Additional labour demand for sustainable soil management measures at a time of high manpower demand raises opportunity costs far more than in low workload periods. Another consideration is also the division of labour in the farm by age, gender, etc.

Ecological innovations affect the farm enterprise as a whole. If mineral fertilizer and methods with lower external input are available to conserve or improve soil fertility, these incur less expenditure but usually require more labour in animal or crop production and make heavier demands on the skill and ability of the farm manager. Sustainable innovations must be tailored to farm capacity.

Experience shows that by far the majority of methods of ecological farming adapted to local conditions have turned out to be unsustainable, particularly in microeconomic terms. Initial acceptance rates decrease rapidly with declining support from the externally funded projects. Of the comprehensive approach all that is often left are single elements, such as trees at the borders of paths and fields. It remains to be seen whether users will themselves replant after felling, but there are grounds to doubt this. In many tropical sites, especially Sub-Saharan Africa, no economically viable techniques of land management have been developed that suit local needs. Developing profitable methods is therefore paramount.

As pointed out in Subchapter 3.2.4, another problem with soil conservation measures is that the benefit only becomes apparent in the long term, while inputs and costs have to be paid for straight away. So there need to be short-term visible benefits from soil conservation measures and external assistance through subsidies and loans particularly for poor farms (see Subchapters 4.1.2 and 4.2.2).

In households where the income stems primarily from off-farm activities, it is usually the women who remain on the farm. The farm is then a source of subsistence livelihood. These households have little incentive to invest in conserving soil because the opportunity costs are too high. If these are reduced by easing the workload in other areas women can also employ their labour power in soil conservation measures.

Risk avoidance is key to smallholder operations. The stress a household places on minimizing the risk depends on different factors, but generally speaking the smallest farmers aim to avoid risks as much as possible. This is also why they are inclined to improve their farming systems step by step, instead of making radical changes. Changes must therefore be compatible with the existing farming system and the strategy of risk avoidance. Recommendations that ignore risk reduction as a prime concern have little prospect of being adopted.

On the other hand, recommendations which do not improve income but promise greater yield security and stabilize annual yield can be quite acceptable to farmers. It is crucial for smallholders to ensure a subsistence minimum even in bad years. Thus the money they are prepared to pay for securing themselves against unpredictable environmental influences is a measure of the value they place on reducing or avoiding risks.

The desire of smallholders to avoid risk can be conducive to resource conservation activities, especially in water management. This also applies to crop diversification aimed at enhancing ground cover.

Table 4.1

Costs to establish physical conservation measures[1]

Country (year)	Measure	Degree of slope	Establishment costs (US$/ha)	Labour (md)[2]	Wage (US$/md)	IRR[3] (%)
Graded bunds and ditches						
Burkina Faso (1986)	Stone bunds (10 m interval)	2%	60 - 120	80	1.00	--
Jamaica (1981)	Hillside ditch & grass barrier	10% 20%	1200 - 1600 2300 - 2900	150 250	6.00 6.00	34 16
Mali (1986)	Graded bunds Grass barriers	2% 2%	110 80	50 30	2.00 2.00	- -
Mexico (1976)	Terracing & maguey plant	7% 9%	(Aguas) 250 (Oaxaca) 240	n.a. n.a.	n.a. n.a.	11 18
Thailand (1979)	Hillside ditch	30%	125	100	1.25	-
Tunisia (1980)	"Banquette"	gentle	1000 - 2000	n.a.	n.a.	n.a.
Terrasses						
Indonesia (1976)	bench terraces & waterways	0-5% 5-30% 30-50%	250 560 1020	210 750 1,520	0.50 0.50 0.50	44 24 13
Indonesia (1989)	bench terraces & waterways	12% 21% 30% 40%	270 450 640 760	360 570 770 850	0.60 0.60 0.60 0.60	24 16 12 9
Jamaica (1970)	bench terraces & waterways	23%	1,440	500	2.00	-
Jamaica (1981)	bench terraces & waterways	20% 32%	3900 - 5200 5000 - 6900	530 670	6.00 6.00	23 14
Thailand (1979)	bench terraces excl. waterways	30%	625	500	1.25	-

[1] Exchange rate per US$: Mali FCFA 300 (1986); Jamaica J$ 0.83 (1970), J$ 1.78 in 1981; Thailand Baht 20 1979); Mexico M$ 12.5 (1976); Indonesia Rp 415 in 1976, Rp 1,800 in 1989.

[2] md : man days;

[3] IRR : Internal Rate of Return on investment

Source: GRAAF 1993

The example of erosion control (Table 4.1) shows that discount rate, planning horizon and expected yield loss if soil conservation measures are not implemented are major determinants for the acceptance of the respective technologies. Anticipated yield loss depends on present yield level. For low input – low output, absolute losses are small so the benefit of soil protection is accordingly low. At the same time raising yield to make an economic difference requires a relatively high input. Technical measures such as terracing or drainage requiring high capital, labour and technological inputs without directly influencing output often overstretch the resources of individual farm enterprises. Inter-farm cooperation or public assistance in organizing and implementing such measures can help here.

Economic incentives to adopt sustainable soil management methods 4.2.2

Microeconomic yardsticks, particularly raising output, are crucial for the adoption of new technologies to conserve soil. It is not always possible to introduce these methods by combining short-term income improvements with long-term objectives. The fewer resources available to the farm the narrower the margin for investments. As land is the most important production factor, especially in agrarian economies, and soil degradation is rapidly spreading, an unbiased decision must be made on whether a widespread and rapid adoption of long-term economically viable production methods to conserve soil is feasible and what incentives or subidies are needed. Although it must be taken into account, adverse experience should not be advanced as an argument for a blanket dismissal of any kind of intervention.

One option in many cases are direct subsidies to purchase plant material and tools. Lending facilities are another, provided the anticipated higher output gives a reasonable assurance of repayment. Other direct income-generating measures are assistance in marketing new products and setting up processing installations such as oil presses for soya beans or dryers for sweet potatoes.

To ensure sustainable innovations it is essential to keep to the following basic rules:

- The timespan for assistance must be limited; it should never be more than start-up help, such as paying investment costs and bridging the time between investment and earning increments.
- Subsidies must stand in reasonable relation to family income, i.e. they should not make up the bulk of income (maximum 30-50%).
- Farmers must be informed about the purpose of the subsidies and the time limit.
- There must be clear conditions for granting subsidies.
- Precedence should be given to material over money even though monetary assistance is cheaper and easier.
- The proper use of material and monetary assistance should be monitored.
- Credit is given preferably in kind, such as improved seed or better livestock that can be passed on to neighbours.

4.3 Research and extension

It was recognized some years ago that the job of research and development and extension is to assist target groups in solving their problems. Apart from suitable methods of participatory technology development, this also calls for an exact definition of the target group(s), the zone of intervention (recommendation domain) and precise information on the decision-making criteria of land users (farmers). The latter aspect is frequently neglected, which is one reason why adoption rates for innovations are too low in most cases despite participatory approaches.

4.3.1 Selection and decision-making criteria of farmers

Farmers do not necessarily apply the same criteria when selecting and taking decisions as scientists and agricultural extension staff. Generally, the production aim is not maximum yield, it is minimum risk.

The major decision criteria are:

- Extent of higher yield
- Quality and utility of new varieties and species
- Certainty of yield
- Labour needs and productivity
- Availability (reliability) and costs of inputs
- Market access, information and prices
- Time lag before measure takes effect

The smaller the enterprise, the poorer the market access and the more unpredictable the yield, the more farmers' criteria and calculations differ from conventional economic methods. In smallholder farms (< 1 ha) with a relatively low yield level, the anticipated higher output must amount to 30-50% before the farmer considers a different technology worthwhile. Smaller increments often go unnoticed.

New soil conservation measures nearly always require a higher manpower input. Because of the delayed increase in yield, labour productivity decreases at first. This is a major obstacle to acceptance particularly if the farmer does not know from experience when he can expect higher labour productivity. Farmers place a value on their labour even when they have no alternative employment in times when the workload is small. Opportunity costs, then, depend on the socio-cultural milieu. A farmer may place considerable worth on social intercourse or simply so-called leisure time, for example, which may well not rank much below paid work.

Another important point is personal experience. Farmers prefer to try out a new technology on a small scale by themselves before accepting it from extension workers. They often seek technologies for specific purposes.

What is needed then is a broad range of measures for different ecological and economic conditions that can be tested and selected by farming families for their particular requirements. Technology packages whose components are difficult to understand and test should be avoided. Acceptance of technology packages is enhanced by a step-by-step introduction that allows users to come to their own decisions.

Generally, farmers do not apply new technologies as recommended by the extension service. They are adapted to current inputs. In smallholder farms manpower is usually short, so farmers try to keep necessary manpower low even if this means lessening the efficiency of the technology. At the same time they want to reduce risk (investment). Soil conservation methods must be tested in advance to check how far they can be adjusted without becoming inefficient or even causing damage (SPERLING & STEINER 1992), particularly in erosion control, where the improper construction of contour dams can cause gullies to form.

This means that in participatory approaches, farmers do not necessarily choose the most efficient technologies, preferring less efficient ones that entail less labour and risk. Simple contour strips made of sticks and stones, for example, have a greater appeal than grass strips, which in turn are more popular than terraces, which take up both more labour and land area. So when farmers are short of land they may prefer these simple though less efficient technologies (see also Table 4.3).

4.3.2 Target groups and recommendation domains

The more uniform the target group, the soil and climate in a recommendation domain, the more successful the appropriate technologies developed.

To define target groups the Reconnaisance Survey developed by the CIMMYT (Centro International para el Mejoramiento de Mais y Trigo) or PRA methods (Participatory Rural Appraisal, Subchapter 4.3.3) can be used. Only after the problem analysis has been conducted jointly with those involved to determine distinctions in terms of farming equipment, gender, workload, role of different farming sectors, etc. can a decision be taken on how to proceed. When defining the target group it is also important to account for traditional structures.

To cater for climate and soil conditions in larger intervention zones, these need to be subdivided into fairly uniform regional recommendation domains. These can be geographical zones, certain soil types or topographic sites requiring specific measures for erosion protection or soil fertility conservation, including recommendations for fertilizer and selection of varieties.

Defining recommendation domains calls for an exact knowledge of soil and climatic conditions. Long-term climatic data and land-use maps furnish the basis for zonation. Not enough attention is paid to and not enough use made of local knowledge even today. Farmers are usually familiar with their soils and they use their own classifications, including criteria such as soil structure, colour, drainage, water retention capacity and suitability for certain crops. Acquaintance with these local classifications facilitates communication with farmers and local extension workers (HABARUREMA 1993).

Recommendation domains should not be confined to physical criteria and include socio-economic criteria also. It is therefore essential to cater for the disparate interests of different types of farm enterprise and target group.

With a view to sustainable soil management, the IBSRAM is currently developing the concept of "resource management domains". These are regions with comparable production capacity, comparable land use (prospects) and socio-economic conditions. The yardsticks should be applied regardless of the size of research region or intervention zone. At a higher level, these resource management domains are based on available resources and at a lower level distinctions are drawn according to socio-economic criteria.

4.3.3 Methods in research, development and extension

The precept that research, development and extension ought to be based on the needs of land users has gained broad acceptance in all countries and is being implemented more or less actively and successfully in farming systems research & extension or participatory technology development. A basic question that has to be posed in each country is who defines needs and aims in research? Should research institutions continue to do this or should it be the task of extension services or farmers' associations? Who assesses the efficiency of research institutions and what yardsticks are applied – the scientists themselves or extension services and farmers' organisations in their capacity as clients? Participatory technology development requires a reform of traditional modes of organization. Above all there is a need to institute cooperation amongst research, development and extension in the form of national committees, scientific advisory boards and networks.

The organization and staffing of agricultural services differ distinctly from one country to another, however. Well-organized agricultural services are far better at developing appropriate technologies in collaboration with the target group and conducting agricultural research than less well-organized ones. Many government agricultural services are understaffed and are thus confined to purely administrative tasks (compiling statistics, allocating inputs, supervising the implementation of goverment directives). For lack of adequate government services, development projects often set up their own facilities aimed at participatory technology development.

Participatory approaches in technology development

A number of different actors must be involved in developing soil management systems to conserve resources: public bodies from local to national level, research institutes, extension services and of course the land users themselves.

Land users do not generally make up a uniform group with the same interests: they vary for example as to ethnic origin, social class, age or gender. Technology development should only involve people who have a definite interest in new technologies and therefore intend to apply them. Development programmes intent on collaborating with the local population can include them in the various stages of technology development: problem analysis, selecting options, conducting trials, evaluating results and disseminating new technologies. Most programmes confine farmer participation to problem analysis and on-farm trials, i.e. the land users have no say in developing sustainable methods of soil management (ASHBY 1990). To develop technologies with higher acceptance rates, however, it is essential to cater for the way land users perceive the problems, make decisions and set production targets, even if these do not always tally with the perceptions of planners, consultants and scientists (WERNER 1993).

The basic principle underlying participatory approaches such as Participatory Technology Development (PTD) or Participatory Rural Appraisal (PRA) is the cooperative way of working: unlike the conventional procedure, outsiders from research and development provide support to the informal farming community. More use is made of traditional knowledge, trials are easier to conduct and the recommendations derived are more closely aligned with the needs and conditions of the target group.

The hallmarks of this cooperative approach can be summarized as follows:

- Activities proposed must address the problems and priorities of the target group.
- Farmers' knowledge must be placed on an equal footing with the theoretical and empirical expertise of scientists and extension workers.
- Dynamic approach: adjustments are made to changing situations in an ongoing exchange.
- The interests of all parties are articulated.

The key concern is always to organize the actors so as to pool as much knowledge and experience as possible for the development process. The following is a brief outline of selected approaches and methods in participatory technology development and extension.

Participatory Technology Development (PTD)

The PTD approach embraces all stages and cycles in technology development. It is based on the documentation and analysis of more than 200 field trials in developing agricultural technologies with farmers (ILEIA 1989). The experience gained can be classed into six categories of activity:

[1] Starting off: evaluate available information, build up relationship of trust with local farmer groups
[2] Participatory analysis: analyze present situation jointly and identify main problems
[3] Search for options: sound out indigenous and formal knowledge, identify farmers' decision-making criteria, select areas for further development
[4] Experimentation: plan trials with and by farmers, collect suggestions for better technologies, form trial groups, conduct trials, carry out participatory monitoring and evaluation
[5] Sharing results: pass on results for assessment, interpretation and possible revision by local and scientific networks – farmers advise farmers

[6] Sustaining and consolidating PTD: establish conducive local institutions and gain political backing, document PTD experience, strengthen ties between farmers and support agencies, scale down outside support gradually

The hallmark of PTD is its stress on the key role of farmers in the pilot phase of a measure. Unlike conventional on-farm trials, where farmers are confined to conducting a prescribed sequence of test runs, PTD supports the farmers' own attempts to try out new technologies. Together with farmers it seeks to improve trial methods to raise confidence in the validity of results. This flexible approach is particularly important in regions with very varied environmental conditions and complex farming systems, where the problems and remedies depend heavily on site specifics, but promoting farmer trials and making systematic use of the outcome will also enhance the capabilites of research and development institutions with limited personnel and transport facilities and the sustainability of their activities (ASHBY 1990, VELDHUIZEN & ZEEUW 1992).

Participatory Rural Appraisal (PRA)

PRA is a complementary approach which like PTD involves outsiders taking part in the local population's development efforts. PRA provides villagers and outsiders with methods and techniques to investigate and learn together. There are currently a number available for various problems and situations (CHAMBERS 1992).

Although PRA is and can be used in different situations and phases of technology development, its strongpoint is joint learning. It is thus particularly effective for identifying problems, understanding farmers' selection criteria, selecting innovations to be tested and for monitoring and evaluation (CHAMBERS 1992).

Animation and self-help promotion in the GRAAP approach

The very general aims of the GRAAP system (raising the population's living standards by self-help) allow of an open-ended, allround approach, as is needed for resource conservation.

Ideally, the GRAAP model functions as follows. The various groups in a village reflect on the various activities they perform to meet their needs. Together, they analyze their situation and grasp the potential and the difficulties inherent in these activities. They seek information and instruction to enable them to find out which measures can be implemented within their limited means and who can assist them. In the next step they implement the measures that they have decided on jointly, undertaking the organization and management themselves. They evaluate progress regularly. This cycle, observation-reflection-action, is repeated constantly because there are many different activities and the problems can only be solved one at a time.

Suitability of the various approaches for resource conservation

The proposed approaches and methods cannot be assigned solely to research or to extension, because each includes elements of both. As the problem complex of resource conservation is very broad and diverse and the solutions have to be more or less specific, thought must be given to which elements in the approaches outlined or others might apply and how far they should intervene in the different phases of development. In participatory approaches, however, the prospects of the population remaining interested and taking a more active role in resource conservation are better.

To effectively help develop sustainable soil management systems participatory approaches need support from local institutions, including research and development institutions.

Local institutions

Cooperation amongst land users in local interest groups or user associations at community, watershed or district level can help a great deal in the participatory development of sustainable soil management systems. Work in groups can be help:

- give greater depth to the situation analysis and problem identification by registering different views and finding common denominators
- promote farmer trials by exchanging results and replication on several farms
- coordinate further development activities to support the PTD process
- make and maintain contacts with service providers to make better use of their facilities
- influence government

However, promoting land user groups is not a precondition for participatory development approaches. Depending on the local context and aims of the programme, cooperation with farmers can take place formally or informally. Local institutions or associations already exist in most communities that can provide a starting point for participatory programmes.

Research and development institutions

A participatory approach brings about a dramatic change in the role of all parties. Researchers, extension workers, NGO staff switch from being impartors of knowledge, input suppliers and inspectors to mediators, educators and research colleagues. Ideally, field personnel assist villagers in analyzing, discussing and planning activities. As mediators, they promote exchange between farmers and villages and contacts with service providers, organizations and sources of information. As educators, they help deepen understanding and develop additional skills and as research colleagues, they contribute research suggestions for testing, supportive activities with surveys and evaluations and replicate farmers' trials under their own supervision.

Participatory technology development actually starts within the research and development organisations, not just by providing training and support to field staff to enable them to cope better with their new roles, but also by developing a number of key functions (ETC, 1992):

- Designing flexible programmes to really respond to the problems and issues of importance to farmers
- Decentralising decision-making to enable effective ongoing communication and work with farmers
- Regularly assessing the effectiveness of field strategy jointly with field staff (an internal learning method in the absence of ready-made participatory approaches)
- Adjusting the roles of field staff and office staff in charge of coordination – who also work with the field staff in a participatory way – by supporting their activities with material and information in line with needs
- Strengthening networks to identify new technologies and options for farmers to try out
- Filing and providing information

4.3.4 Organization and function of extension services

To help solve problems and develop solutions to fit the context in sustainable soil management, development agency personnel need to change the way they think.

In particular, extension officers or field staff, i.e. the people directly collaborating with farmers at the interface between the promotion and the target system, play a major role (WATERS-BAYER 1992):

When analyzing the situation, their task is to develop a more precise, more comprehensive and more discriminate awareness of the problem (WATERS-BAYER 1992, p.259) both on the part of the farmers and the development agency. They also have to find out about farming practices, record them and make them available to scientists. Through their cooperation and the respect they show for the farmers' knowledge, they raise farmer confidence in their own practices. They can encourage farmers to try out innovations from other farmers or research bodies and adjust these to their own needs and conditions. The extension workers propose suitable technical, implementation and documentation options, but the farmers select these themselves. Through the ongoing contacts and exchange of information between farmers and field staff, new ideas are disseminated faster and more effectively than via traditional extension channels. Extension workers can assist farming organisations by establishing or strengthening outside links to obtain additional information and materials where required.

Field staff can only pursue a participatory approach with the approval or at least acceptance of their superiors. A participatory approach therefore also places the following demands on executing or development agencies (VON DER LÜHE 1993a):

- Enable and promote cooperation and exchange expertise, knowledge and know-how amongst farmers, extension workers and scientists to open channels of communication
- Delegate decision-making powers to the grass roots, transforming the development agency into a service provider to assist and coordinate the process with its information and expertise on request
- Improve pay for extension workers
- Improve and extend training for scientists and extension workers to refresh and upgrade their diagnostic and methodological skills and knowledge (Training courses aimed at developing this competence are now available and being successfully conducted locally and abroad.)

An unsolved problem in reforming extension services is that although the new approaches have been tried out on a small scale they have not been implemented on a broader scale for lack of funds and an increasing number of government extension services are even being shut down due to shortage of funds.

4.3.5 Assessment of participatory approaches in SSWNM

The participatory approach is no guarantee that innovations will be adopted by farmers. Apart from the discrepancy between technical and economic efficiency, there is another major reason. Nearly all innovations developed in on-farm trials with the more or less close involvement of farmers are based on ideas introduced from outside that do not stem from the farmers themselves. Especially in sustainable soil management there is a lack of indigenous knowledge in many regions because the problems are new. Until recently, for example, little attention has been paid to soil erosion in many regions. Though developed jointly, these ideas are still not the farmers' own ideas. They remain the ideas of outsiders. As long as farmers' ideas are not consistently picked up and developed in joint on-farm trials, the dilemma of participatory research or technology development will remain unsolved. For researchers and extension workers, however, this means putting up with the second best solution.

Another constraint on participatory technology development is time. Assisting target groups in finding solutions to production problems usually requires more time than the traditional non-participatory approach of research and promotion. However, almost no donor organization is willing to accept the consequences of applying participatory approaches and adjust project schedules accordingly (see Subchapter 3.3).

4.4 Developing technologies for various ecological conditions

4.4.1 Methodological approaches

Only partial solutions have been found for the causes of soil degradation explained in Chapter 3. Technology development in the tropics is hampered by diverse geographical and seasonal environmental conditions. Technologies must also be geared to the agro-ecological and socio-economic conditions of the farm enterprises because solutions can only apply to quite specific conditions and can only be replicated to a limited extent.

This is why studies on the agro-ecological context, currently being conducted in temperate climates are acutely relevant for the tropics. The approach here is to implement large, interdisciplinary projects to gain an understanding of the interrelationships of physical, chemical and biological processes and material flows in well-defined and representative stretches of terrain. This kind of research is being increasingly taken up by the resource management programmes of international research centres. The necessary organisational foundation for a systematic agro-ecological approach must be laid by decentralizing research and setting up stations for the major agro-ecological zones. This will help gain the systemic understanding needed to develop and assess sustainable soil management systems.

There is also a discernible trend toward developing networks to collect comparative supra-regional data (TSFB: Tropical Biology and Fertility Programme; IBSRAM). These aim at standardizing the available methods, adjusting measures to regional specifics and harnessing national research capabilities.

Scientific findings are increasingly fed into models (e.g. IGIS, CENTURY, USLE, SCUAF, etc.) to enable their application to other situations and obviate costly and inefficient case-by-case research. For example, GTZ is currently preparing a handbook for erosion forecasts.

In more adaptive national agricultural research, transferring findings is difficult because the agro-ecological zones themselves only provide comparatively rough parameters. To select and develop approaches for sustainable soil management, the microspatial variables, such as climate, parent rock, topography and human influences must be taken into account. These can be considerable and are more pronounced at low-input level. Added to these are the seasonal variables, especially the volume and distribution of rainfall.

These microspatial variables require special testing and evaluation methods to extrapolate findings for other sites. Researchers are prone to lessen the diversity of trial sites by tillage and fertilizers to make statistics easier to verify, but this detracts from the practical relevance of the findings. To be of greater practical value, trial methods must cater for changing environmental conditions, by conducting multi-site trials or including the soil as an experimental variable, for example. One option is to set up trials along a defined toposequence (STEINER 1992) and evaluate the results using regression rather than variance. To ensure a purposive search for solutions, recommendation domains and types of farming systems need to be demarcated.

Utlimately, research cannot find a solution for every particular situation. More promising are the kinds of collaboration amongst research, extension and application discussed in Subchapter 4.4. Research should offer a broad range of options that can be adjusted to specifc conditions in the process of development and extension.

Approaches and technological options in sustainable soil management 4.4.2

There are a number of technological options that could be suitable as components in soil management systems for resource conservation. These include endogenous developments in response to ecological and economic conditions on different sites. Other so-called improved technologies are based on research and development by national and international institutions and NGOs. These are described in numerous publications by FAO and other organizations.

Whether endogenous or developed from research, every soil conservation technology must help achieve one of the following aims (WOOD & HUMPHREYS 1982, cited in DOUGLAS 1994):

- Minimize soil erosion (erosion control)
- Conserve, improve and, under certain conditions, restore the physical, biological and chemical properties of the soil (soil fertility and structure)
- Enable the soil to retain water (water balance) and regulate surface run-off
- Regulate soil temperature: higher in uplands, lower in lowlands (temperature control)

The technological measures should have a positive effect on the key variables in all the objectives listed above: organic matter and nutrient balance. The measures for the various target complexes can be summarized as follows:

Erosion control

Paramount here is the avoidance of run-off. This is best achieved by full vegetation cover, which controls splash and sheet erosion. So cropping measures must be consistently recommended that ensure vigorous vegetation growth and rapid ground cover (e.g. early sowing, improved varieties, higher seed density, cover-crops, mixed cropping, underseed, inter-row cropping and planted fallows, organic and inorganic fertilizer). Splash erosion in particular can be controlled by mulching or leaving harvest residues on the soil. Effective measures on slopes with a low incline are planting on banks and tied ridges.

Rill and gully erosion are usually controlled by terracing or other barriers parallel to the slope, such as earth embankments, stone lines, ditches or contour strips planted with grass or hedging.

Alternative tillage methods such as contour ploughing and minimum tillage are effective against different forms of soil erosion. Minimum tillage is one of the most efficient and cheapest erosion control measures. Due to the need for machinery and herbicides in most cases, minimum tillage is confined almost solely to larger, mechanized enterprises, but methods already exist for smallholders using manual labour or animal traction. These methods are, however, not widespread and they require further development.

Windbreak hedges, protection strips and planting plots with loose soil (sand) are standard techniques against wind erosion.

Conserving and improving soil fertility

There are a number of measures to counter soil degradation and improve the biological, chemical and physical properties of soils. Priority is given to the efficient use of the available on-farm resources, above all organic fertilizer to replaces decomposed organic matter and nutrient loss. The major forms of organic fertilizer are green manure, harvest residues, manure and compost, also litter and cuttings from trees and shrubs. In many cases it is, however, advisable to supplement farm resources with external inputs (compensating nutrient loss).

Nitrogen loss can be offset, at least partially, by using symbiotic N fixation (green manure with legumes and to a lesser extent seed legumes). However, N fixation presupposes a certain degree of soil fertility. In degraded acidic and low-phosphate soils, rhizobia are not active.

The use of harvest residues, manure and compost does not usually bring about the necessary long-term increase in output. Either the production of biomass is limited because the soil is already degraded or because of the lack of nutrients such as phosphate and potash, farm fertilizer is accordingly short of these as well.

Gathering organic substance (grass, leaves, branches) on non-agricultural fields, and their use as mulching, litter or compost will not work in the long term. In many regions such reserve land has already disappeared or is being overused, and transport facilities are also lacking. This method has been used successfully in past centuries in Germany to develop fertility in poor soils but it has impoverished forest and pasture soils and we are only just beginning to fully appreciate the consequences.

A lasting increase in biomass production for adequate recycling of organic matter to improve soil structure, infiltration, water retention and ground cover to protect against erosion is only feasible with external fertilizers. Mineral fertilizers are therefore not incompatible with sustainable soil management. On the contrary, mineral fertilizers can figure as a major component in ecologically and economically sustainable agriculture. Lime for example is indispensable when using acidic soils and rock meal is important for the gradual subsequent delivery of nutrients. Nevertheless, fertilizer use is more likely to be efficient and profitable on high than on low potential lands.

Soil water balance

On semi-arid and sub-humid sites, water is only available in limited quantities in the form of rain and irrigation water, at least at intervals, and must therefore be used as efficiently as plant nutrients. This calls for less run-off and optimum infiltration and retention of rainwater in the soil. This can be achieved by appropriate soil management methods, such as:

- Improving ground cover
- Conserving organic matter
- Breaking up (ploughing) the soil
- Roughing the surface
- Building dams, furrows, contour lines
- Terracing

For reasons of manpower input, pure cropping measures always take precedence over construction measures, such as terracing and digging ditches. Water-use efficiency can also be raised by selecting suitable species and varieties.

On humid sites, techniques are needed to utilize the existing water (paddy rice), control drainage of excess rainwater (terraces and waterways) and drain soils to prevent waterlogging and landslides (outlet and drainage ditches).

Temperature control

In the lowlands of semi-arid tropics soil temperatures can rise high enough to jeopardize crop germination. Methods to control soil temperature should reduce temperature on the surface or top layer far enough to ensure that crop germination and development can proceed unhindered. Mulching with stones and plant materials insulates the soil surface and reduces evaporation at the same time. Shielding the soil from the sun with vegetative cover, secondary plants in mixed cropping or with shrubs and trees in agroforestry also help prevent the soil surface from overheating.

As agroforestry systems generally moderate temperatures they also protect crops in tropical uplands or in the subtropics against low temperatures and frost. Mulching is another way to protect against ground frost. Manure and compost can further plant growth by raising soil temperatures.

Description of measures

Sustainable soil management cannot be achieved with isolated single measures – a number of measures need bundling and coordinating. The initial concern is to eliminate stress factors and factors that inhibit growth. Suitable measures are listed in Table 4.2:

Table 4.2

Measures against various soil factors that inhibit plant growth (problem factors) and their effects

problem factor	measures	effects
high intensity rains	integration of trees, green manure, mulching, compost, manure, early sowing	longer and more ground cover, higher infiltration thanks to improved structure and less surface sealing

Table 4.2 (continued)
Measures against various soil factors that inhibit plant growth (problem factors) and their effects

problem factor	measures	effects
low nutrient reserves	planting legumes, organic mulching, compost, manure, natural and planted fallowing, choosing low-consumption varieties, reforestation, nutrient recycling, topsoil concentration in plant hillocks and beds, off-site organic and mineral fertilizer	enrichment of system with external nutrients or better use and enrichment of existing nutrients, minimizing losses
low nutrient storage capacity	mulching, manure, compost, green manure, intensive fallowing, reduced tilling, split-application of fertilizers	maximum conservation of organic matter in the soil through high biomass supply and less mineralisation
aluminium phytotoxicity	using resistant species and varieties, incorporating organic matter or silicate-rich material (volcanic slag, cement) adding gypsum and liming	binding of free aluminium ions by complex formation, displacement of Al from thesorption sites, Al precipitation by raising pH
phosphate fixation	adding organic matter, better P-utilization through mykorrhiza using low solubility P forms, single pant and row application, using efficient mykorrhiza strains (under trial)	occupation of fixing sorption sites, slowing down P-transformation in low solubility forms, smaller contact area fertilizer/soil,
alkalinity	mulching, drainage, selecting salt-tolerant species and varieties, planting on sides of dams, using sulphate fertilizer	improved salt leaching, reduced evapo-transpiration, less salinated microspaces
unstable structure	conserving organic matter and raising biological activity by adding organic material, reducing soil temperature through leaf cover and mulching, reducing tillage, changing ion cover of clay minerals by using fertilizer, (gypsum in irrigation water to reduce Na saturation), using organic mulching and synthetic polymers	preservation of structure forming substances, above all organic matter, mitigating aggressive forces (rainfall, temperature), less dispersion

Table 4.2 (continued)
Measures against various soil factors that inhibit plant growth (problem factors) and their effects

problem factor	measures	effects
vertisol, hydromorphic soils	measures of surface formation (bed and chamber), using soil during dry season, minimum tillage, perennial crops, planting crops less sensitive to swelling and shrinking	less waterlogging, higher resistance to shrinking/swelling
water shortage	improving structure, protecting surface (mulching, vegetative cover), applying technical bracing measures and surface forming (grass strips, stone lines/dams, dams, furrows, mini catchments, terraces	lower run-off volume and speed, better infiltration

In general, tropical soils are less susceptible to erosion than temperate ones, but this is more than offset by the aggressive climate. By selecting appropriate cropping systems soils can be protected to a large degree as described above. Ground cover is essential (Table 3.3).

If run-off and the consequent erosion cannot be reduced enough by cropping techniques, run-off speed and hence kinetic energy must be reduced by shortening the field (contour lines or buffer strips) and flattening slope inclination. Simple measures obviating movements that impair soil structure are preferable to more expensive though technically more efficient ones (DERPSCH et al. 1988). Slope incline, erodibility, profile depth are the most important parameters when choosing measures (Table 4.3).

Table 4.3

Soil conservation measures in marginal highlands

Soil depth	Slope Gentle < 12%	Moderate 12-27%	Strong 27-36%	Very strong 36-47%	Steep 47-58%	Very steep > 58%
Deep > 90 cm	C1	C2	C3	C4	FT	F
Moderatly deep 50-90 cm	C1	C2	C3	C4/P	FT/AF	F
Shallow 20-50 cm	C1	C2/P	C3/P	P	AF	F
Very shallow < 20 cm	C1/P	P	P	P	F	F

Source: GRAAF 1993

Symbols indicate most intensive use:
C1: annual cropping with few measures (vegetative);
C2: annual cropping with terracing of hillside ditches (mechanisation possible);
C3: annual cropping with terracing or hillside ditches (walking tractor only);
C4: annual cropping with terracing (manual labour);
P: pasture; if wet, zero grazing on slopes ≥45%;
FT: Fruit trees, if widely spaced, interspace to be grass covered;
AF: Agroforestry;
F: Forestry

All soil conservation measures take up land. In densely populated regions with land shortage this is an important criterion when choosing measures (Table 4.4). Here too, basic, technically less efficient measures that take up less land should be given precedence. In addition, land loss must be compensated by higher productivity. This is another reason for preferring biological measures, since these have a direct effect on soil fertility.

As already mentioned in Subchapter 4.3, the localized approach precludes general recommendations, such as alley cropping or contour bunding with vetiver grass as advocated by the World Bank. As the results from networks repeatedly indicate, there are no "standard solutions" and one measure produces better results than another in the specific context (cf. Table 4.5).

Table 4.4

Land and labour requirements of common erosion control measures in Africa

Conservation technique	Land absorbed per ha in %	Person hrs needed to construct 100 m
Bench terracing	7.5 - 52.5	808
Grass stripps	16.7	
Contour bunding	9.1	
stick and stone bunding	2.2	30 - 31
broad based banks	0	
Contour cultivation	0	19
Conservation tillage	0	
No method (i.e. stick and stone collecting only)	*	15

Source: SPERLING & STEINER 1992

Table 4.5

Yields using different technologies at different sites

Sites	Crops	Technology	Yields (in t per ha) 1989	1990	1991
Philippines (Mabini)	green maize	local technology	0,10	2,10	0,34
		alley cropping, low input	0,32	3,06	0,98
		alley cropping, high input1	1,20	5,54	1,36
		alley cropping, high input 2	1,74	4,73	1,04
Thailand (Chiang Rai)	upland rice	local technology	1,10	0,80	1,67
		alley cropping,	1,15	0,78	1,49
		Bahia grass strips	0,97	0,64	1,17
		waterways	0,83	0,85	1,18
		Agroforestry	1,13	0,88	1,90

Source: International Board for Soil Research and Management 1992, cited by Maag 1993

Crucial in developing sustainable soil management systems is that sustainability cannot be evaluated in under three years. It is essential to take this into account in all projects and programmes.

4.5 Promotion of national executing agencies

4.5.1 Selection of executing agencies

Partners in development cooperation are the so-called executing (or implementing) agencies in developing countries. The highly complex sustainable soil management measures require the collaboration of disparate organizations even beyond the agricultural sector. The main ones inlcude research institutions, extension services, local institutions (e.g user associations, production cooperatives) and networks.

Which organizations are chosen to implement projects or project components depends on the problems and their importance for and influence on the target group. Traditional government partners are frequently constrained by administrative rules and regulations, are inflexible and disinclined to innovate and they are also usually very short of funds and badly equipped. Smaller non-governmental organizations are more autonomous and adaptable, but they have a heavy regional bias. In any case, it is important that the executing agency has close contacts with the target group, the land users.

The major executing agencies and their capabilities for the participatory development and implementation of measures are described below.

National agricultural research

National agricultural research preforms a major function in resource conservation because as well as research activities it is involved in decision-making at ministerial level. Until recently research has been closely geared to crop/livestock improvement in most countries, and has therefore paid too little attention to overriding aspects such as economics, farming-system and agricultural policy. Agricultural research should link international and national structures and farmers and extension workers and thus help in particular to design and disseminate technology development approaches. In addition to technology development, its job is to document and distribute information.

Extension services

Thanks to their hierarchical and well-established structures government extension services usually have good contacts with the various ministries. A participatory approach calls for some major changes to these structures (see Subchapters 4.3.3 and 4.3.4). More competence and decision-making powers should in particular be conferred on the lowest level (field staff) and this means that extension workers must be trained differently. Extension services should not just be confined to presenting and disseminating technology packages; they should take on a coordinating, liaison and training role. Target populations often distrust public extension services because of adverse past experience and will therefore take a very reticent attitude toward new approaches.

Following disappointments with the meagre success of some cooperation projects with government agencies, collaboration is being increasingly sought with non-governmental organizations. Care must be taken here to weigh up the advantages of greater autonomy and flexibility against the disadvantages of limited influence, restricted spread effect and possible disruptions in continuity. Private organizations can, however, perform a pilot function.

Local institutions and traditional structures

As pointed out in Subchapters 4.1.4 and 4.3.3, when land users join together to form interest groups and user associations at community, watershed or district level this can greatly assist the development of sustainable land management systems. In some countries, traditional structures can even provide a source of local knowledge with a multitude of mutual obligations and social control mechanisms which also need to be incorporated when developing resource conservation measures.

National and regional networks

To step up exchange amongst the various government and non-governmental organizations and expedite the dissemination of promising innovations, national and regional networks for research and development should be instituted or promoted. Such facilities, frequently supported by international research centres, have proved very useful for discussion and further training.

Promotion measures 4.5.2

The staffing, equipment and the internal organization of partners often fall short of the requirements posed by the jointly planned project objectives. Before implementation measures, there is therefore often a need to strengthen all the partners involved. Key areas here are organizational development, counterpart training and upgrading, adequate provision of resources and allocation of competence.

Organizational development

This comprises:

- Introducing participatory planning and monitoring methods
- Adaptable programme design to really respond to the problems and issues that are important to farmers
- Delegating responsibility
- Decentralizing duties and decision-making for effective and ongoing communication and work with farmers
- Informing all parties about decisions
- Regularly monitoring efficiency of the strategies developed together with field staff
- Strengthening networks to identify new technologies and test options for farmers
- File and distribute information

Training and upgrading

Today's target group participation requires well-trained and highly motivated staff in the partner organizations with the necessary self-confidence to treat farmers as partners.

Counterpart training and upgrading should account for the different hierarchy levels. Training is subdivided into a technical section and a section to impart methodological, didactic and diagnostic skills. This latter section includes:

- Participatory techniques of situation analysis, e.g. PRA methods
- Advising groups, chairing group meetings
- Techniques for steering discussions
- Production and use of aids

Initial training should be followed by regular further training in all fields, which should allow broad scope for exchanging experience.

4.6 Evaluation of available technologies and potential development approaches

4.6.1 Evaluation criteria for sustainable technologies and development approaches

Many technologies and methodologies only succeed within a matrix of interventions at different levels. This requires a coordination of the different actors at the various levels which is usually lacking. Therefore preconditions, essential for the application of certain technologies are frequently missing.

Another complication in evaluation are the many different factors of influence which make it difficult to transfer findings to other sites. The same applies when trying to reproduce results.

To assess success or failure the indicators and criteria need to be defined and issues settled such as who benefits, when is the technology or development approach successful and for how long and under what conditions. The most important questions and criteria are listed in Table 4.6.

The timespan is of particular importance for sustainable soil management systems as both ecological and economic sustainability can only be determined after some years. Misjudgements often result from overhasty project evaluations under the pressure of short project duration and the final outcome is project failure.

Generally speaking sustainable soil management has been achieved for the soil resources in a given intervention zone when the six basic ecological criteria cited in Table 4.7 have been met. These criteria can be checked at all times and in all places and they can therefore also serve as indicators for evaluating sustainable soil management.

Table 4.6
Definition of successful development approaches

[a] What is the framework?

- succesful for whom? the soil, the user, the community (district, watershed), society as a whole?
- succesful today or in future?
- what are the general conditions at local, regional, national and international level, e.g.
  - does the technology/approach prevent soil erosion?
  - does the technology/approach improve soil fertility?
  - what is land law/agricultural legislation?
  - what role do institutions play?

[b] What are the conditions for a successful approach?

- acceptable for local users and the community?
- low costs?
- feasible (technically, ecologically)?
- does it cater to local needs?
- simple to install and maintain?
- does it respect/safeguard the rights of users and owners?
- does it minimize dependency on institutional assistance (minimum subsidies, self-financing)?
- does it allow of dynamic and flexible development/change?

[c] What are the criteria of success (under the above mentioned general conditions)?

effective
- reduces erosion/soil degradation to a tolerable level
- raises output/productivity and household income
- improves living standards and social welfare

reproducible/transferable
- allows widespread acceptance
- needs a minimum of external assistance
- can be maintained by the land users
- requires little input (costs, labour)

sustainable
- long-term
- without infringing on current and future land use
- for the whole watershed/intervention zone (without detriment to uphill/neighbouring users)

fits in
- in general development activities at individual, community and intervention zone level
- includes/allows the participation of land users
- does not deprive other current or future land users of land

Source: WOCAT 1993

Table 4.7

Indicators to evaluate sustainable soil management

[1] Soil mass should be conserved for the long term in small land units.
[2] Soil fertility and biology should be conserved long term and damage by toxic substances from outside minimized.
[3] Soil use should be stepped up, when marginal return has been significantly increased and when in addition to arable land enough additional land is guaranteed for biotopes with semi-natural or primal biodiversity.
[4] All forms of degradation (erosion, biological, chemical, physical degradation), should be prevented. In degraded soils soil formation should be enhanced to improve soil biology and fertility.
[5] Natural bio-diversity and the other natural resources of a region should be conserved or restored by appropriate land-use models to ensure that the biological community is not endangered by the degeneration or extinction of individual species.
[6] Local land use should not hamper the sustainable development of a zone at all or as little as possible, especially in social, institutional and economic respects.

Source: HURNI 1993

In a world of continuous socio-economic change, no system of sustainable production and soil management can provide the final answer.

The basic problem of developing and implementing sustainable soil management measures, however, is that results cannot simply be transferred and reproduced because of the multiple factors of influence (This problem has already been mentioned in Subchapter 4.2). Adapting promising technologies and methods to regional and/or local conditions requires continuous research efforts. This problem is frequently overlooked by donor organizations when planning new projects. In most regions there is still not sufficient data available for an ex-ante evaluation of prospective technologies. Even well-known technologies like alley cropping or green manuring cannot be transferred without several years of adaptive research because choice of varieties, sowing time, cutting time, etc. must always be adjusted to local conditions.

Ever changing ecological and socio-economic conditions raise new problems requiring new answers. These include the use of marginal land and the regeneration of degraded soils. These areas are spreading due to progressive soil degradation. Population growth puts pressure on more farmers to use this land for cropping. To date, hardly any appropriate technologies have been developed for these zones.

Technological options versus general economic parameters 4.6.2

For all the discussion about the necessary reform of the general political and socio-economic conditions the fact remains that we have yet to find satisfactory technological solutions to many problems and ostensible solutions have proved less sustainable than originally hoped. So creating favourable basic conditions is not in itself a guarantee of sustainable soil use. Moreover, the influence donor countries can exert on the political and economic parameters in partner countries is very limited. In the final analysis, all they can do is proffer options to national governments to choose and adopt at their own discretion. Influence exerted via international organizations (e.g. World Bank) or international agreements (e.g. GATT, AGENDA 21) is also subject to narrow restrictions and is a very protracted process. To develop the sustainable use of the resources soil, water and nutrients, efforts have to address different intervention levels – international and national, at farm and at plot level. To supplement the material presented in Subchapters 4.1 to 4.5, we shall take another critical look at the technical solutions and potential development approaches and the action that needs to be taken.

Sustainable technological options in soil and water management in individual eco-regions 4.6.2.1

Humid and sub-humid tropics

No satisfactory substitute has yet been found for traditional bush-fallow or slash & burn methods in tropical rainforests. For a long time alley cropping was recommended as an alternative. This method has proved to be less sustainable than hoped and has only been adopted to a limited degree. The competition for light, water and nutrients is difficult to influence in favour of food crops. Alley cropping seems to find greater application in erosion control on hillsides and steep lands and as a source of fodder for small ruminants. The only genuine sustainable option in these agro-ecological zones is perennial cropping combined with ground cover (e.g. Pueraria).

Semi-arid tropics

Replenishing the soil with enough organic matter remains a major problem. Full use has still not been made of integrating livestock farming and manure management. Sorghum and millet produce enough harvest residues, but these are required for other purposes. Apart from this, straw can only be incorporated in the soil with machinery and additional mineral fertilizer. The acidic savanna soils of South America pose a particular problem. Ways of using this land still need to be developed.

Highlands, steep lands and hillsides

For these areas, there is still a lack of cropping techniques to conserve soil such as all-year-round ground cover, minimum tillage or crop rotation with optimum ground cover. In densely-populated regions there are fewer livestock and hence less manure, so methods have to be developed to replenish the soil with enough organic matter and nutrients.

Acidic soils

For acidic soils, either in highlands or in savanna regions, there are still no technlogical solutions for widespread use. Because of the large quantities required, lime and organic fertilizer can only be applied sporadically and for specific crops. In addition, the use of lime can produce aluminium-phosphate-complexes that initiate or aggravate phosphate shortage.

4.6.2.2 Limits of some recommended approaches

Agroforestry

For a long time, agroforestry was considered the answer to most problems of sustainable soil management. It has now become apparent, however, that even agroforestry has its limits. Where the subsoil lacks nutrients, as is often the case in deeply weathered tropical soils, trees cannot "pump" nutrients into the upper layers. Even under good management, trees compete for water, light and nutrients with the food crops and reduce yield, so the trees must yield a direct economic benefit in exchange: marketable fruits, fodder, or stakes for beans and yams. Despite initial successes in agroforestry, often due to direct interventions by development projects (e.g. free distribution of plants), it remains to be seen whether farmers will plant new trees to replace the ones they have felled.

Recycling organic matter

Although organic recycling is urgently needed to compensate decomposed organic matter and nutrient loss, it cannot produce new nutrients and thus raise the productivity of soils with low nutrient status. Recycling alone cannot halt the decline along the downward stability spiral to escape the poverty trap.

Erosion control measures

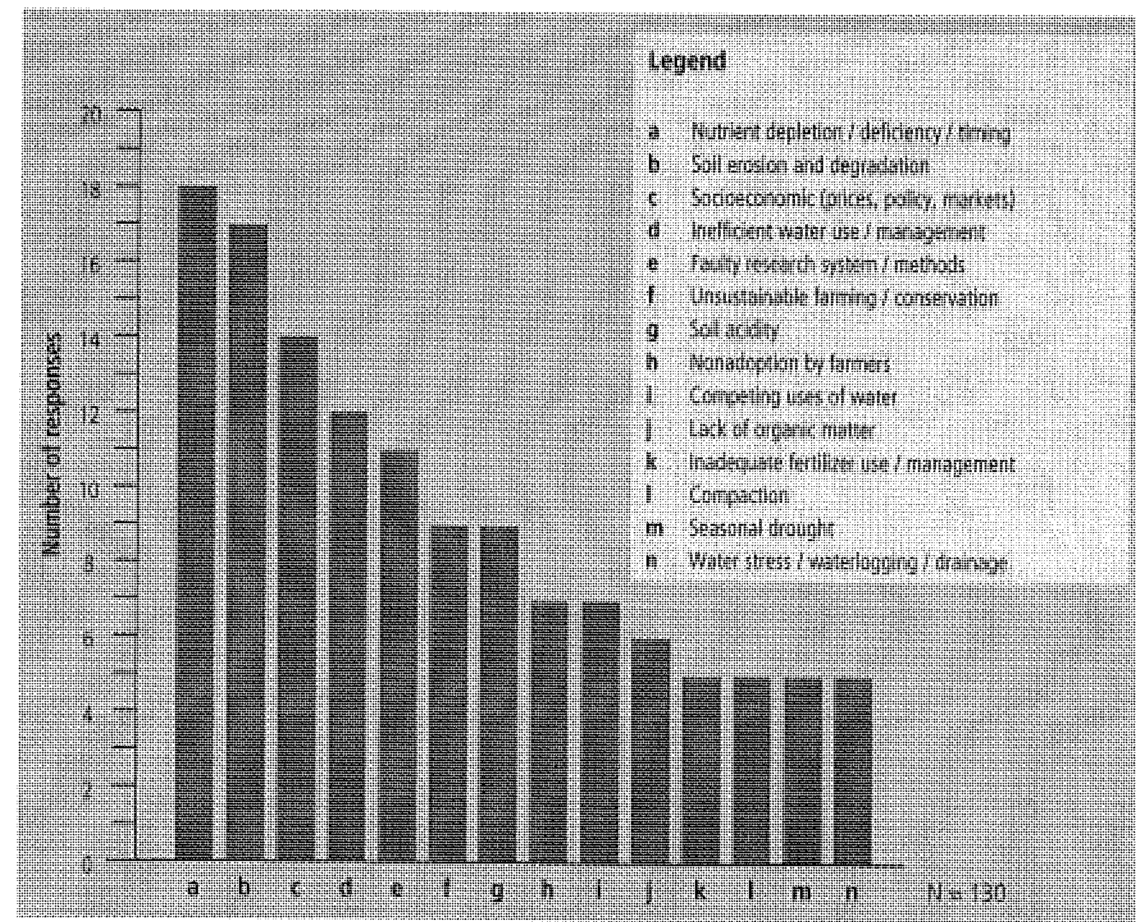
Erosion reduction, or if possible, prevention is a precondition of sustainable use, but it does not improve soil fertility status. Erosion control must therefore be accompanied by measures to improve nutrient status, especially as erosion control action is usually only taken after the soil has already been significantly degraded. Erosion control measures only raise yield directly in arid areas, where soil and water conservation have priority.

4.6.2.3 Escalating problems

Nutrient balance

Without question, the most important challenge in the coming years is nutrient depletion of soils. This assessement is underscored by the IBSRAM expert survey (IBSRAM 1994). Even where soil is not actually being "mined" the nutrient balance is seldom in equilibrium, let alone positive (Chapter 3). Only a significant increase in mineral fertilizer use can improve it. Higher prices for mineral fertilizer due to the structural adjustment programmes have, however, resulted in a marked decline in the use of mineral fertilizers in most African countries. To raise output as required, the efficiency of mineral fertilizer use must increase significantly. This is a priority task of research and development. Farmers must also be provided with more mineral fertilizer. Whether subsidies are needed or not will have to be examined on a case-by-case basis. Countries that already have a food deficit can only choose between importing food or mineral fertilizer (with subsidies) to raise their own production. Structural adjustment programmes should be less doctrinaire and cater more for real needs.

Figure 4.2
Assessment of major soil-related problems
Source: IBSRAM 1994, page 31



Sustainable soil management in non-mechanized hand-hoeing farms

Assuming farmers use available resources rationally, existing production systems cannot simply be changed by reallocating resources. All innovations aimed at conserving soil, water and nutrients require more manpower and hence often exacerbate the existing labour shortages at peak periods. They are also difficult to implement with the present equipment – alley cropping, tied ridging, organic fertilizer or incorporating harvest residues, for example. A breakthrough can generally only be achieved by improving the means of production, e.g. animal or motor traction with the appropriate tillage tools (for example West Africa, South America) and means of transport. Increased power and appropriate tools allow timely soil tillage (making use of early rains), inter-row cropping or underseed, incorporating harvest residues, minimum tillage and direct sowing.

Transport of organic fertilizer from the homestead to the fields poses a major problem, which has often been simply ignored in the past. As mechanization presupposes a certain scale of enterprise or land area, new forms of organization (amalgamating farms, private contractors or the like) are also needed.

4.6.2.4 Promising approaches

Biological nitrogen fixation

An equilibrium, of the nitrogen (N) balance at least, can be achieved by the systematic use of biological N fixation. Including N fixing legumes in rotation, inter-row cropping of legumes and green manuring can help improve the N balance. Adaptive research is necessary to maximize the efficiency of such systems and to minimize losses, especially through leaching. The efficiency of N fixation itself can probably be raised by selecting more efficient rhizobium strains, rhizobium x varieties and selective use of non-symbiotic N fixation. This calls for considerable strategic research.

Minimum tillage

Ploughing and hoeing worsen soil erosion. The best soil protection, in contrast, is good ground cover, ideally all year round together with reduced soil tillage. Perennial crops, cover crops, cropping systems (mixed cropping) that promote rapid ground cover, underseed, inter-row and direct sowing are principles or techniques that curtail erosion, promote soil biology, improve soil structure and optimize the C balance. Individual elements must be integrated into existing farming systems in line with the specific situation. Often new tools are required (e.g direct sowing) and basic changes made to production methods. The successful results, however, speak for themselves, e.g. in Paraná, Brazil.

4.6.2.5 Additional research needs

A major advantage of models to calculate and forecast nutrient movements, erosion processes or the impacts of individual measures on the whole system is that they supply information more rapidly than field trials, allow predictions of various situations and are considerably cheaper. Models are an excellent didactic aid and are well suited for explaining the implications of particular measures to political decision-makers and convincing them of the need for soil conservation measures. Models require a good database, which in many cases still needs establishing.

4.6.3 Socio-economic reforms versus technical options

The profitability of technical options for individual farm enterprises changes with the general economic conditions. Falling export prices (e.g. for coffee), subsidy cuts or cancellations (structural adjustment programmes) for inputs (mineral fertilizers) and external market influences such as food aid or imports (liberalization of trade) affect production systems directly. Generally, production systems adapt to overall conditions. How realistic is it to expect socio-economic reforms to foster sustainable soil management and who should bring about these changes? The resolutions adopted by the

UNCED Conference in Rio have not effected any positive change. Despite calls by the donor countries for sustainable development, structural adjustment programmes and GATT have had the opposite effect.

Donor countries have little chance of exerting any direct influence over policy in partner countries. This begs the question of what is easier – changing the policy framework or adapting the technical options to general conditions? This question cannot be answered here. One possibility might be for bilateral and multilateral donor organizations to help countries develop national strategies of sustainable soil management. This is no easy task, but it would ensure that technological options and economic policy are accounted for in long-term planning and land users are also included in developing such a strategy. Only if land users, primarily farmers, are convinced that investments in soil conservation are in thier own interest can they actively work towards changing their general conditions. This presupposes a change of the role of farmers:

- Farmers must become clients who articulate their needs
- Farmers must collaborate actively in research and development
- Farmers must have a greater voice by cooperating in associations

Development cooperation can support and guide this process of rethinking.

Selected Literature

AGUILERA, F. 1979: El problema de la salinidad y el sodio en el Valle del Cauca. Suelos Ecuat. 10, pp. 98-114.

ALBRECHT, H. 1992: Nachdenken über Beratung. Einsichten aus Erfahrungen mit dem «Training and Visit» Ansatz der Weltbank. In: Hoffmann, V. (éd.) 1992: Beratung als Lebenshilfe. Humane Konzepte für eine ländliche Entwicklung. Margraf, Weikersheim, pp. 129-142.

ASHBY, J.A. 1990: Evaluating technology with farmers: a handbook. IPRA Project, CIAT, Cali, Colombia.

AUGSTBURGER, F. 1991: Die Bedeutung traditioneller Stukturen in der landwirtschaftlichen Beratung. Ein Beispiel aus dem andinen Raum. Landwirtschaftliche Beratungszentrale Lindau.

BAUER, E. 1992: Schwachstellen und Lösungsansätze in Beratungsprojekten der Technischen Zusammenarbeit im ländlichen Raum. Band 1: Hauptbericht. Eigenmaßnahme der GTZ, Berlin.

BAUER, E. 1994: Grundsätze und Vorgehensweisen bei der Ableitung von Beratungsinhalten in Entwicklungsländern. Unpublished manuscript, Hohenheim.

BLAIKIE, P. et BROOKFIELD, H. 1987: Land degradation and society. Methuen London and New York.

BLASCO, M. et C. SOTO 1978: Estado actual de las investigaciones sobre micronutrientes en América Latina. Suelos Ecuat. 9, pp. 160-164.

BRANDT, H. 1994: Von Thaer bis Tschajanow. Tradition und Wandel in der Wirtschaftslehre des Landbaus. Wissenschaftsverlag Vauk. Kiel.

BREUER, J. L994: Hartsetzende Böden Nordkameruns. Thèse de 3ème cycle. Chaire de pédologie de l'Université technique de Munich.

BUDELMAN, A. et POL, F. VAN DER 1992: Farming systems research and the quest for a sustainable agriculture. Agrofor. Sys. 19, pp. 187-206.

BUOL, S.W., P.A. SANCHEZ, R.B. CATE, M.A. GRANGER 1975: Soil fertility capability classification. In: E. Bomemisza et A. Alvarado (éd.): Soil management in tropical America. North Carolina State Univ., Raleigh, pp.126-141.

BYERLEE, D. et COLLINSON, M. 1980: Planning technologies appropriate to farmers – concepts and procedures. CIMMYT, Mexico.

CHAMBERS, R. 1992: Rapid, relaxed, and participatory. IDS Discussion Paper 311, IDS, Université du Sussex, Brighton, UK.

CRUTZEN, P.J. et ANDREAE M.O. 1990: Biomass in the tropics: impact on atmospheric chemistry and geochemical cycles. Science 250, pp. 1669-1678.

DAVIS, T.J. et SCHIRMER I.A. (éd.) 1987: Sustainability Issues in Agricultural Development. Proceedings of the Seventh Agriculture Sector Symposium. World Bank, Washington.

DERPSCH, R., ROTH, C.H., SIDIRAS, N., KÖPKE, U. 1988: Erosionsbekämpfung in Paraná, Brasilien: Mulchsysteme, Direktsaat und konservierende Bodenbearbeitung. Schriftenreihe der GTZ Nr. 205. TZ-Verlagsgesellschaft Rossdorf.

DOUGLAS, M. 1994: Sustainable Use of Agicultural Soils. A review of the prerequisites for success or failure. Development and Environment Reports No. 11. Group for Development and Environment, Institute of Geography, Berne University, Switzerland.

DUXBURY J.M., M.S. SMITH, J.W. DORAN, C. JORDAN, L. SZOTT, E. VANCE 1989: Soil organic matter as a source and a sink of plant nutrients. In: Coleman D.C., Oades J.M., Uehara G.(éd.): Dynamics of soil organic matter in tropical ecosystems. NifTAL Project, Department of Agronomy and Soil Science, University of Hawaii, Honolulu, Hawaii, pp. 33-67.

EL-SWAIFY, S.A. 1991: Land-based limitations and threats to world food production. Outlook on Agriculture 20, pp. 235-242.

EL-SWAIFY, S.A. et DANGLER, E.W. 1982: Rainfall erosion in the tropics: a state of the art. In: Soil erosion and conservation in the tropics. Soil Sci. Soc. Am. Spec. Publ. 43, pp. 1-25.

ENQUETE COMMISSION "Protecting the Earth's Atmosphere" of the German Bundestag (ed.) 1992: Climate change – a threat to global development. Economica Verlag, Bonn; Verlag C.F. Müller, Karlsruhe.

FALLOUX, F. 1987: Land Management, Titling and Tenancy. In: Davis, T.J., Schirmer, I.A. (ég.) 1987: Sustainability Issues in Agricultural Development. Proceedings of the Seventh Agriculture Sector Symposium. World Bank, Washington.

FAO 1979: A provisional methodology for soil degradation assessment. FAO, Rome.

FAO 1982: Potential population supporting capacities of lands in the developing world. Technical report of project FPA/INT/513 Land Resources for Populations of the Future. FAO/FNUAP/ IIASA, Rome.

FAO 1984: Land, food and people. Economic and Social Development Series No. 30. FAO, Rome.

FAO 1986: African Agriculture: the next 25 years. Annex II, The land resource base. FAO, Rome.

FAO 1990: Sustainable development and natural resource management. FAO, Rome.

FAO 1991a: A study for the reasons for success or failure of soil conservation projects. FAO Soils Bulletin 64, FAO, Rome.

FAO 1991b: Issues and perspectives in sustainable agriculture and rural development. Main document No. 1. FAO/Netherlands Conference an Agriculture and Environment, S-Hertogenbosch, the Netherlands 15-19 April. FAO, Rome.

FAO 1993: Averting a disaster. International Agricultural Development November/ December 1993, pp. 7-10

FONES-SUNDELL, M. 1989: Perspectives of soil erosion in Africa: Whose problem? Gatekeeper Series No. SA14. IIED, London.

GLASOD 1990: Global assessment of soil degradation. World Maps (4 pages). Wageningen (Netherlands) ISRIC and PNUE.

GOEDERT, W.J. (éd.) 1985: Solos dos cerrados: Tecnologias e manejo. Nobel, São Paulo.

GRAAF, JAN DE 1993: Soil conservation and sustainable land use. An economic approach. Royal Tropical Institute (KIT), Amsterdam.

GRANDIN, B.E. 1988: Wealth ranking in small holder communities: a field manual. IT Publications, London, UK.

GREENLAND, D.J. et SZABOLCS, I. (ed.) 1994: Soil resilience and sustainable land use. Wallingford, UK.

GROHS, F. 1994: Economics of soil degradation, erosion and conservation: a case study of Zimbabwe. Wissenschaftsverlag Vauk. Kiel.

GRUPPE FÜR ENTWICKLUNG UND UMWELT 1993: Nachhaltige Bodennutzung in Entwicklungsländern. Fakten und Zusammenhänge, Lösungsansätze und Beispiele. Ergebnisse der Tagung vom 16.-17. November 1992 in Fribourg. Berichte zu Entwicklung und Umwelt Nr. 7. Bern.

HABARUREMA, E. 1993: Etude de la classification vernaculaire des sols dans trois communes de la préfecture de Butare et des possibilites de son utilisation par les services de vulgarisation agricole. Université Nationale du Rwanda, Campus de Butare, Faculté d'Agronomie/Institut des Sciences Agronomiques du Rwanda, Systèmes de Production, Projet GTZ/ISAR.

HOFFMANN, V. 1992: Beratungsansätze: Von der Uniform zum Maßanzug. In: Hoffmann, V. (éd.) 1992: Beratung als Lebenshilfe. Humane Konzepte für eine ländliche Entwicklung. Margraf, Weikersheim, pp. 271-276.

HURNI, H. 1993: Nachhaltige Bodennutzung: Vom Betrieb zum Internationalen Marktsystem. In: Nachhaltige Bodennutzung in Entwicklungsländern. Berichte zu Entwicklung und Umwelt Nr. 7. Bern University.

IBSRAM 1994: Soil, water and nutrient management research – a new agenda. IBSRAM Position Paper, Bangkok.

IFAD 1992: Soil and water conservation in Sub-Saharan Africa. Towards sustainable production by the rural poor. FIDA, Rome.

ILEIA 1989: Participatory technology development in sustainable agriculture: proceedings of the ILEIA workshop on operational approaches. ILEIA, Leusden, Pays-Bas.

LEE, K.E. et WOOD, T.G. 1971: Termites and soils. Academic Press London. Cité d'après Douglas, M. 1994: Sustainable use of agricultural soils. A review of the prerequisites for success or failure. Development and Environment Reports No. 11. Group for Development and Environment, Institute of Geography, Bern University, Switzerland.

LOPES, A S. 1980: Micronutrients in soils of the tropics as constraints to food production. In: Int. Rice Res. Inst.: Priorities for alleviating soil-related constraints to food production in the tropics. Los Baños, Philippines, pp. 277-298.

LOPES, A.S. et F.R. COX 1979: Relação de características físicas, químicas e mineralógicas en solos sob cerrados. Rev. Bras. Cienc. Solo 3, pp. 82-88.

LÜHE, N. VON DER 1993a: Zur Bedeutung des Rapid Rural Appraisal für die landwirtschaftliche Beratung in Afrika. In: Afrika Spectrum 28 (1), pp. 37-52.

LÜHE, N. VON DER 1993b: Über die Rolle von Forschung und Beratung in landwirtschaftlichen Innovationsprozessen. In: Preuß, H.-J. A. et Steinacker, G. (éd.): Beteiligung von Zielgruppen an der nationalen Agrarforschung in Entwicklungsländern. Materialien des Zentrums für regionale Entwicklungsforschung, Band 28. Giessen, pp. 143-155.

MAAG, H.-P. 1993: Asia land sloping land management network. In: Gruppe für Entwicklung und Umwelt, Geographisches Institut, Universität Bern: Nachhaltige Bodennutzung in Entwicklungsländern. Bern.

MAYDELL, O. VON 1994: Agrarpolitische Ansätze zur Erhaltung von Bodenressourcen in Entwicklungsländern. Landwirtschaft und Umwelt. Schriften zur Umweltökonomik, Band 9. Wissenschaftsverlag Vauk. Kiel.

MOFFAT, L., GEADAH, Y. et STUART, R. 1991: Two halves make a whole: balancing gender relations in development. Canadian Council for International Cooperation. Ottawa, Canada.

NEUE, H.E. et C.P. MAMARIL 1985: Zinc, sulfur and other micronutrients in wetland soils. In: Int. Rice Res. Inst: Wetland soils: Characterization, classification and utilization. Los Baños, Philippines, pp. 307-320.

OLDEMAN, L.R., HAKKELING, R.T.A. et SOMBROEK, W.G. 1991: World map of the status of human-induced soil degradation. An explanatory note. ISRIC, PNUE, Wageningen.

OLDEMAN, L.R., ENGELEN, V.W.P. VAN et PULLES, J.H.M. 1990: The extent of human-induced soil degradation. Annex 5 "World Map of the status of human-induced soil degradation, an explanatory note". ISRIC, Wageningen.

OTZEN, U. 1992: Stabilization of agricultural resources. Concept, requirements and measures to ensure agricultural development, with examples from Southern Africa. Occasional Papers of the German Development Institute, No. 103. Berlin.

OVERHOLT, C. et al. 1991: Gender and development: A framework for project analysis. FAO, Rome.

PLATTEAU, J.-P. 1992: Land reform and structural adjustment in Sub-Saharan Africa: controversies and guidelines. FAO Economic and Social Development Paper No. 107. FAO, Rome.

POL, F. VAN DER 1992: Soil mining. An unseen contributor to farm income in southern Mali. Bulletin 325, Royal Tropical Institute (KIT), Amsterdam.

PONNAMPERUMA, F.N. et A.K. BANDYOPADHYA 1980: Soil salinity as a constraint on food production in the humid tropics. In: Int. Rice Res. Inst.: Priorities for alleviating soil-related constraints of food production in the tropics. Los Baños, Philippines, pp. 203-216.

RAMÍREZ, A. 1979: Evaluación de la relación calcio/magnesio en suelos del Valle de Cauca. Suelos Ecuat. 10, pp. 147-155.

RHOADES, R.E. et BEBBINGTON, A. 1991: Farmers as experimenters. In: Haverkort B., van der Kamp, J. et Waters-Bayer, A. 1991: Joining farmers' experiments: experiences in participatory technology development. Intermediate Technology Publications 103-105, London.

RICHARDS, P. 1986: Coping with hunger: hazard and experiment in an african rice-farming system. The London Research Series in Geography No. 11, Allen & Unwin Publishers, London.

SANCHEZ, P.A. et LOGAN, T.J. 1992: Myths and science about the chemistry and fertility of soils in the tropics. In: R. Lal, P.A. Sanchez (éd.) 1992: Myths and science of soils of the tropics, SSSA Special Publication No. 29, Soil Science Society of America, American Society of Agronomy, Madison, USA, pp. 35-46.

SCHÖNHUTH, M. et KIEVELITZ, U. 1993: Les méthodes participatives de recherche et de planification dans la coopération au développement: diagnostic rapide en milieu rural, diagnostic participatif. Une introduction commentée. Schriftenreihe der GTZ N° 231. TZ-Verlagsgesellschaft, Rossdorf.

SEILER, W. et CRUTZEN P.J. 1980: Estimates of gross and net fluxes of carbon between the biosphere and the atmosphere from biomass burning. Climatic Change 2, pp. 207-247.

SHANER W., PHILLIP, P. et SCHMEHL, W. 1982: Farming systems research and development. Guidelines for developing countries. Westview Press. Boulder Colorado.

SPERLING, L. et K.G. STEINER 1992: Farmers and sustainable agriculture: Socio-economic concerns in the development of new soil management practices. In: Tiessen, H. et E.Frossard, SCOPE/PNUE 1992: Phosphorus cycles in terrestrial and aquatic ecosystems. Saskatoon, Canada, pp. 30-43

STANGEL, P., PIERI, C., MOKWUNYE, U. 1994: Maintaining nutrient status of soils: macro-nutrients. In: Greenland & Szabols (ed.) 1994: Soil resilience and sustainable land use. Wallingford, UK, pp. 171-197.

STEINER, K.G. 1992: Développement des technologies d'une agriculture durable dans un environnement diversifié. Document de travail N°18. GTZ/ISAR. Rubona, Rwanda.

STEINER, K.G., BLANKEN, J., UWERA, M.J., SEKAYANGE, L., NDYANABO, E. 1993: Développement participatif des techniques de conservation des sols dans deux zones agroécologiques du sud du Rwanda. Document du travail N°10. GTZ/ISAR, Rubona, Rwanda.

STOCKING, M. 1986: The cost of soil erosion in Zimbabwe in terms of loss of three major nutrients. FAO Consultants' Working Paper, Rome.

SWIFT, M.J. et SANCHEZ, P.A. 1984: Biological management of tropical soil fertility for sustained productivity. Nature and Resources Vol. XX, No. 4 October - December 1984, UNESCO Paris.

TIFFEN, M., MORTIMORE, M., GICHUKI, F. 1994: More people, less erosion. Environmental recovery in Kenya. Chichester, UK.

PNUE 1992: Saving our planet. The state of the environment (1991-1992). Nairobi.

PNUE, ISRIC 1991: United Nations Environmental Programme – International Soil Reference and Information Centre. GIS evaluation of GLASOD map (cf. Oldeman et al. 1990). Nairobi.

VELDHUIZEN, L.R. VAN, ZEEUW, H. DE 1992: Learning for people-centred technology development: a training guide. Vols. 0, 1, 2, 3, 4 and 5. ETC Foundation, Leusden, Netherlands.

WATERS-BAYER, A. 1992: Unterstützung bäuerlicher Forschung und Kommunikation: Die Rolle landwirtschaftlicher Beratung. In: Hoffmann, V. (ed.) 1992: Beratung als Lebenshilfe. Humane Konzepte für eine ländliche Entwicklung. Margraf, Weikersheim, pp. 257-270.

WERNER, J. 1993: Participatory development of agricultural innovations: procedures and methods of on-farm research. Publication GTZ No. 234, Eschborn.

WILKE, B.M., DUKE, B.J. et JIMOH, W.L.O. 1984: Mineralogy and chemistry of Harmattan dust in Northern Nigeria. Catena, 11, pp. 91-96.

WORLD OVERVIEW OF CONSERVATION APPROACHES AND TECHNOLOGIES (WOCAT) 1994: Workshop Proceedings. Bern.

YOUNG, A. 1976: Tropical soils and soil survey. Cambridge University Press. Cambridge, UK.

YOUNG, A. 1989: Agroforestry for soil conservation. CAB International, Wallingford, UK.