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Discussion Paper 27

Soil Degradation

A Threat to Developing-Country Food Security by 2020?

Sara J. Scherr

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Soil Degradation

A Threat to Developing-Country Food Security by 2020?

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Foreword

While there is growing appreciation for our soil resources and the need to assure sustainability in their management, we do not as yet fully understand where, when, and how soil degradation affects food security; how important this problem is relative to other constraints in developing countries; and what policy and other actions to take to mitigate adverse effects of soil degradation. Until relatively recently, there has been a dearth of research on this topic, leading to uninformed dialogues and debates and leaving policymakers somewhat at a loss about whether and what to do to address soil degradation threats to food security.

In this comprehensive paper, Sara J. Scherr lucidly explains why and when soil degradation should be of particular concern to policymakers interested in assuring food security. She reviews over 80 recent studies to assess the past and present food-security related effects of soil degradation, and, on the basis of this evidence and assessments of the likely future trends in agricultural land use, she predicts future patterns of soil degradation and the threats they pose to food security in the developing world by 2020. Scherr convincingly argues that soil degradation does not have to threaten food security in developing countries and provides guidance on policy and research priorities to reduce these threats in each of the major pathways of agricultural land use in developing countries.

Per Pinstrup-Andersen
Director General, IFPRI

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Acronyms and Abbreviations

AEZ	Agroecological Zone
AGDP	Agricultural Gross Domestic Product
ASSOD	Assessment of Human-Induced Soil Degradation in South and Southeast Asia
CBA	Cost-Benefit Analysis
CGE	Computable General Equilibrium
CGIAR	Consultative Group on International Agricultural Research
EPIC	Erosion Productivity Impact Calculator
FAO	Food and Agriculture Organization of the United Nations
GAIL	Gross Annual Immediate Losses
GDFL	Gross Discounted Future Losses
GDCL	Gross Discounted Cumulative Losses
GDP	Gross Domestic Product
GIS	Geographic Information System
GNP	Gross National Product
GLASOD	Global Assessment of Soil Degradation
HYV	High-yielding varieties
IFPRI	International Food Policy Research Institute
IIASA	International Institute for Advanced Systems Analysis
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
ISRIC	International Soil Research and Information Centre
K	Potassium
KSH	Kenya Shillings
MVP	Marginal Value Product
N	Nitrogen
NEAP	National Environmental Action Plan
NPV	Net Present Value
OM	Organic matter
P	Phosphorus
SCUAF	Soil Conservation Under Agroforestry
SOTER	World Soils and Terrain Digital Database
SWNM	Soil, Water, Nutrient Management
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USLE	Universal Soil Loss Equation
WANA	West Asia and North Africa
WOCAT	World Overview of Conservation Approaches and Technologies

1. Introduction

Global population in the year 2020 is projected to reach nearly 8 billion, 35 percent higher than the 1995 population (UN 1996). Demand for food and fiber will rise by an even higher percentage, as incomes grow, diets diversify, and urbanization accelerates. The International Food Policy Research Institute (IFPRI) estimates that if current levels of agricultural research and investments in agriculture and social welfare continue, developing-country foodgrain production will increase by only 1.5 percent per year during 1995–2020 and livestock production will grow by 2.7 percent per year, rates much lower than in previous decades. Growth will have to come about mainly through yield increases from existing agricultural lands. Food imports will necessarily increase, but even so one out of every four children under six years of age in developing countries will still be malnourished in 2020, a modest improvement from one out of three malnourished children in 1995 (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1997). To improve on these projections, IFPRI argues for a 2020 Vision for Food, Agriculture, and the Environment that is "a world where every person has access to sufficient food to sustain a healthy and productive life, where malnutrition is absent, and where food originates from efficient, effective, and low-cost food systems that are compatible with sustainable use of natural resources" (IFPRI 1995).

But can this hopeful vision, and even the more modest baseline projections, really be achieved? IFPRI suggests that realizing the 2020 Vision calls for sustained action in six priority areas:

- Strengthening the capacity of developing-country governments to perform appropriate functions;
- Enhancing the productivity, health, and nutrition of low-income people and increasing their access to employment and productive assets;
- Strengthening agricultural research and extension systems in and for developing countries;
- Promoting sustainable agricultural intensification and sound management of natural resources;
- Developing efficient, effective, and low-cost agricultural input and output markets; and
- Expanding international cooperation and assistance and improving its efficiency and effectiveness.

However, the possible impact of these actions on agricultural area, yield potential, and productivity of degrading agricultural soils has not been seriously addressed. Indeed, because of the lack of comprehensive data linking soil quality to agricultural productivity, the models on which the 2020 projections of future production growth are based do not include soil quality as a component of productivity,[1] nor the building of soil capital and other land-improving investments as components of agricultural investment.

Yet there is growing concern in some quarters that intertemporal degradation of agricultural soil resources—that is, a decline in long-term productive potential—is already seriously limiting production in the developing world, and that the problem is getting worse (Lal 1990; UNEP 1982; UNCED 1992). Degradation is also associated with off-site problems of sedimentation, carbon emis-

[1] Components of productivity include public and private research on crop varietal improvement and crop management, agricultural extension and farmer schooling, markets, infrastructure, and irrigation (Rosegrant, Agcaoili-Sombilla, and Perez 1995). Past rates of soil degradation are implicitly reflected in the historical yield-trend data used to develop trend projections.

sions affecting climate change,[2] reduced watershed function, and changes in natural habitats leading to loss of genetic stock and biodiversity. In response to these concerns, international programs are being developed or proposed to combat soil degradation (FAO 1992; Toulmin 1993; Sanchez et al. 1997; IFAD 1992; Fortin and Engelberg 1997; World Bank 1997). Efforts are being made to monitor soil degradation more systematically (Pieri et al. 1995; Dumanski et al. 1991; ISRIC 1998). International agricultural research centers have expanded their work to understand and improve tropical soil management and rehabilitation (DSE/IBSRAM 1995; Kumwenda et al. 1996; Nelson et al. 1997).

Despite this increased public attention and the commitment of land management specialists, many policymakers remain unconvinced that agricultural soil degradation warrants priority attention. Indeed, information on the physical aspects of soil degradation as traditionally reported by soil scientists—rates of soil erosion, the extent of farming areas with particular degradation processes, tons of soil lost, and so on—is inadequate as a guide and catalyst to policy action.

Policymaker Concerns about Soil Degradation

Policymakers typically consider soil quality not as a policy objective in itself, but as an input into achieving other policy objectives. Soil degradation is not seen as posing a serious policy concern unless it threatens one of these other objectives. Before taking concrete action—be it through indirect policies that modify farmers' incentives for soil management, or through direct policies that provide services or subsidies to farmers and public investment for rehabilitation or research—policymakers need a clear understanding of which groups of producers and which farming systems are experiencing what types of degradation problems, and how important these problems loom relative to other challenges facing the farm sector. Analysis of causal factors explaining soil degradation and the effectiveness of alternative interventions can then be targeted to high priority areas and issues.

Four areas of economic impact from soil degradation on farm productivity are (or should be) of particular policy interest:

- *Aggregate supply, stability, or price of agricultural output*, when lands with degrading soils are a significant source of supply for national consumers or export markets, and alternative sources of supply are not available or not economical;
- *Agricultural income or economic growth*, when soil degradation leads to lower production or higher costs, reducing agricultural income and its multiplier effects on an economically significant scale, and alternative sources of economic growth are limited or expensive to develop;
- *Consumption by poor farm households*, when lands with degrading soils are a critical source of food security for subsistence or semi-subsistence producers with few alternative livelihood options; and
- *National wealth*, when degradation reduces the long-term productive capacity of soil resources deemed to be of future economic or environmental significance, threatening the resource base and food security of future generations.

Environmental effects of soil degradation may also elicit major policy concerns if they threaten food security, food supplies, economic growth, or national welfare in downstream areas, or natural resources valued for meeting other environmental policy objectives, such as watershed or habitat protection. These issues are outside the scope of this paper, but may in some cases generate larger economic losses than on-site effects (Enters 1998).

Objective and Scope

The objective of this paper is to examine available evidence to see if and where soil degradation poses a significant threat to food security by 2020. While off-site environmental concerns due to soil degra-

[2] Smyth and Dumanski (1993) report that the current release of CO_2 from land degradation is 10–30 percent of that from burning fossil fuel. Land conversion is also one of the largest human-induced sources of N_2O, which leads to greenhouse gas accumulation and ozone depletion.

dation are significant and often justify policy intervention,[3] this paper focuses only on the effects of changing soil productivity.

Until recently, little data have been available for assessing the economic effects of soil degradation. But increased researcher interest and attention to the critiques of earlier analyses have produced a new generation of studies on soil degradation that are more rigorously designed, forge a stronger link between technical and socioeconomic analysis, and provide more policy-relevant findings.

The analysis in this paper draws from a review of 26 global or regional studies and 54 national or subnational studies in 26 developing countries of the economic effects of soil degradation (Scherr 1997b). Most were English-language publications; a systematic review of non-English literature was not done. The geographic coverage of the existing literature is limited. No regional impact studies were found for East Asia and the Pacific or West Asia and North Africa. Only a few countries, such as Ethiopia, India, and Kenya, are the subject of multiple studies. While many studies address the effects of soil erosion, far fewer tackle the problems of nutrient depletion and salinization. Almost none address the effects of changes in a soil's physical properties, such as compaction or acidification. Studies have been concerned primarily with cropland rather than grazing land.

The most common assessment of economic losses compares gross losses from degradation with some measure of the national agricultural economy. While many studies examine the gross impact of degradation on crop production, few investigate the net effect on supply, taking into account the market response to changing prices, substitution of production from other producing areas for local supply, or other secondary effects. Only a handful of studies have evaluated the effects of soil degradation on the food consumption or nutrition of poor farmers. No studies of the effects of degradation on national wealth exist, other than those that estimate land area going out of production or the changing class of soil quality. None assess the long-term relative importance of lands suffering productivity loss; only a few have analyzed soil productivity change using long time horizons. No studies of the economic effects of soil quality improvement exist.

Overview of Findings

While a fully reliable picture of soil degradation and its implications in developing countries does not exist as yet, and the effects of demographic and economic trends on future patterns of degradation cannot be predicted with certainty, the evidence is sufficient to warrant serious attention by the policy community.

The early, high estimates of soil degradation have not been substantiated. Degradation appears not to threaten aggregate global food supply by 2020, though world commodity prices and malnutrition may rise. Soil quality is declining at a modest rate in aggregate, and in Asia, for example, the soil quality of more than half of the soils used for production has been stable for the past few decades. The area of degraded soils is extensive, however, and the effects of soil degradation on food consumption by the rural poor, agricultural markets, agricultural income, and, in some cases, national wealth are significant. The effects of degradation are evident in many subregions with degradation-prone soils (particularly in Sub-Saharan Africa), inadequately managed irrigation (particularly in South Asia), and rapidly intensifying production without the economic incentives or the technologies for good resource husbandry (densely populated, marginal lands in many parts of the developing world). Many of these subregions have no apparent alternative livelihood options, sources of food supply, or nonagricultural development potential. And while soil degradation poses particular problems for the poor—and is sometimes a result of poverty—its effects appear likely to have far-reaching consequences for economic development in many countries.

[3] An expert consultation on land degradation held in 1995 emphasized key environmental issues related to off-site erosion, deforestation in threatened habitats, degradation of natural vegetation, water scarcity and conflict, and agrochemical pollution (Scherr and Yadav 1996).

Policies that support more dynamic agricultural development between now and 2020 may encourage farmers in some areas to improve soil husbandry even without more direct action. In many other areas, however, the rising pressures of rapid population and market growth on agricultural land, together with constraints posed by economic stagnation or a lack of technology for dealing with some types of soil problems, threaten to accelerate soil degradation and its economic effects. It is highly unlikely that agricultural trade and other distribution mechanisms will evolve rapidly enough to counter the grave nutritional and economic effects of these processes. Active policy intervention will be needed to avert the consequences of soil degradation and harness land improvement to broader development efforts.

Organization

This paper is organized in five chapters. The next chapter discusses the existing literature and some key methodological and conceptual issues for evaluating the economic effects of soil degradation. Chapter 3 summarizes and interprets evidence of the past economic effects of soil degradation at the global level and in three regions for which studies are available: South and Southeast Asia, Sub-Saharan Africa, and Mexico and Central America. Chapter 4 draws from this evidence and also from evidence of likely future trends in land use and management to predict future patterns of soil degradation and the potential threats these pose for reaching the 2020 Vision. The final chapter suggests priorities for policy action and research to reduce these threats.

2. Evaluating the Impact of Soil Degradation on Food Security

The key soil characteristics that affect yield are nutrient content, waterholding capacity, organic matter content, soil reaction (acidity), topsoil depth, salinity, and soil biomass. Change over time in these characteristics constitutes “degradation” or “improvement.” Degradation processes include erosion, compaction and hard setting, acidification, declining soil organic matter, soil fertility depletion, biological degradation, and soil pollution (Lal and Stewart 1990).[4] Soil quality (see box) may be improved through leveling the land, depositing sediment deposition, increasing organic matter, improving soil nutrient status, terracing, controlling erosion, improving irrigation drainage systems, or rehabilitating compacted soils and erosion gullies or other seriously degraded areas.

Change in soil quality over time can be a complex phenomenon. Quality can vary across sites, soil types, and production systems. Furthermore, soil quality is only one of many variables influencing agricultural yield, which is, in turn, only one of many factors influencing food consumption, food availability, and farm income. This complicates the evaluation and interpretation of the effects of soil degradation and the design of appropriate policies in response.

Box—Agricultural Productivity and Soil Quality

Soil quality is the inherent capability of the soil to perform a range of productive, environmental, and habitat functions. This study is concerned mainly with the soil’s productive function, hence it is important that the definitions of productivity used below in relation to soil quality are clear.

Diverse definitions of “productivity” have created some confusion. In this paper, the term “potential soil productivity” is used to refer to the *potential* of the soil system to accumulate energy in the form of vegetation (following Tengberg and Stocking 1997, 4), controlling for the use of other inputs. “Soil productivity” is used to refer to the actual yield of usable vegetation, also controlling for input use. “Agricultural productivity” refers to the relationship between the average or real output of economically usable products divided by an index of all fixed and variable inputs. Because economists conventionally have analyzed “land productivity” simply as total output divided by land area (assumed to be a fixed factor), soil quality has not been considered. Yet measures of change in “total factor productivity” over time that do not include soil quality are likely to overestimate the contribution of other factors. On the other hand, the effect of soil quality change on agricultural productivity is limited by its importance as a productive factor relative to other factors, and the degree of complementarity and substitutability between soil quality and other factors and inputs. Soil quality contributes relatively more to agricultural productivity in low-input production systems.

[4] See the appendix for definitions of the various types of degradation.

Vulnerability of Soils to Degradation

The widespread tendency to minimize the importance of soil quality for agriculture stems in part from the experience of temperate agriculture. The most productive temperate soils are geologically "new." A result of glaciation in the last Ice Age, these soils are both fertile and relatively resistant to degradation. By contrast, though some tropical highland soils are also "new," formed through the deposition of volcanic materials from old eruptions, most are of infertile parent material or have been highly weathered over the millenia, resulting in the leaching of soluble nutrients from soils and acidification. The higher temperatures, greater high and low extremes of rainfall, and greater rainfall intensity typical of the tropics subject soils in most developing countries to significant risk of climate-induced degradation.

Indeed, only a third of all rainfed, cultivable area in developing countries (excluding China, for which data were not available) is free of major soil-related constraints that limit production (Table 1). The 10 percent of land in steep slopes is especially prone to erosion, as are shallow soils; the extensive areas with low natural fertility require active nutrient replenishment and supplementation to sustain even moderate yields over time; and sandy soils require careful management to retain water. Chemical soil constraints are also widespread: 36 percent of tropical soils have low nutrient status; one-third have sufficiently acid conditions for soluble aluminum to be toxic for most crops (acidity is exacerbated by inorganic fertilizer application); 22 percent are tropical clays that fix phosphorus; 5 percent have critically low cation exchange capacity; and some are saline or alkaline (Sanchez and Logan 1992, cited in Tengberg and Stocking 1997, 9–10).

Poor land husbandry can have quite different long-term effects on different types of soils, and costs of and returns to soil improvement can vary substantially, depending upon soil *resilience* (the resistance to degradation) and soil *sensitivity* (the degree to which soils degrade when subjected to degradation processes). For example, ferralsols, which have low available nutrient supplies, strong acidity, low available phosphorus, no reserves of weatherable minerals, and easily lost topsoil organic matter, demonstrate low resilience and moderate sensitivity to water erosion. Even with good soil cover, yields decline rapidly without a combination of structures and biological measures to control erosion. By contrast, luvisols, with moderate nutrient levels, low-to-moderate organic matter content, and weak topsoil structure prone to crusting, have moderate resilience and low-to-moderate

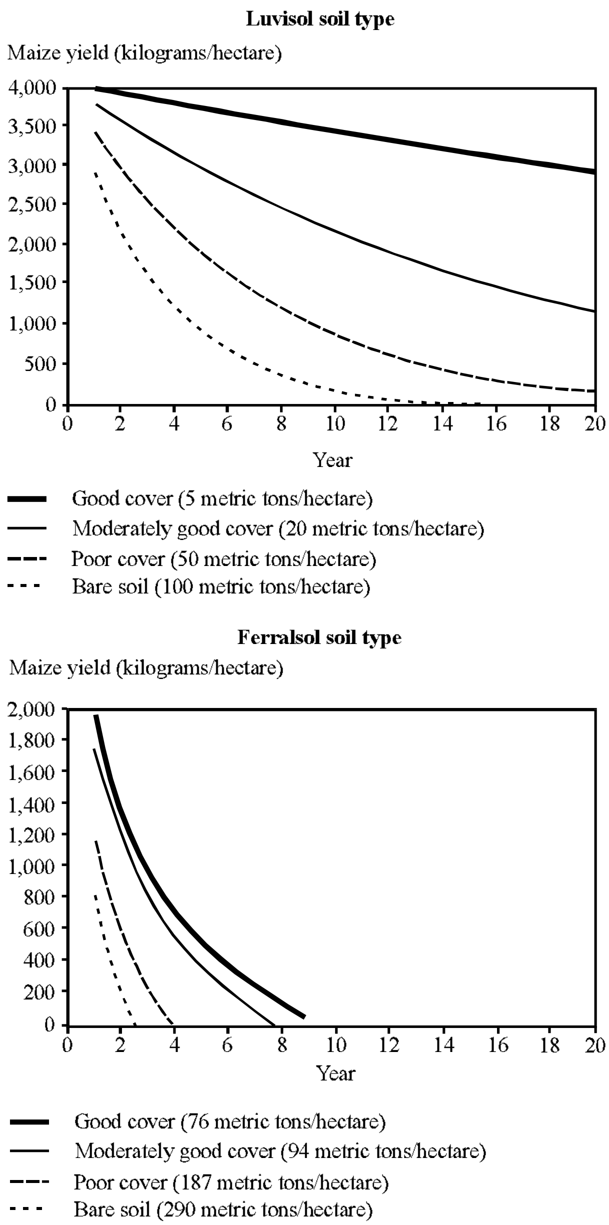
Table 1—Share of land with terrain and soil constraints in total rainfed land with crop production potential

Constraint	Sub-Saharan Africa	Latin America and the Caribbean	Near East/ North Africa	East Asia (excluding China)	South Asia	Developing countries (excluding China)
			(percent)			
Steep slopes (16–45 percent)	11	6	24	13	19	10
Shallow soils (<50 centimeters)	1	10	4	1	1	1
Low natural fertility	42	46	1	28	4	38
Poor soil drainage	15	28	2	26	11	20
Sandy or stony soils	36	15	17	11	11	23
Salinity, sodicity, or excess of gypsum	1	2	3	1	2	1
Total land with crop production potential affected by one or more constraints[a]	72	72	43	63	42	67
No major constraints	28	28	57	37	58	33

Source: N. Alexandratos 1995, Table 4.2, p. 155.
[a]Individual constraints are nonadditive, that is, they may overlap.

sensitivity. Maintaining their productivity requires both tillage practices that maximize surface water infiltration and biological measures that maintain soil cover (Tengberg and Stocking 1997; see Figure 1). While some soils, like alfisols, can be maintained for a long time with only inorganic fertilizer application (if farmers make sure that they do not crust), Luvisols require complementary use of organic inputs because they are low in organic matter to begin with (Swift 1997).

Figure 1—Effects of soil erosion on maize yields for different types of soil



Source: Tengberg and Stocking 1997, figures 4 and 6.

Assessment of the Effects of Soil Degradation

An assessment of the productivity-related economic effects of soil degradation that is relevant to policymaking first requires estimates of the changes over time of the type, scale, and rate of physical soil quality at a subregional or higher scale. These changes must then be linked to consequent changes in agricultural yield or production costs, and these, in turn, to resulting changes in consumption, market supply, farm income or economic growth, and the long-term value of the resource base.

Assessing Soil Quality Change Over Time

Methods for soil quality assessment were developed mainly for use at the plot level, and are problematic to scale up, even when substantial plot-level data are available (Halverson, Smith, and Papendick 1997). No developing country has in place a national monitoring system for soil quality. Researchers trying to assess soil quality change above the plot level, have used approximate measures, including

- Consultation with experts, long familiar with particular regions, who provide a ranking or qualitative assessment of the scale and processes of degradation within the region, according to agreed-upon criteria (see, for example, Oldeman, Hakkeling, and Sombroek 1991);
- Review and comparative evaluation of published studies on degradation from many different sites within a region (see, for example, Lal 1995; Dregne and Chou 1992);
- Extrapolation of the results of case studies, field experiments, and other micro- or watershed-level data to the national level (see, for example, cases in Bøjö 1996); and
- Estimates constructed from examination of secondary data on land use change, representative ecological conditions, and so on (see, for example, Rozanov, Targulian, and Orlov 1990).

Assessing the Effects on Agricultural Productivity

The effects of soil degradation on agricultural productivity (see box) vary with the type of soil, crop, degradation, and initial soil conditions, and may not be linear. Lower potential production due to degradation may not show up in intensive, high-input systems until yields are approaching their ceiling. Reduced efficiency of inputs (fertilizer, water, biocides, labor) could show up in higher production costs rather than lower yields.

Effects on productivity are most commonly estimated using coefficients based on plot-level experimental trials or cross-sectional farm surveys. Many researchers estimate production effects using the Universal Soil Loss Equation.[5] Since trial and survey data are unavailable for a number of soils and degradation processes, studies often base assumptions about aggregate physical yield effects on degradation-yield relationships taken from the literature or estimated by soil experts. Few studies use historical time-series data on yield and production cost; even fewer attribute yield or cost change to soil quality change, controlling for other variables.

Most research methods provide only a rough estimate of the nature and relative importance of degradation across large areas, though a few valuable studies disaggregate by type of soil, topography, location, crop, or farm household.

Indicators of Economic Impact

Many different indicators have been used in research on the economic effects of soil degradation. Welfare effects have been measured by changes in the number of food-insecure households or malnourished children; the amount of food consumed from farm production; the level of rural household income or consumption; the degree of community-level food self-sufficiency; and the rates of migration. Effects on agricultural supply have been measured by changes in average crop yields or aggregate crop production, aggregate market supply, export or import levels, and level and variability of crop prices. Economic losses have been assessed by comparing the value of lost production, the value of inputs needed to compensate for lost nutrients, or current or discounted future income streams to farm income, national income, or economic growth rates, or by measuring changes in input efficiency. Effects on national wealth have been measured only by changes in the aggregate amount or quality of agricultural land (Scherr 1997a).

Evolution of Methods for Impact Assessment

Studies of the productivity-related economic effects of soil degradation can be divided into three periods. Those published in the late 1970s and 1980s were intended mainly to draw public attention to the issue. They used rather simplistic approaches, calculating gross aggregate effects of soil erosion on agricultural lands (assuming little use of conservation practices) and resulting gross economic losses.

Global and regional analyses published in the early 1990s were more systematically designed and reflective of broad field experience. They relied mainly on secondary data, literature reviews, and surveys of regional soil experts, and used fairly simple economic models, if any. National and subnational studies used similar methods, but with more disaggregated data, to construct models that measured impact. Typically in the early 1990s, the economic impact of degradation was measured in terms of the value of lost yields, the value of plant nutrients lost through erosion, or the costs of soil rehabilitation. These changes were valued at market prices. The approaches of this period have been

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[5] The Universal Soil Loss Equation (USLE) was developed in the 1970s to estimate erosion risks and levels in temperate agriculture, but it has been adapted for tropical conditions. The USLE equation is A = R*K*L*S*C*P, where A = long-standing average annual soil erosion in metric tons/hectare; R = rainfall erosive factor (which depends on the frequency, quantity, seasonal distribution, and kinetic energy of heavy rainfall); K = soil erodibility factor (dependent on soil type); L = slope-length factor; S = slope steepness factor; C = farming practice and crop-type factor (dependent on the stage of cultivation and the cover by crops, other vegetation, or residues); and P = soil conservation measures (which depend on farm management practices). The USLE was developed and further refined for use at the farm-plot level, but it has been widely applied (and some would say, misapplied) at the landscape and even national levels to estimate erosion (Wischmeier and Smith 1978).

criticized for their degree of aggregation, simplistic assumptions about degradation-production relationships, failure to examine least-cost alternatives to rehabilitation, and failure to consider likely farmer or market responses to supply or cost shifts. Since the mid-1990s a third generation of studies has used more sophisticated models and methods for collecting and analyzing data to disentangle causal relationships and explore variation in soil conditions and management (see, for example, Enters 1998). Many projects have begun to collect primary data from representative soil, farm, or village units in order to develop more reliable biophysical yield models for different types of environments, degradation, and soil management. Research increasingly focuses on effects at the national and subnational levels, and this allows for more policy-relevant analysis (Scherr 1997a).

Predicting Future Effects: Conceptual Challenges

Even with the best information on past and current trends, three other central issues must be considered before predictions about future trends regarding soil degradation can be made with any confidence:

(1) To what extent is soil degradation reversible at an economically reasonable cost?;
(2) To what extent will farmers respond on their own to protect or rehabilitate their soils?; and
(3) To what extent will structural change in agricultural economies affect our reliance on currently degrading soil resources?

Reversibility of Soil Degradation

Where soil degradation is reversible at low-to-moderate economic cost (relative to agricultural product prices and land values), even significant degradation may result in little long-term economic loss. Prevention is not always cheaper than a cure. For example, farmers who cease to undertake soil-protecting investments during prolonged periods of low food prices may resume those practices when prices rise. Farmers also may mine soil nutrients (soil capital) over a period of time in order to accumulate alternative forms of more economically valuable capital, but subsequently use that capital to rebuild soil resources. Land abandonment after prolonged soil degradation could serve to keep the land fallow long enough for it to recover key long-term productive attributes.

If, on the other hand, degradation through lack of proper soil husbandry in the short term leads to permanent reductions in the soil's productive potential, strategies leading to degradation are less likely to be economically justifiable. What constitutes "irreversibility" is a matter of some debate among soil scientists due to inadequate research. Only nutrient depletion and imbalance and surface sealing and crusting can be rapidly and relatively cheaply reversed (Table 2). Many water, nutrient, and biological problems in soils can be reversed over 5–10 years through soil-building processes and field- or farm-scale investments and management changes. Some types of physical and chemical degradation, such as terrain deformation and salinization, are extremely difficult or costly to reverse. The feasibility and cost of soil rehabilitation depend in part on soil type, production system, and severity of degradation. For many soil types, little is known about the effects of degradation or the thresholds for soil quality below which future investment in restoration is uneconomic.

Farmer Response to Soil Degradation

Historical evidence suggests that a linear extrapolation of current soil degradation trends will be a poor guide to future soil quality. Farmers depend upon the land for their livelihood. It is uncommon for them to be unaware of serious soil degradation unless they are recent immigrants to a new agroecological zone, the process of degradation has not yet affected yields, or its cause is invisible (acidification, for example). We should expect, therefore, that farmers will respond to degradation with new land management or investment if they perceive a net benefit from doing so and can acquire or develop appropriate technology. Trajectory 1 in Figure 2 illustrates such a process of innovation, in which increasing pressure on soil resources over time initially leads to soil degradation, but farmers eventually respond by improving soil management practices and making investments to restore, main-

Table 2—Relative reversibility of soil-degradation processes

Type of degradation	Degradation process	Largely reversible, low cost	Reversible, significant cost	Largely irreversible/ very high cost
Physical	Clay pans, compaction zones		X	
	Surface sealing and crusting	X		
	Subsidence			X
	Topsoil loss through wind or water erosion		X (if active deposition)	X
	Terrain deformation (gully erosion, mass movement)			X
Waterholding	Reduced infiltration/impeded drainage		X	
	Reduced waterholding capacity		X	
	Waterlogging		X (farm scale)	X (landscape scale)
	Aridification		X	
Chemical	Organic matter loss		X	
	Nutrient depletion/leaching	X		
	Nutrient imbalance	X		
	Nutrient binding		X	
	Acidification		X (if liming feasible)	X
	Alkalinization/salinization			X
	Dystrification			X
	Eutrophication		X	
Biological	Reduced biological activity due to soil disturbance		X	
	Reduced biological activity due to agrochemical use		X	
Pollution	Contamination		X	
	Pollution (accumulation of toxic substances)			X

Source: Informal consultation with tropical soil experts and various texts on degradation.

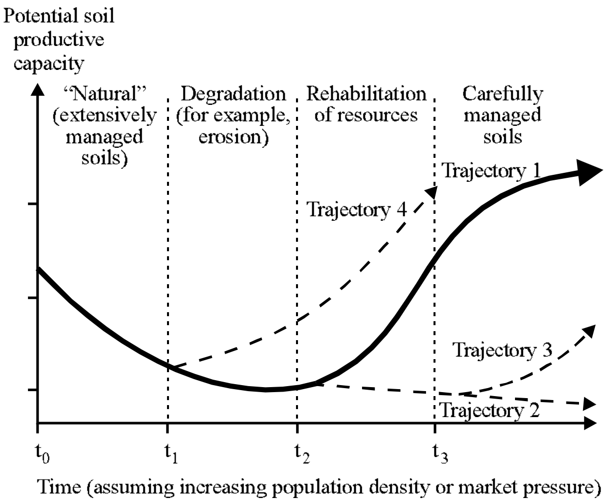
tain, or even ultimately *improve* the soil's productive potential. Empirical examples of such a process have been widely documented (Ruthenberg 1980; Templeton and Scherr 1997; Tiffen, Mortimore, and Gichuki 1994).

Farmers respond not only by making major conservation investments such as terrace construction on steep slopes, land-leveling in irrigated areas, land drainage, and revegetation of denuded landscapes, but also by using alternative crop mixes and cropping intensities; land-clearing and fallow practices; spatial patterns and niches of crop production; tillage and planting density and timing practices; agroforestry practices; vegetation management outside crop fields; crop-residue management; livestock population, species, and feeding practices; or farming implements. Farmers may modify the layout of farm paths, fences, windbreaks, and other linear features or barriers in order to affect soil and water movement (Scherr et al. 1996).

The conservation community has discovered that farmers' decisions about conservation practices and investments are inextricably linked to production (Shaxson et al. 1997). If good land-husbandry practices are to be widely adopted, they must not only replenish soil resources, but also contribute to increased productivity and farm income in the short term (Sain and Barreto 1996; Partap and Watson 1994). Farmer willingness to invest in soil improvement is closely associated with the overall economic profitability of farming and an economic and policy environment that facilitates commercialization, reduces price risks, increases access to infrastructure, increases security of land access, and encourages technical innovation (see, for example, Clay, Reardon, and Kangasniemi 1998; Shiferas and Holden 1997; Hopkins, Delgado, and Gruhn 1994).

When farmers fail to take action (trajectory 2 in Figure 2) or delay taking action until significant, irreversible degradation has taken place (trajectory 3), it

Figure 2—Innovation in soil resource management under population or market pressure



Note: t_0 to t_3 are time periods. Trajectory 1 indicates a flexible and innovative response to degradation by farmers. Trajectory 2 indicates a failure to take action. Trajectory 3 indicates a delay in taking action until significant degradation has occurred. Trajectory 4 indicates that policy intervention encouraged farmers to respond sooner or more effectively than would otherwise have been expected on the basis of their existing incentives.

usually means that they lack knowledge about effective means for soil improvement; lack access to the farm resources, such as labor, capital, or inputs, needed to make the improvements (a particular concern for the poor); believe the economic contribution of the plot to their livelihood is marginal; expect low economic returns from available options for soil improvement; or are uncertain about reaping the longer-term benefits of soil improvement due to tenure insecurity or price or climate risks (Scherr and Hazell 1994). Under these conditions, targeted policy action is needed to slow or reverse soil degradation. Policy intervention may also be desirable to accelerate farmer response in situations where social benefits are greater than farmers' private benefits (trajectory 4 in Figure 2).

The trajectories of soil degradation and improvement vary considerably among different pathways of development. These variations result from differences in the soil resource base, demographic patterns, market integration, local institutions, and policy actions (Clay, Reardon, and Kangasniemi 1998; Scherr et al. 1996). Judicious use can be made of limited public investment resources to address soil degradation only if we are able to better predict when and how farmers will respond to degradation and intervention.

Structural Change in Agricultural Economy

Even if existing estimates of the economic effects of soil degradation in recent decades are correct, they cannot necessarily be extrapolated to 2020. There is no certainty that all of the developing world's soils currently under cultivation will constitute important resources for agricultural production in the decades ahead. Structural changes in global and national economies, trading patterns, and infrastructure development may make some soil resources much more important than others. Technological breakthroughs may make some "problem" soils much more productive in the future, while unforeseen events may contaminate soils that are most productive at present. Thus, evaluation of future threats of degradation requires that we assess the likely future trends in the broader economy and their implications for soil management. Some possible scenarios are presented in Chapter 4. Past and present challenges are presented first, in Chapter 3.

3. Past and Present Effects of Soil Degradation

The past half century has been a period of unprecedented agricultural change in developing countries in response to large population increases, integration of rural areas into national and international agricultural and other markets, new technologies, and infrastructure development. Major increases in aggregate agricultural production in this period have been associated with different kinds of soil degradation. This chapter reviews the available evidence on the economic effects of degradation—at the global level and for three developing regions: South and Southeast Asia, Sub-Saharan Africa, and Mexico and Central America—and assesses the importance of soil degradation to policy concerns.

Land Use and Management in Developing Countries Since the 1950s

It is useful to examine the overall patterns of agricultural change in developing countries first. Rural population increase, expansion of cultivated area, and intensification of production have all affected soil quality. Although the rural population growth rate in developing countries declined from 2.2 percent in 1960–65 to 1 percent in 1990–95, the absolute number of rural dwellers grew almost 40 percent, from 2.0 to 2.8 billion over the same period (UN 1995). Rural population was fairly stable in Latin America, but it increased 37 percent in Asia (outside Japan) and a remarkable 68 percent in Africa. Total growth rates in 1970–88 for agricultural production in developing countries (4.1 percent per year in East Asia; 3.1 percent in South Asia, Near East, and North Africa; 2.6 percent in Latin America and the Caribbean; and 1.8 percent in Sub-Saharan Africa) have rivaled or surpassed growth rates in the industrialized countries (1.2 percent per year in the same period), though not on a per capita basis.

This growth came in part from extensive clearing of new agricultural lands. Yet even with this expansion, arable land per capita declined from just under 0.5 hectare in 1950 to just under 0.3 hectare in 1990 (FAO 1993). Yield increases on land already in production thus contributed far more to total production. For example, more than 90 percent of the growth in developing-country cereal production between 1961 and 1990 came from yield growth (World Bank 1992b).

It should not be surprising that agricultural expansion and yield growth on such a scale would be associated with some degradation of soil resources. Yet the patterns of degradation vary in the different pathways leading to agricultural intensification and reflect the level of resource endowments in each pathway (Scherr 1997b). The five main pathways are summarized below (also see Table 3).

Irrigated Lands

Area under irrigation in developing countries in 1995 totaled 190 million hectares—an increase of 60 percent since the early 1960s (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1997). Irrigated land now accounts for about 7.5 percent of all arable and grazing lands (Nelson et al. 1997). In low- and middle-income countries, the proportion averages 20 percent of arable and perennial cropland, reaching 34 percent in East and South Asia. Only in Africa has irrigation, at only 4 percent of arable land, been unimportant (World Bank 1997). In 12 developing countries, including populous states like Egypt, China, Iran, Iraq, North Korea, and South Korea, and Pakistan, more than 40 percent of all arable land was under irrigation in 1994.

Table 3—Major pathways of change in agricultural land use in developing countries and associated degradation problems

Land type	Main changes	On-site soil degradation	Other resource degradation
Irrigated lands	60 percent increase in irrigated area, 1961–90; increased multiple cropping	* Salinization and waterlogging * Nutrient constraints under multiple cropping * Biological degradation (agrochemicals)	* Nutrient pollution in ground/ surface water * Pesticide pollution * Water-borne disease * Water conflicts
High-quality rainfed lands	Transition from short fallow to continuous cropping, HYVs, mechanization	* Nutrient depletion * Soil compaction and physical degradation from overcultivation, machinery * Acidification * Removal of natural vegetation, perennials * Soil erosion * Biological degradation (agrochemicals)	* Pesticide pollution * Deforestation of commons
Densely populated marginal lands	Transition from long to short fallows or continuous cropping; Cropping in new landscape niches	* Soil erosion * Soil fertility depletion * Removal of natural vegetation, perennials from landscape * Soil compaction, physical degradation from overcultivation * Acidification	* Loss of biodiversity * Watershed degradation
Extensively managed marginal lands	Immigration and land-clearing for low input agriculture	* Soil erosion from land-clearing * Soil erosion from crop/livestock production * Soil nutrient depletion * Weed infestation * Biological degradation from topsoil removal	* Deforestation * Loss of biodiversity * Watershed degradation
Urban and peri-urban agricultural lands	Rapid urbanization; diversification of urban food markets; rise in urban provery	* Soil erosion from poort agricultural practices * Soil contamination from urban polutants * Overgrazing and compaction	* Water pollution * Air pollution * Human disease vectors

Irrigation brought myriad changes in land husbandry practices, increased multiple cropping, new purchased inputs (hybrid varieties, chemical inputs), land leveling, and new forms of local organization. While yields and production have increased markedly, some soils have also degraded, particularly due to poor management of water causing salinization and waterlogging, but also more subtle nutrient management problems which have slowed down yield increases in recent years. High fertilizer and pesticide applications have often contaminated water supplies.

High-Quality Rainfed Lands

"High-quality" rainfed lands are located mainly in areas with naturally deep, fertile, and less-weathered soils: temperate zones (for example, Argentina, southern Brazil, Chile, South Africa); volcanic regions in the tropical highlands (for example, the East African highlands, Java); and tropical regions with vertisols and alfisols (for example, South Asia, West African savannahs). These lands account for about 605 million hectares, or 23 percent of arable and grazing lands in developing countries, and, with irrigated lands, for about 35 percent of the rural population (Nelson et al. 1997).

In these prime rainfed lands, farmers have greatly increased cropping intensity, even where permanent agriculture had already been the norm. The Green Revolution—which brought increased use of hybrids, increased chemical use, mechanization, and a trend toward monocropping—also played a pivotal role in these areas. In some cases, inappropriate use of machinery has led to soil compaction; poor vegetation management has exposed soils to erosion; and substitution of organic inputs with chemical fertilizers has led to declining organic matter and acidification of vulnerable soils.

Densely Populated Marginal Lands

Most agricultural land area in developing countries falls outside the category of high-quality, relatively resilient irrigated and rainfed land. These "marginal" lands, which have lower-quality or degradation-prone soils, and are subject to harsher and more variable climates, account for about 69 percent of arable and grazing lands and 65 percent of rural population[6] (Nelson et al. 1997). They are associated with two contrasting pathways, distinguished by rural population density.

Large areas of long-settled marginal lands are now under intensive crop production as a result of high and rapidly growing rural population and development of agricultural markets. Cultivation has spread into landscape niches, such as steep slopes, with poorer and more vulnerable soils. Human settlements compete for use of agricultural lands. External inputs are often less available, more costly, and less profitable than in the high-potential areas, and intensive farming practices (typically borrowed from high-potential areas) are often not adapted to marginal environmental conditions. Overexploitation for subsistence and commercial uses has led to loss of vegetation for soil cover. Soil erosion and nutrient depletion are common, though there is evidence that intensification has sometimes led to greater use of soil-protecting practices (Tiffen, Mortimore, and Gichuki 1994; Clay, Reardon, and Kangasniemi 1998; Turner, Hyden, and Kates 1993; Reij, Scoones, and Toulmin 1996; and Templeton and Scherr 1997).

Extensive Agriculture in Marginal Lands

Other marginal lands—commonly considered the "agricultural frontier"—have much lower populations. As land is relatively abundant, it is managed using labor-extensive practices such as long crop fallows or extensive grazing.

In the 1950s, it was estimated that around 200 million people on 14 million square miles (10 percent of the world's population on 30 percent of exploitable soils) were practicing shifting cultivation (Nye and Greenland 1960). Between the early 1960s and the mid-1990s, land area under annual crops increased by 19 million hectares in Asia, 28 million in South America, and 31 million in Africa. Area under permanent pastures expanded even more in aggregate terms, while total forest and woodland area declined, especially in Asia and South America (FAO 1995). It is estimated that 200 million landless people have migrated to tropical forests since the 1960s, and that as many as 500 million people—most of them poor—now use shifting cultivation systems (ASB undated).

Most of the land claimed from these frontier areas has lower intrinsic soil quality or poses higher production risks due to factors such as steep slopes and very high or very low rainfall. Population densities in these areas are relatively low, infrastructure limited, and market development weak. Soils are degraded by the land-clearing process itself, by decreasing fallow periods that deplete nutrients, and by widespread burning to control weeds and pests and provide ash for plant nutrition. Large areas have been abandoned due to nutrient and organic matter depletion and weeds. In Southeast Asia, *Imperata* grass now covers 40 million hectares; in the Amazon there are an estimated 20 million hectares of degraded pastures (ASB undated). There are few economic incentives for investing in land improvement, because land is still relatively abundant, of low market value, and often available without secure land rights.

Urban and Peri-Urban Agricultural Land

During the 1980s, the importance of urban agriculture accelerated dramatically throughout the

[6] "Densely populated" is used here as a relative term indicating population pressure on arable lands from smallholder farming using short-fallow or permanent cultivation systems. Actual densities may be as low as 30 per square kilometer in areas with lots of unusable and low-quality land, or as high as 1,000 per square kilometer. The term "marginal lands" is conventionally used. However, readers should remember that lands are typically defined as "marginal" for the purpose of plow-based grain cultivation. These lands may be superior production sites for other types of products or production systems.

world. The Urban Agriculture Network has estimated that by the early 1990s, approximately 800 million people globally were actively engaged in urban agriculture, of whom 200 million were farmers producing for sale on the market (many part time). Evidence from eight African and three Asian countries showed 33–80 percent of urban families engaged in food, horticultural, or livestock production. Low-income urban residents, who would otherwise spend a very high proportion of their income on food, typically engage in agriculture to increase their food security, income levels, and sometimes the nutritional quality of their food. Middle- and high-income urban farmers grow food mainly to improve diet quality or supplement incomes with high-value crops (Cheema et al. 1996, Tables 2.1 and 3.1).

Contrary to popular belief, a high proportion of urban land is available for agriculture.[7] In Beria, Mozambique, 88 percent of the city's "green spaces" are used for family agriculture. Large areas of many cities are so used: Beijing (28 percent of the city); Zaria, Nigeria (66 percent); Hong Kong (10 percent); Bangkok (60 percent of the metropolitan area); and San José, Costa Rica (60 percent of the metropolitan area). Farmers may borrow, rent, or squat on the land they farm.

Global Effects of Soil Degradation

The land surface of the earth totals 13.0 billion hectares, of which 1.5 billion are unused wasteland and 2.8 billion are unused but largely inaccessible (Oldeman 1994). Of the 8.7 billion hectares under use, most is suitable only for forest, woodland, grassland, or permanent vegetation. Only 3.2 billion hectares are potentially arable. About half of this potentially arable land is currently cropped and 41 percent is considered moderately to highly productive (Table 4).

Table 4—Global supply and use of land

Type of land	Area
	(billion hectares)
Total ice-free land area in the world	13.4
Total land area without water bodies	13.0
Land used	8.7
Potentially arable land	3.2
Moderately to highly productive	1.3
Low productive land	1.9
Current use of potentially arable land	3.2
Cropland	1.5
Permanent pasture, forest, and woodland	1.7

Source: Buringh and Dudal 1987. Data for total land area without water bodies and land used are from Oldeman 1994.
Note: Potentially arable land is defined as land that can be cultivated or maintained in permanent pasture or both.

The 16 studies reviewed below assess the global extent, rate, and effects of soil degradation. Their data suggest that soil quality on three-quarters of the world's agricultural land has been relatively stable since the middle of the twentieth century. On the rest, however, soil degradation is widespread and the pace of degradation has accelerated in the past 50 years. Productivity has declined substantially on approximately 16 percent of agricultural land in developing countries, especially on cropland in Africa and Central America, pasture in Africa, and forests in Central America. Large land areas of 5 to 8 million hectares have gone out of production each year. Increased land in production and under irrigation, increased productivity through new varieties and inputs, and improved marketing systems have compensated for some productivity losses caused by degradation. But in the specific regions, countries, and subregions where it is widespread, the economic and welfare effects of soil degradation pose pressing policy challenges.

[7] Horticulture takes place in homesites, parks, rights-of-way, rooftops, containers, wetlands, and greenhouses. Livestock are produced in zero-grazing systems, rights-of-way, hillsides, coops, peri-urban areas, and open spaces. Agroforestry is practiced using street trees, homesites, steep slopes, within vineyards, greenbelts, wetlands, orchards, forest parks, and hedgerows. Aquaculture is practiced in ponds, streams, cages, estuaries, sewage tanks, lagoons, and wetlands. Food crops are grown in homesites, vacant building lots, rights-of-way for electric lines, schoolyards, church yards, and the unbuilt land around factories, ports, airports, and hospitals (Cheema et al. 1996, Table 5.1).

Historical Soil Degradation

There is historical evidence of large-scale soil degradation in many parts of the world in the past 5,000 years (Hillel 1991; Hyams 1952). UNEP (1986) calculated that 2 billion hectares of land that was once biologically productive has been irreversibly degraded in the past 1,000 years. Rozanov, Targulian, and Orlov's (1990) analysis of global changes in the humusphere found that there has been a loss of humus at a rate of 25.3 million tons per year on average ever since agriculture began 10,000 years ago. This loss accelerated to 300 million tons per year in the past 300 years and 760 million tons per year in the past 50 years. Nearly 16 percent of the original stock of organic soil carbon may have been lost. Within the past 300 years, 100 million hectares of irrigated land alone apparently have been destroyed and another 110 million hectares have come to suffer from diminished productivity due to secondary salinization. The amount of land thus affected is nearly equivalent to the 220 million hectares of global irrigated area in 1984. Rozanov, Targulian, and Orlov conclude that more productive land may have been irreversibly lost in the past 10,000 years than is currently under agricultural production.

Extent of Degradation

During the past half century, soil degradation concerns have focused principally on soil erosion. The earliest reports typically were cast in terms of tons of soil lost,[8] a measure difficult to use for policy assessment. The Global Assessment of Soil Degradation (GLASOD), based on a formal survey of regional experts, was the first worldwide comparative analysis to focus specifically on soil degradation (Oldeman 1994). GLASOD was designed to provide continental estimates of the extent and severity of degradation from World War II to 1990.[9] The study concluded that 1.97 billion hectares—23 percent of globally used land—had been degraded.

Thirty-eight percent of all agricultural land had become degraded, along with 21 percent of permanent pasture and 18 percent of forests and woodland (Table 5). Nine percent of all cropland, pasture, and woodland was lightly degraded in 1990; 10 percent was moderately degraded, implying a large decline in productivity; and 4 percent was strongly degraded, implying a virtual loss in productive potential. Water erosion caused the most degradation, followed by wind erosion, soil nutrient depletion, and salinization (Tables 6 and 7). Overgrazing was the leading proximate cause, followed by deforestation and agricultural activity.

Of all degraded soils, 58 percent were in drylands and 42 percent in humid areas.[10] For the tropics alone, 915 million hectares had been degraded by water erosion, 474 million by wind erosion, 239 million by chemical degradation and 50 million by physical degradation (Lal 1994, using GLASOD data). Estimates show that nearly 20 percent of 1.1 billion hectares of global dryland soils have been degraded. This is well below estimates from Dregne and Chou's (1992) comprehensive review of literature on dryland degradation (including degradation of soil as well as vegetation and nonagricultural soil functions). They found that more than 70 percent of drylands in Africa, Asia, and South America are degraded—30 percent of irrigated drylands, 47 percent of rainfed drylands, and 73 percent of rangelands.

[8] For example, Judson (1968) estimated that 14.7 billion tons of soil were lost annually due to human-induced soil erosion, in addition to 9.3 billion tons due to natural processes. Brown (1984) extrapolated from data for the United States, USSR, China, and India to conclude that one-third to one-half of global cropland had "excess" soil loss from erosion beyond a sustainable level.

[9] The objective of GLASOD was to create awareness about the status of soil degradation. Over 250 soil and environmental scientists cooperated in preparing 21 regional maps of human-induced soil degradation, using a common methodology. Following delineation of physiographic units with homogeneous topography, climate, soils, vegetation, and land use, each unit was evaluated for its degree, relative extent, and recent past rate of degradation, as well as for the forms of human intervention causing degradation. Types of degradation were ranked in importance. Map segments were compiled and reduced to the final 1:10 million scale of the GLASOD map. The map units were digitized and linked to a GLASOD database to calculate the areal extent of degradation. Since the maps rely on expert evaluation, they may reflect unsubstantiated biases and assumptions.

[10] "Dryland" was defined as climatic regions with annual precipitation/evapo-transpiration ratio of ≤ 0.65; "humid" are those regions with less than 0.65.

Table 5 —Global estimates of soil degradation, by region and land use

Region	Agricultural land			Permanent pasture			Forests and woodland			All used land				
	Total	Degraded	Percent	Total	Degraded	Percent	Total	Degraded	Percent	Total	Degraded	Percent	Seriously degraded	Percent
	(million hectares)			(million hectares)			(million hectares)			(million hectares)			(million hectares)	
Africa	187	121	65	793	243	31	683	130	19	1,663	494	30	321	19
Asia	536	206	38	978	197	20	1,273	344	27	2,787	747	27	453	16
South America	142	64	45	478	68	14	896	112	13	1,516	244	16	139	9
Central America	38	28	74	94	10	11	66	25	38	198	63	32	61	31
North America	236	63	26	274	29	11	621	4	1	1,131	96	9	79	7
Europe	287	72	25	156	54	35	353	92	26	796	218	27	158	20
Oceania	49	8	16	439	84	19	156	12	8	644	104	17	6	1
World	1,475	562	38	3,212	685	21	4,048	719	18	8,735	1,966	23	1,216	14

Sources: For all totals, FAO 1990, and for others, Oldeman, Hakkeling, and Sombroek 1991.

Notes: The last two columns refer only to land that is moderately, strongly, or extremely degraded. In the GLASOD study "lightly degraded soil" is defined as having somewhat reduced agricultural suitability, but is suitable in local farming systems. Original biotic functions are still largely intact, and restoration to full productivity is possible through modifications in farm management. "Moderately degraded soil" is soil that offers greatly reduced productivity, but is still suitable for use in local farming systems. Major improvements are needed that are typically beyond the means of local farmers; the original biotic functions are partially destroyed. In "strongly degraded soil" productivity is virtually lost and soil is not suitable for use in local farming systems; the original biotic functions are largely destroyed. Major investments and/or engineering works would be needed to restore land to full productivity. "Extremely degraded soil" is defined as a "human-induced wasteland," unreclaimable, beyond restoration, and with biotic functions that are fully destroyed. Data for permanent pasture and forests and woodland include arable and nonarable land.

Table 6—Global extent of chemical and physical soil degradation, by region

Region	Chemically degraded area				Physically degraded area			Total degraded land	Total degraded land as percent of total land used
	Loss of nutrients	Salinization	Pollution	Acidification	Compaction, sealing, and crusting	Water-logging	Loss of organic matter		
	(million hectares)								
Africa	45	15	+	1	18	1	–	81	4.8
Asia	15	53	2	4	10	+	2	86	3.0
South America	68	2	–	–	4	4	–	78	5.1
Central America	4	2	+	–	+	5	–	12	6.0
North America	–	+	+	+	1	–	–	1	+
Europe	3	4	19	+	33	1	2	62	7.7
Australia	+	1	–	–	2	–	–	3	
World	136	77	21	6	68	11	4	323	3.7

Source: Oldeman, Hakkeling, and Sombroek 1991.

Note: Degradation figures include data for slightly, moderately, strongly, and extremely degraded lands. Plus sign means negligible; minus sign means none reported.

Table 7—Global extent of soil degradation due to erosion, by region

Region	Area eroded by water erosion: Light	Moderate	Strong and extreme	Total	Area eroded by wind erosion: Light	Moderate	Strong and extreme	Total	Total area eroded	Total area seriously eroded	Total area seriously eroded as a percent of total land used
	(million hectares)										
Africa	58	67	102	227	88	89	9	186	413	267	16
Asia	124	242	73	441	132	75	15	222	663	405	15
South America	46	65	12	123	26	16	. . .	42	165	93	6
Central America	1	22	23	46	246	4	1	5	51	50	25
North America	14	46	. . .	60	3	31	1	35	95	78	7
Europe	21	81	12	114	3	38	1	42	156	132	17
Oceania	79	3	222	83	16	. . .	27	16	99	3	3
World	343	526	223	1,094	269	254	26	548	1,642	1,029	12

Source: Oldeman, Hakkeling, and Sombroek 1991.

Notes: The last two columns refer only to land that is moderately, strongly, or extremely degraded. In the GLASOD study "lightly degraded soil" is defined as having somewhat reduced agricultural suitability, but is suitable in local farming systems. Original biotic functions are still largely intact, and restoration to full productivity is possible through modifications in farm management. "Moderately degraded soil" is soil that offers greatly reduced productivity, but is still suitable for use in local farming systems. Major improvements are needed that are typically beyond the means of local farmers; the original biotic functions are partially destroyed. In "strongly degraded soil" productivity is virtually lost and not suitable for use in local farming systems; the original biotic functions are largely destroyed. Major investments and/or engineering works would be needed to restore land to full productivity. "Extremely degraded soil" is defined as a "human-induced wasteland," unreclaimable, beyond restoration, and with biotic functions that are fully destroyed. Ellipses indicate negligible amounts.

Effects on Productivity

Data on the effects of degradation on global productivity are necessarily very rough. Pimentel, Allen, and Beers (1993) estimate, based on available secondary data, that global production is 15–30 percent lower as a result of all the various effects of soil erosion. Buringh and Dudal's (1987) estimates are even higher. Using an International Institute for Advanced Systems Analysis (IIASA) model that assumes no soil conservation, they predicted that just between 1984 and 2000, 22 percent of the more productive crop, pasture, and forest land—including 14 percent of the most productive soils—would be degraded. Erosion-induced soil nutrient depletion would result in a 29 percent decline in rainfed crop production and a 19 percent loss in total potential production (South America would lose 10 percent, Africa 17 percent, Southwest Asia 20 percent, Central America 30 percent, and Southeast Asia 36 percent).

Other figures for the effects on global productivity, based more on empirical evidence, are much lower. Dregne and Chou (1992) estimate that more than a third of irrigated land in Asia and more than half of rainfed land in Africa and Asia had experienced a 10 percent loss in productive potential, while 8 percent of irrigated and 10 percent of rainfed land in Asia had experienced at least a 25 percent loss in potential productivity, with lower incidence elsewhere. They estimated that over half the rangelands had experienced more than 50 percent loss in potential productivity. Using GLASOD data, Crosson (1995b) estimated an aggregate global loss of 11.9–13.4 percent of agricultural supply, assuming a 15 percent, 35 percent, and 75 percent yield decline, respectively, for light, moderate, and strongly degraded cropland soils, and a 5 percent, 18 percent, and 50 percent decline for pasture soils. Global production would be 12–13 percent higher if the 15 percent of strongly and extremely degraded lands were restored to full productivity. Oldeman (1998) used Crosson's coefficients to calculate that global cropland production was 12.7 percent lower and pasture production 3.8 percent lower than they would have been without degradation, for a total agricultural loss of 4.8 percent. With higher estimates of pasture yield decline, global loss increases to 8.9 percent (Table 8).

Economic Effects

While environmental economists have used resource valuation techniques to estimate the global value of other natural resources, no such studies are available for soil (Costanza et al. 1997). Early crude estimates of the annual cost of soil erosion hovered around U.S.$26 billion, about half the cost borne by developing countries (UNEP 1980). A decade later, Dregne and Chou (1992) proposed $28 billion per year as the cost of dryland degradation. Pimentel, Allen, and Beers (1993) valued the plant nutrients lost annually just through sediment loss and nitrogen in water runoff at $5 billion, or 0.4 percent of the annual global value added in agriculture.

Effects on Consumption by Poor Farmers

There has been no global mapping of the relationship between poverty and soil quality or soil degradation. However, a number of factors suggest that soil degradation affects the rural poor in a particularly negative way. Studies in Asia and West Africa in the 1980s (reviewed in Malik 1998) found that the rural poor were more dependent on agriculture than the nonpoor. The poor depended more on annual crops, which typically degrade soils more than other crops. They also relied more on common property lands, which tend to suffer greater degradation than privately managed land. When the principal assets of the poor comprise low-productivity or degrading lands, and their ability to seek more remunerative livelihood options is restricted by economic, political, or social conditions, they may fall into a poverty "trap," in which they lack sufficient assets to undertake the land husbandry and investment necessary to maintain or increase productivity (Malik 1998). The poor tend to be "pushed" to marginal lands by political forces, expulsion of squatters from higher-quality lands during modernization, or the inability to compete for higher-quality land. Because the poor use fewer inputs, they rely more on intrinsic soil quality.

Poverty may also exacerbate degradation when poor people can meet subsistence food, feed, and fuel needs only through overexploitation of natural vegetation and consumption of organic residues from farming and livestock-keeping that would otherwise help replenish the soil. The poor play a significant role in expansion of farming into marginal

Table 8—Average cumulative loss of productivity during the post-Second World War period as a result of human-induced soil degradation, worldwide and by region

Region	Cropland	Pasture land	Crops and pastures (low estimates of impact)	Crops and pastures (high estimates of impact)
			(percent)	
Africa	25.0	6.6	8.1	14.2
Asia	12.8	3.6	4.7	8.9
South America	13.9	2.2	4.1	6.7
Central America	36.8	3.3	8.7	14.5
North America	8.8	1.8	3.0	5.8
Europe	7.9	5.6	4.6	9.0
Oceania	3.2	1.1	1.2	3.2
World	12.7	3.8	4.8	8.9

Source: Oldeman 1998, 4, Table 1.

Notes: These figures were calculated by multiplying the area by a coefficient of yield loss for each soil degradation category. In the case of cropland, the coefficients were 15 percent loss for "light" soil degradation, 35 percent for "moderate," 75 percent for "strong," and 100 percent for "extreme" degradation. In the case of pasture land, the corresponding coefficients were 5 percent for light, 18 percent moderate, and 50 percent strong. For combined crop and pasture land, two different sets of coefficients were used: 5 percent for light, 18 percent for moderate, 50 percent for strong, for pastures; and 15, 35, and 75 percent, respectively, for cropland.

lands, especially when nonfarm employment opportunities decline. Thus a negatively reinforcing relation between poverty and soil degradation can develop. There is also evidence, however, that poor farmers may respond effectively to soil degradation, both to reverse degradation and to cushion its effects on their livelihoods (Scherr 1999).[11]

Agricultural Land Loss

Estimates of the annual rate of loss of agricultural land due to degradation range from 5 to 12 million hectares, or about 0.3 to 1.0 percent of the world's arable land. On the higher end are Lal and Stewart (1990), who estimated that 12 million hectares were being destroyed and abandoned annually. UNEP (1986) estimated that 6 million hectares were being lost each year through desertification processes. GLASOD calculated that since the mid-1940s 5–6 million hectares per year had been permanently lost to agriculture through human-induced soil degradation, a rate (0.3–0.5 percent of the world's arable land area) comparable to earlier estimates by Dudal (1982). Rozanov, Targulian, and Orlov (1990) estimated that 6–7 million hectares per year are being irreversibly lost.

Effects of Soil Degradation in South and Southeast Asia

Regional studies and studies for Bangladesh, China, India, Indonesia, and Pakistan show that soil degradation—mainly from nutrient depletion and salinization—has a significant effect on national agricultural supply in South and Southeast Asia. Estimates of the total annual economic loss from soil degradation range from under 1 to 7 percent of agricultural gross domestic product (AGDP). Given that more than half of all land is *not* affected by degradation, the economic effects in the degrading areas would appear to be quite serious.

Extent of Degradation

The extent of soil degradation in Asia was evaluated in five major studies in the 1980s and 1990s. A literature review by FAO (1986) found that 31 percent of the total land area in 13 Asian-Pacific countries was degraded, with the highest incidence ($\geq$30 percent) in China, India, Laos, Thailand, and Viet Nam, and the lowest incidence (<10 percent) in Tonga, Bangladesh, and Myanmar (Table 9). The main hazard was soil nutrient depletion, though waterlogging and salinity also posed significant problems.

Dregne and Chou's (1992) literature review of dryland degradation concluded that 71 percent of Asian drylands are degraded, and 39 percent "severely" so. They estimated that degradation affected 35 percent of irrigated lands, 56 percent of dry rainfed lands, and 76 percent of rangelands.

Young (1993) and national soil experts in eight South Asian countries[12] revised the continental GLASOD figures, incorporating the best available national data. GLASOD data indicated that a total of 43 percent of the agricultural land in these eight countries was affected by some type of degradation. Most nondegraded land was either in rainfed lands of the humid zone or irrigated alluvial areas in both humid and dry zones. The revised figures showed that 25 percent of the region's agricultural land had been degraded by water erosion, of which 60 percent was moderately or strongly degraded (that is, costly or nearly impossible to reverse). Another 18 percent had been degraded by wind erosion (of which 77 percent was moderately or strongly degraded), and 13 percent by soil fertility decline (less than 10 percent was moderate or severe). Two percent was degraded by waterlogging (three quarters was moderate or severe), 9 percent by salinization (72 percent moderate or severe), and 6 percent by lowering of the water table (40 percent was moderate).

Using a more detailed and nationally representative GLASOD-type methodology, however, the Assessment of Human-Induced Soil Degradation in

[11]Wealthier farmers, agricultural investors, and multinational corporations typically control more total land area than the poor, and play a prominent role in large-scale clearing of natural vegetation, overuse of agrochemicals, large-scale degradation of grazing lands, and overexploitation of soils for commercial production.

[12] Afghanistan, Bangladesh, Bhutan, India, Iran, Nepal, Pakistan, and Sri Lanka.

Table 9—Degraded cropland in selected countries in the Asian-Pacific region

Country	Total land area	Arable and permanent cropland	Arable and permanent cropland as a percent of total land area	Total degraded land	Total degraded land as a percent of total land area
	(thousand hectares)			(thousand hectares)	
Bangladesh	13,017	9,292	71	989	7.4
China	932,641	96,115	10	280,000	30.0
India	297,319	168,990	57	148,100	49.8
Indonesia	181,157	21,260	12	43,000	24.0
Laos	23,080	901	4	8,100	35.0
Myanmar	65,754	10,034	15	210	3.2
Pakistan	77,088	20,730	27	15,500	17.3
Philippines	29,817	7,970	27	5,000	16.8
Samoa, Western	283	122	43	32	11.3
Sri Lanka	6,463	1,901	29	700	10.8
Thailand	51,089	22,126	43	17,200	33.7
Tonga	72	48	67	3	4.5
Viet Nam	32,549	6,600	20	15,900	48.9
Asian-Pacific region	1,710,329	366,089	21	534,734	31.3

Source: Watershed Management in Asia and the Pacific: Needs and Opportunities for Action, Technical Report FO:RAS/85/017, FAO, Rome, 1986 (cited in FAO 1992). Arable and permanent cropland data are for 1989.

South and Southeast Asia (ASSOD), found 20 times greater decline in soil fertility and organic matter, triple the extent of salinization, and nearly 100 times the extent of waterlogging than in the GLASOD study (van Lynden and Oldeman 1997; also see Table 10). Agricultural activity had led to degradation on 27 percent of all land and deforestation on 11 percent; overgrazing played a minor role.

ASSOD collaborators collected data on type of farm management for nearly half of the degraded land. They found little association between land management and degradation: 38 percent of degraded lands were under a high level of management, 36 percent under medium management, and 25 percent under low management (defined as “traditional” systems existing for more than 25 years). In recent years, however, degradation increased more often under low and medium management.

Two unique historical data sets based on soil surveys dating from the 1940s recently became available for China and Indonesia. These data suggest that nutrient depletion may not have been as severe since the 1940s as commonly assumed (Lindert forthcoming a and b; Lindert, Lu, and Wanli 1996a and 1996b). The researchers found declines in organic matter and nitrogen in Java and North China, with a rise in total phosphorus and potassium in Java. There was little overall change in nutrient status in South China over the period. Cropping intensity correlated with nutrient depletion; erosion appeared to have had a minor effect on soil degradation.

Agricultural Supply

Dregne (1992) concluded in a literature review that well-confirmed instances existed of permanent soil productivity loss of at least 20 percent due to human-induced water erosion in significant areas of China, India, Iran, Israel, Jordan, Lebanon, Nepal, and Pakistan. Strong presumptive evidence of such effects existed in Indonesia, the Philippines, Syria, Thailand, and the Caucasus region. He concluded that wind erosion, while widespread in dry areas, had not had much effect on long-term soil productivity.

Using the GLASOD data, Oldeman (1998) calculated that since World War II soil degradation in Asia had led to a cumulative loss of productivity in cropland of 12.8 percent, and 4.7–8.9 percent loss in cropland and pastures together (Table 8).

ASSOD data showed major, irreversible productivity loss[13] (that is, strong or extreme degradation) only in small areas. However, moderate degradation was found on a tenth of all lands, and serious fertility decline or salinization on more than 15 percent of arable land (van Lynden and Oldeman 1997, Table 4.5). In South and Southeast Asia, 11 percent of agricultural land had badly degraded soils. In terms of proportion of land area, degradation was reported to be most serious (more than 20 percent of land badly degraded) in India, Pakistan, the Philippines, and Thailand.

Studies in China found that degradation had reduced grain yields. One calculated that for the period

Table 10—ASSOD estimates of the area and effect of soil degradation in South and Southeast Asia

Type of degradation	Land degraded by degree of degradation: Nondegraded or negligible	Light	Moderate	Strong or extreme	Degraded land as a percent of total land
	(percent)				
Loss of topsoil from water erosion	84.3	9.5	5.3	0.9	15.7
Terrain deformation from water erosion	95.1	1.2	0.9	1.8	4.9
Off-site effects in uplands from water erosion	99.7	0.2	. . .	0.6	0.3
Topsoil loss from wind erosion	94.6	4.0	0.9	0.4	5.4
Terrain deformation from wind erosion	95.8	0.4	0.6	3.2	4.2
Off-site effects from wind erosion	99.2	0.1	0.5	0.2	0.8
Fertility decline					
Total land	93.8	3.7	2.4	0.1	6.2
(Arable land)	(69.6)	(18.0)	(11.9)	(0.5)	(30.4)
Salinization					
Total land	97.9	1.1	0.8	0.2	2.1
(Arable land)	(89.8)	(5.5)	(3.8)	(0.9)	(10.2)
Dystrification					
(Arable land)	(99.3)	(0.5)	(0.2)	. . .	(0.7)
Aridification					
Total land	98.7	1.3	. . .	. . .	1.3
(Arable land)	(93.3)	(6.3)	. . .	(0.4)	(6.7)
Compaction					
Total land	99.9	0.1	. . .	. . .	0.1
(Arable land)	(98.7)	(0.8)	(0.4)	. . .	(1.3)
Waterlogging					
Total land	99.6	1.0	0.3	0.1	1.4
(Arable land)	(92.9)	(5.0)	(1.4)	(0.7)	(7.1)

Source: van Lynden and Oldeman 1997.

Notes: Estimates of arable land degradation were calculated by the author using FAO data on total arable land area, and assuming that all land reported by ASSOD with these types of degradation were arable lands. This is generally but not always true, and thus these figures may overestimate soil degradation on arable lands. ASSOD stands for Assessment of Human-Induced Soil Degradation in South and Southeast Asia. The total area surveyed was 1,843.4 million hectares. The total area of arable land reported by the Food and Agriculture Organization of the United Nations was 380 million hectares (20.6 percent). "Light" degradation implies little impact on productivity. "Moderate" implies major impact and a need to compensate for degradation with high management. Medium management does not compensate and low management leads to significant productivity decline. "Strong" or "extreme" implies a major impact on productivity that cannot be compensated for even with high levels of management and is unproductive under low management. Ellipses indicate negligible amounts.

[13] Changes in productivity were expressed in relative terms, that is, the current average productivity compared to the average productivity in the nondegraded situation, assuming a given input use. For instance, if yield averaged 2 tons of rice per hectare previously, but only 1.5 tons at present, despite high inputs (and all other factors being equal), "strong" degradation was present (van Lynden and Oldeman 1997, 8–9). "Moderate" degradation indicates either that no change in production had occurred despite high management levels, that a small decrease had occurred despite medium management, or that a large decrease had occurred under low management.

1983–89, total grain production would have been 60 percent higher in the absence of a deteriorating environment. Increased floods and drought caused 30 percent of this yield loss, erosion 19 percent, salinity 0.2 percent, and increased multiple-cropping intensity 11 percent. Environmental degradation during the period cost the country as much as 5.6 million metric tons of grain per year—a figure equivalent to nearly 30 percent of China's yearly grain imports in the early 1990s. Without the effects of a deteriorating environment, mostly erosion, rice yields would have grown 12 percent faster in the late 1980s and early 1990s. Erosion affected maize, wheat, and cash crops in North China the most, reducing production by up to 20 percent in the 1980s and 1990s (Huang and Rozelle 1994 and 1996; Huang, Rosegrant, and Rozelle 1996). A grain-yield function estimated for 1975–90, pooling data for 23 provinces, found yield to be significantly influenced by degradation, with elasticities of grain yield of –0.146 for soil erosion, –0.003 for salinization, and –0.276 for multiple cropping intensity. The latter elasticity was probably due to nutrient depletion (Huang and Rozelle 1994 and 1996).

For India, Sehgal and Abrol (1994) synthesized the results of national soil surveys, a survey of national soil experts, and crop experimental data to estimate the scale and productivity effects of soil degradation. They concluded that although no significant degradation affects 36 percent of the land area in India, 5 percent of the land is suffering from low degradation (less than 15 percent loss in yield), 11 percent from moderate degradation (15–33 percent loss), 43 percent from high degradation (33–67 percent loss), and 5 percent had become so degraded that soils were unusable.

A 1985–86 household- and plot-level study in four villages in Uttar Pradesh, India, found significant effects of salinization and waterlogging on productivity over the preceding 10-year period (Joshi and Jha 1991). Paddy yield declined by 61 percent and wheat yield by 68 percent on salt-affected soils. The average yield of high-yielding paddy varieties on alkaline plots decreased by 51 percent and local varieties by 46 percent. Under waterlogged conditions, the corresponding figures were 41 percent and 26 percent. Alkalinity accounted for as much as 72 percent of the difference in gross income between normal and salt-affected plots; the other 23–28 percent could be attributed to reduced input use on degraded soils (Joshi and Jha 1991).

Ali and Byerlee (1998) used district-level data for 33 crops, 8 livestock products, and 17 input categories to estimate changes in total factor productivity from 1971 to 1994 in 4 irrigated production systems of Punjab province, Pakistan. Average annual growth in total factor productivity was moderately high, at 1.25 percent for both crops and livestock, but wide regional variation in productivity growth was observed, with negative growth in the wheat-rice system. A second disaggregated data set on soil and water quality was then used to analyze underlying effects of resource degradation through application of a cost function. Ali and Byerlee found that continuous and widespread resource degradation lowered productivity growth in the province by about 58 percent on average. The largest effect was in the wheat-rice system, where resource degradation more than offset the productivity effects of technological change.

More subtle types of degradation in Asia's intensive, irrigated agricultural systems are a growing concern in the scientific community (Olk et al. 1996; Cassman and Harwood 1995). Long-term experiments on plots representing the major farming systems in India found mixed evidence. There were negative trends in soil productivity without the use of farmyard manure, and flat trends with manure, in an annual, double-crop, irrigated rice system in the warm, subhumid tropics of Orissa. In the warm, subhumid subtropics of Uttar Pradesh, an irrigated rice-wheat system showed negative soil productivity trends for rice and flat trends for wheat. In the warm semiarid subtropics of the Punjab, a maize-wheat cropping system showed flat productivity trends for maize and positive for wheat (Cassman, Steiner, and Johnson 1995).

Agricultural Income and Economic Growth

Young (1993) estimated the annual cost of soil degradation in South Asia at $9.8–$11.0 billion, the equivalent of 7 percent of AGDP. Water and wind erosion accounted for more than two thirds of the loss, salinization and waterlogging for about a fifth, and soil fertility decline the rest. In Pakistan, the value of reduced wheat production due to waterlogging and salinization in 1993 equaled about 5 percent of AGDP, while in India, annual cereal production loss amounted to about 5 percent of AGDP. Pagiola (1995) concluded that total factor productivity in Bangladesh had declined between 1975 and 1985 due to deteriorating nutrient balance and loss of organic matter. Significant negative trends over time were found for both farmer production and experimental plots.

The densely populated and intensively cultivated island of Java appears to have experienced high soil degradation (De Graaff and Wiersum 1992; Diemont, Smiet, and Nurdin 1991). Magrath and Arens (1989) calculated that agricultural productivity was declining by a rate of 2–5 percent a year due to soil erosion, creating annual economic losses of nearly 1 percent of the gross national product (GNP) (or approximately 3 percent of AGDP). Repetto et al. (1989) found that for two crop groups on 25 soil types, the one-year costs of erosion in Java in 1984 equaled 4 percent of the annual value of rainfed farm output—the same order of magnitude as the annual recorded growth in agricultural production in the uplands. The capitalized losses in future productivity equaled 40 percent of the total value of annual production.

Huang and Rozelle (1994 and 1996) and Huang, Rosegrant, and Rozelle (1996) calculated that the economic loss from soil degradation in China in the late 1980s reached $700 million (1990 prices)—an amount equal to China's budget for rural infrastructure investment, though less than 1 percent of AGDP. But Lindert's (forthcoming b) study showed that despite some nutrient depletion in China, the economic value of topsoil rose by nearly 8 percent between the 1950s and 1980s (4 percent in the north, 16 percent in the south). The shifts to soil-preserving products and practices largely accounted for this gain.

Consumption by Poor Farmers

None of the Asian studies analyzed the impact of soil degradation on food consumption by the poor. However, an econometric analysis of the effects of policy on soil erosion and salinization, using district-level data in China, showed that degradation had a much greater effect on poor and densely populated areas than other areas, and that general agricultural policies had a greater impact on this outcome than specific land management policies (Rozelle, Huang, and Zhang 1997).

Effects of Soil Degradation in Sub-Saharan Africa

Soil degradation is widespread in Sub-Saharan Africa. Agricultural lands are especially prone to erosion and nutrient depletion. Reported yield losses range from modest levels (2 percent decline over several decades) to catastrophic (>50 percent), depending on crop, soil type, climate, and production systems, with most studies reporting significant losses. Direct economic losses due to declining yields and lost nutrients are large in terms of the national economy, even in recent studies using more conservative methods of estimation. Several studies assessed the effects of degradation on rural poverty, but results were not consistent.

More subnational studies of the economic effects of degradation exist for Sub-Saharan Africa than for other regions. These studies are concerned mostly with marginal lands that are experiencing rapid population growth and a shift from short-fallow systems to permanent cropping, and with high-quality rainfed lands that have high population densities.

Extent of Degradation

Five continental-scale studies have assessed the extent of soil degradation in Africa. A literature review by Dregne (1990) of 33 countries found compelling evidence of serious land degradation in subregions of 13 countries: Algeria, Ethiopia, Ghana, Kenya, Lesotho, Mali, Morocco, Nigeria, Swaziland, Tanzania, Tunisia, Uganda, and Zimbabwe. In another literature review, focused on drylands only, Dregne and Chou (1992) estimated that 73 percent of drylands were degraded and 51 percent severely degraded. They concluded that 18 percent of irrigated lands, 61 percent of rainfed lands, and 74 percent of rangelands located in drylands are degraded.

The GLASOD expert survey found that 65 percent of soils on agricultural lands in Africa had become degraded since the middle of this century, as had 31 percent of permanent pastures, and 19 percent of woodlands and forests (Oldeman, Hakkeling, and Sombroek 1991). Serious degradation affected 19 percent of agricultural land. A high proportion (72 percent) of degraded land was in drylands. The most widespread cause of degradation was water erosion, followed by wind erosion, chemical degradation (three-quarters from nutrient loss, the rest from salinization), and physical degradation. Overgrazing accounted for half of all degradation, followed by agricultural activities, deforestation, and overexploitation.

Lal (1995) calculated continent-wide soil erosion rates from water using data from the mid to late 1980s, and then used these rates to compute cumulative soil erosion for 1970–90. The highest erosion rates occurred in the Maghreb region of Northwestern Africa, the East African highlands, eastern Madagascar, and parts of Southern Africa. Excluding the 42.5 percent of arid lands and deserts with no measurable water erosion, Lal found that land area affected by erosion fell into the following six classes of erosion hazard: none, 8 percent; slight, 49 percent; low, 17 percent; moderate, 7 percent; high, 13 percent; and severe, 6 percent.

Stoorvogel, Smaling, and Janssen (1993) undertook a continental-scale study of soil nutrient depletion in the early 1990s. They calculated that average annual nutrient loss on arable lands in 1982–84 amounted to 22 kilograms per hectare of nitrogen, 2.5 kilograms of phosphorus, and 15 kilograms of potassium. The main loss of nutrients occurred through the harvest and removal of the crops and inadequate use of organic and inorganic inputs. The authors extrapolated that the average nutrient loss over the past 30 years equaled 1.4 tons per hectare of urea fertilizer, 375 kilograms of triple superphosphate, and 896 kilograms of potassium chloride. Rates of nutrient depletion were especially high in densely populated and erosion-prone countries in East and Southern Africa—Ethiopia, Kenya, Malawi, and Rwanda in particular. Countries in semiarid environments, Botswana and Mali, for example, experienced low or zero depletion rates.

Subnational studies of nutrient depletion found annual losses of 112 kilograms per hectare of nitrogen, 2.5 kilograms of phosphorus, and 70 kilograms of potassium in the western Kisii highlands of Kenya; and significantly lower losses in southern Mali (Smaling 1993; Smaling, Nandwa, and Janssen 1997). Farm monitoring and modeling of nutrient cycles for the western highlands of Kenya found that more nitrogen (63 kilograms per hectare) was being lost through leaching, nitrification, and volatilization than through removal of crop harvests (43 kilograms per hectare). Depending on type of farm management practice, net nitrogen balances on cropped land varied between –39 and 110 kilograms per hectare per year, and net phosphorus balances between –7 and 31 kilograms per hectare per year (Shepherd and Soule 1998).

Agricultural Supply

Using GLASOD data, the productivity loss in Africa from soil degradation since World War II has been estimated at 25 percent for cropland and 8–14 percent for cropland and pasture together (Oldeman 1998; also see Table 8). These figures are consistent with Dregne's (1990) estimates that irreversible soil productivity losses of at least 20 percent due to erosion had occurred over the past century in large parts of Algeria, Ethiopia, Ghana, Kenya, Lesotho, Morocco, Nigeria, Southern Africa, Swaziland, Tunisia, and Uganda. More dramatic productivity declines under agricultural intensification are suggested by a review of African farm-survey and experimental data, which shows that in originally fertile lands, under continuous cropping without nutrient inputs, cereal grain yields declined from 2–4 tons per hectare to under 1 ton per hectare (Sanchez et. al. 1997).

The effects of erosion on crop productivity may be smaller, though still important. Crop yield losses in 1989 due to past erosion ranged from 2 to 40 percent, with a mean of 6.2 percent for Sub-Saharan Africa (8.2 percent for all Africa). In the absence of erosion, 3.6 million tons more of cereal (8.2 million for the continent), 6.5 million tons more of roots and tubers (9.2 million), and 0.4 million tons more of pulses (0.6 million) would have been produced in 1989 (Lal 1995).

Country-level data on productivity effects are quite varied. A study of the effects of soil erosion in Malawi (World Bank 1992a) found that annual yield loss for specific crops grown in Malawi varied from 4 to 11 percent. National- and district-level estimates for Lesotho showed negative but statistically insignificant yield declines for maize and sorghum that were associated with degradation (Bøjö 1991b). Grohs 1994 (reported in Bøjö 1996) evaluated the effects of erosion on yield across eight provinces in Zimbabwe and found no statistically significant influence of erosion on the yield trend for maize, possibly due to the overriding importance of rainfall variability in these areas. A crop growth simulation model for the Chaouia Plains in Morocco showed that erosion had a significant impact on yields only on slopes with a gradient of over 15 percent. Yields declined 20–30 percent over 50 years, but returns to wheat declined 40–50 percent (Pagiola 1994).

Field studies in three ecoregions of Tanzania that included experimental trials and field surveys of crop growth under different erosion and acidity conditions were used to construct models of soil erosion-productivity relationships. For every millimeter of topsoil depth reduction, maize yields declined by less than 1 percent to 5 percent for different soil types. Highland maize yields in four farming systems in different ecozones declined significantly, although with application of fertilizer, the decline was only half as much. Fertilizer-induced soil acidification reduced highland maize yield to zero in 20 years; with application of lime, yields dropped to half in 30 years. Cotton yields could be maintained with adequate chemical inputs; coffee yields were also stable (Aune et al. 1997; Aune 1995). A large field survey in Tanzania found that yields were 30 percent higher in the least eroded soil classes than in the most eroded classes (Kilasara et al.1995).

Agricultural Income and Economic Growth

Perhaps due to the centrality of agriculture in African economies, the economic effects of soil degradation are relatively high. Bøjö (1996) evaluated evidence on the economic losses due to soil erosion from 12 studies completed in 8 countries in Sub-Saharan Africa (Table 11). The gross annual immediate loss (the lost value of that year's production) ranged from under 1 percent of AGDP in Ethiopia, Madagascar, Mali, and South Africa, to 2–5 percent of AGDP in Ethiopia[14] and Ghana, and exceeded 8 percent in Zimbabwe. The gross discounted future loss (the value of the stream of losses due to a particular year's soil degradation) ranged from <1 percent in Ethiopia and Zimbabwe to 18 percent in Malawi. The gross discounted cumulative loss (which assumes a continued process of degradation over time), calculated for five countries, ranged from under 1 percent of AGDP to a high of 36–44 percent in Ethiopia. Except in Zimbabwe, most erosion effects were less than 5 percent of AGDP.

For Zimbabwe, using experimental data from the 1950s and 1960s on four soil types and numerous crops to derive the cost of fertilizer replacement for soil nutrients lost through depletion and erosion, Stocking (1986) concluded that nitrogen and phosphorus losses on arable lands were equal to three times the level of total fertilizer applications in 1984/85 (not including nutrients in run-off water). The total annual loss from arable land amounted to US$150 million ($5–20 per hectare), and to US$1.5 billion for all land.

Estimates of the effect of soil degradation on the broader economy in Ghana show productivity losses due to soil degradation of 2.1 percent per year in cocoa and 2.9 percent per year in all agriculture. As a result, economic growth declines by 1 percent, even with increased fertilizer use. In some scenarios, real economic growth declines up to 4.8 percent over the course of 8 years (Alfsen et al. 1997).

Household and field survey data from Rwanda illustrate farm income effects of erosion. Farm fields with higher erosion have lower marginal value product (MVP) of land—30 percent lower on the more eroded soils. The MVP for labor is 15 percent

[14] Estimates for effects of erosion in Ethiopia vary with the methodology used. Sutcliffe found the economic value of damage from soil erosion to be only a tenth of that of the 1986 Ethiopian Highlands Reclamation Study; however, he reported much higher costs from nutrient loss (Sutcliffe 1993; Bøjö 1996). Bøjö and Cassells (1995) reassessed Sutcliffe's data, concluding that net yield loss from cropland was half or less of the gross figures used in the Sutcliffe analysis, though they also emphasized nutrient depletion problems.

Table 11—Comparative analysis of national-level annual economic effects of soil erosion in Africa

Study	Country	Gross annual immediate loss	Gross discounted future loss	Gross discounted cumulative loss
			(US$ million)	
FAO (1986)	Ethiopia	14.8 (<1)	—	2,993 (44)
Sutcliffe (1993)	Ethiopia	155 (5)	15 (<1)	—
Bøjö and Cassells (1995)	Ethiopia	130 (4)	22 (<1)	2,431 (36)
Convery and Tutu (1990)	Ghana	166.4 (5)	—	—
Bøjö (1991b)	Lesotho	0.3 (<1)	3.2 (5)	31.2 (5)
World Bank (1988)	Madagascar	4.9 – 7.6 (<1)	—	—
World Bank (1992a)	Malawi	6.6 – 19.0 (3)	48 – 136 (18)	—
Bishop and Allen (1989)	Mali	2.9 – 11.6 (<1)	19.3 – 76.6 (4)	—
McKenzie (1994)	South Africa	18 (<1)	173 (4)	503 (<1)
Stocking (1986)	Zimbabwe	117 (9)	—	—
Norse and Saigal (1992)	Zimbabwe	99.5 (8)	—	—
Grohs (1994)	Zimbabwe	0.6 (<1)	6.7 (<1)	44.7 (<1)

Source: Calculations are based on Bøjö 1994 and 1996 (methods detailed by author from original studies). Costs of erosion include yield losses and value of nutrients lost through erosion.

Notes: Data in parentheses indicate percent of agricultural gross domestic product (AGDP). AGDP data are based on figures for 1992 from the World Bank (1994), inflated by 3.9 percent per year to 1994. Percentages are based on midpoint values of economic losses, where an interval is used. A dash indicates that the figure could not be calculated because data were not available.

lower on high erosion farms than on those with low erosion. Conservation investments on less degraded farms increased MVP by 27 percent. For moderately and very degraded farms, the increments were 28–34 percent and 42 percent, respectively (Clay, Reardon, and Kangasniemi 1998; Byringiro and Reardon 1996). Data from monthly farm monitoring in three districts in Kenya found that the average cost of replacing depleted soil nutrients was equivalent to 32 percent of average net farm income (Jager et al. 1998).

Consumption by Poor Farmers

Geographic information systems have been used to examine the correlation of key poverty indicators for West Africa with the GLASOD data on soil degradation and agroclimatic zones. The proportion of children who died before the age of five was highest (more than 30 percent of children) in areas with high soil degradation. A little over half of all mortality occurred in areas of high or very high degradation. Other variables, such as adult female literacy, rate of primary school enrollment, and incidence of children with stunted growth do not show a clear relation with degradation as measured by GLASOD. Poverty indexes are correlated more with agroclimatic zones. The incidence of child mortality declines moving from arid to moist subhumid climates (that is, from north to south) and adult female literacy rates and primary school enrollment rise strikingly (UNEP/GRID-Arendal 1998).

A bioeconomic linear programming model using nutrient budgets from a sample of farms in the western highlands of Kenya found that farmers with low and medium resource endowments had only 7–13 percent of the farm income of farmers with high resource endowments, due to lack of resources for soil nutrient replenishment (Shepherd and Soule 1998). However, a study based on monthly monitoring of 26 representative farms in three other districts of Kenya found no relation between net farm income and soil nutrient balance (Jager et al. 1998).

Effects of Soil Degradation in Mexico and Central America

Summarized here are two regional studies and ten national studies, all published in English. Several of these studies concern degradation in densely populated marginal lands, particularly hillsides. Agricultural supply and income effects in these areas appear to be very significant; large rural consumption effects due to degradation are implied but not documented. Policy issues include erosion and off-site effects of agrochemical use in some high quality lands in Costa Rica and Mexico. Salinization of irrigated lands in Mexico also was cited as a problem, but its effects were not documented.

Extent of Degradation

Dregne and Chou (1992) estimated that about 430 of the 570 million hectares of drylands in South America, Central America, and the Caribbean had been moderately to very severely degraded. A quarter of irrigated lands had been degraded through salinization and waterlogging, 38 percent of rainfed cropland through water erosion, and 80 percent of rangeland through degradation of natural vegetation.

The GLASOD study found that nearly a third of land in Central America (excluding Mexico) was degraded, including 74 percent of agricultural land and 38 percent of forest land, largely due to water erosion. Half of the degraded soils were moderately affected and half were strongly or severely affected (Tables 6–8).

Agricultural Supply

Using the GLASOD data, Oldeman (1998) calculated that agricultural productivity in Central America was 37 percent lower than what it would otherwise have been without soil degradation—the largest loss of any region. The cumulative loss for South America was 13.9 percent, only a little more than Asia (Table 8).

Lutz, Pagiola, and Reiche (1994) examined the potential profitability of soil conservation measures in Central America and the Caribbean. Without conservation measures, over a 10-year period, peanut yields would remain stable in the Dominican Republic; maize yields would decline by 20–25 percent in the subhumid hillsides of Honduras; bean yields also would decline by 20–25 percent in the Dominican Republic; coffee yields would decline by 10 percent in the Costa Rican highlands; maize and sorghum yields would decline by 60 percent in the hillsides of Haiti; and cocoyam yields would drop to zero in the humid lowlands of Costa Rica.

White and Jickling (1994) evaluated soil erosion effects in the humid, bimodal Central Plateau of Haiti, finding an annual yield decline in corn and sorghum of 6 percent in the first 10 years without conservation, with smaller declines thereafter. Net financial returns declined to zero after 24 years.

Cuesta (1994) compared the effect of uncontrolled soil erosion on crop production in three sites in different ecozones of Costa Rica. Highland coffee yields declined by half in 3 years and to zero in 20 years. Highland potato yields declined more slowly, by 40 percent after 50 years. Lowland cocoyam yields declined by more than half the first year and to zero in the fourth year.

These studies probably underestimate the effectiveness of farmers' soil protection practices, particularly on more erosion-resistant soils and in permanent crop fields. Pagiola and Dixon (1997) assessed the qualitative effect of soil erosion in El Salvador through a household and plot survey. Farmers reported that erosion was causing significant problems on 36 percent of fields on mild slopes, 70 percent of fields on moderate slopes, and 82 percent of fields on steep slopes. However, severe long-term productivity declines were only expected on 16 percent of fields on steep slopes and 5 percent of fields on moderate slopes.

Agricultural Income and Economic Growth

Solórzano et al. (1991) evaluated the economic effects of soil erosion in Costa Rica by measuring the cost of replacing lost nutrients. Annual replacement costs were found to equal 5.3–13.3 percent of annual value-added in agriculture in the same year.

McIntire (1994) examined typical farming situations in five tropical and eight highland or semiarid states of Mexico. Erosion led to an average estimated loss in maize production valued at 2.7 percent of AGDP, reaching 12.3 percent in some states. Economic losses were nine times higher in the highlands and semiarid regions than in the lowland tropics. Generally, losses were four times higher without than with soil conservation measures. At a 5 percent discount rate, losses were 3–4 times higher than those calculated at a 10 percent rate.

Alfsen et al. (1996) constructed a national CGE model integrating soil erosion effects for Nicaragua based on local expert assessment of productivity losses. Annual productivity loss due to erosion in 1991 was assumed to be less than 1 percent per year for bananas, rice, sugar, and vegetables; 1–2 percent per year for coffee, cotton, and sorghum; and more than 2 percent per year for sesame, maize, beans, and pasture. This level of erosion would have major national economic effects: GDP, imports, exports, and consumption in the year 2000 are projected to decrease by 4–7 percent from the baseline scenario, while total investment is projected to decrease by 9 percent.

Consumption by Poor Farmers

Few of these studies addressed the effects on farmer welfare. In a study of four villages in central Honduras, Casey and Paolisso (1996), using household surveys, soil sampling, and group interviews, found that declining household income due to soil degradation had led to reduced male labor in farming and increased off-farm labor. An increase in women's labor in maize production occurred in poor households despite declining returns to labor.

The Alfsen et al. (1996) CGE model calculated that erosion in 1991–2000 in Nicaragua would lead to a rise in the producer and domestic price indexes by 1.7 percent and 2.1 percent, respectively, compared to the 2000 baseline, while consumer price indexes would increase by 4.0–5.8 percent for different social groups. A large part of the cost of erosion is passed on from smallholders to other social classes through price effects. Assuming no unemployment in the rural sector, net urban migration would increase from 3.5 percent of urban labor supply to almost 4 percent per year.

4. Future Effects of Soil Degradation and Threats to Developing-Country Food Security

The coming quarter century will witness still another dramatic transition in agricultural production systems in the developing world. Predicting future soil degradation policy priorities, given existing data limitations and major uncertainties about key variables, is rather like gazing into a crystal ball. However, consideration of how projected trends may relate to soil quality may help to outline the major issues for monitoring and debate.

Future Trends in Agricultural Demand and Supply in Developing Countries

Changes in population, food demand, trade, technology, and climate between the present and 2020 are likely to modify many of the underlying determinants and effects of soil degradation.

Population Growth

Between 1995 and 2020, global population is expected to increase by 35 percent, reaching 7.7 billion people,[15] of whom 84 percent will be in developing countries. The population of Africa will almost double. By 2015, 94 percent of the world's rural population (3 billion people) will be in the developing countries (UN 1995 and 1996). Demand for food and other products from cultivable land will increase, and per capita landholdings in developing countries will decline from 0.3 hectare in 1990 to 0.1–0.2 hectare in 2050 (FAO 1993), to particularly low levels in Asia and North Africa, which are expected to reach such a level of land pressure by 2025 (Table 12). Demand for land for nonagricultural purposes (homesteads, infrastructure, and so on) and vegetation and water resources to meet subsistence food, fuel, and raw material needs will also rise with increasing population.

Food Demand

Food production must rise by even more than population to meet new demands expected from income growth, placing further pressure on soil resources. IFPRI's IMPACT model[16] projects that global demand for cereals will increase by 41 percent between 1993 and 2020, with 80 percent of increased demand coming from the developing countries. Meat demand is projected to increase by 63 percent, and demand for roots and tubers by 40 percent, with 90 percent of this increase coming from the developing world. Sub-Saharan Africa will generate the largest increases in demand, albeit from very low levels (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1997).

Rising incomes, urbanization, occupational changes, more advanced marketing systems, and

[15] This is the medium-variant projection of the 1996 revised United Nations projections (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1997).

[16] IMPACT is a partial equilibrium, nonspatial global trade model that represents a competitive market for 17 crop and livestock commodities covering 37 countries. It is specified as a set of particular country or regional submodels, within which supply, demand, and prices are determined. The submodels are linked through trade. Demand is a function of prices, income, and population growth. Growth in crop area and yield per hectare for each crop and country are determined by crop prices and the rate of technological change. The world price of a commodity is its market clearing point. The model links income growth in the agriculture and non-agriculture sectors. The projected yield growth rates, however, include a "best assessment" of future yield reduction due to soil degradation, taking into account the available information on past effects of soil degradation on yields and expert assessments of future effects.

Table 12—Current and projected levels of cultivable land

Region	Per capita landholdings 1990	2025
	(hectares)	
Sub-Saharan Africa	1.60	0.63
West Asia and North Africa	0.22	0.16
Rest of Asia (without China)	0.20	0.12
Central and South America	2.00	1.17

Source: Norse et al. 1992.
Note: China was not included in this analysis.

cultural changes will likely increase demand not only for meat (and cereals for animal feed), but also for fresh fruits and vegetables, fish, and processed and semi-processed foods and seasonings (Huang and Bouis 1996). These changes offer the possibility for farmers to diversify production away from the typically more erosive basic grains.

Trading Patterns

The IMPACT model projects that developing countries as a group will have annual growth in cereal production of only 1.5 percent during 1993–2020 (assuming that rates of soil degradation do not change), compared with 2.3 percent during 1982–94 (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1997). This level will be insufficient to meet the expected increase in demand. With the exception of Latin America, developing countries are projected to more than double their net imports of cereals. Demand for tropical tree products (coffee, cacao, oil palm) will grow and their production should improve soil protection, assuming production methods encourage good canopy cover and no tillage.

Some have predicted that agricultural production will move even more sharply away from the tropics because of biophysical constraints, including soil quality (Sachs 1997). However, it seems unlikely that poorer countries will develop a comparative advantage in industry or international services by 2020, and it is not clear how even the import levels projected above will be paid for, particularly by the poorer African countries.

Malnutrition and Poverty

IFPRI research suggests that prospects for a food-secure world in 2020 look bleak if the global community continues with “business as usual.” Under the most likely scenario, 150 million children under the age of six years are projected to be malnourished in 2020, just 20 percent fewer than in 1993 (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1997). One out of four children would be malnourished, down from 33 percent in 1993. Child malnutrition in Sub-Saharan Africa, however, could increase by 45 percent. A prolonged economic downturn in Asia could increase the global and regional numbers.

Before the economic downturn in Asia in 1998, growth rates for developing countries as a group were expected to be almost double those for developed countries. However, even under that optimistic scenario, unless significant and fundamental changes occur in many developing countries, disparities in income levels and growth rates both between and within countries are likely to persist. Poverty is likely to remain entrenched in South Asia and Latin America and to increase considerably in Sub-Saharan Africa (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1997). Any increase in the rate of soil degradation will significantly increase rural poverty and malnutrition rates, especially in Africa. In South Asia, the effects may be felt most by the rural landless, who depend upon farm employment. Increased rural poverty will also reduce input use, push more poor people onto marginal lands, and reduce capacity for land-improving investment.

Climatic Changes

Climatic factors are likely to increase uncertainty in agricultural production over the next few decades. Major weather fluctuations associated with El Niño (a periodic large-scale warming of the sea surface off the South American coast) have brought flooding and drought to many producing areas and reduced fish stocks (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1997). This severe weather will exacerbate soil degradation, for example, by increasing rainfall intensity in some areas and reducing vegetative cover in others.

Global warming may change soil degradation patterns. On the positive side, increasing carbon dioxide levels will increase photosynthesis and, potentially, improve vegetative cover. There may be greater precipitation in some currently water-stressed areas. However, increasing temperatures will not only have negative effects on plant growth, but accelerate soil degradation processes. In a warmer world the intensification of weather phenomena such as storms, floods, droughts, and heat spells will not only exacerbate production instability, but intensify soil degradation. Warmer temperatures in northern latitudes may extend agricultural production areas, and could increase the global importance of temperate zone agriculture (Rosenzweig and Hillel 1998).

Nontraditional Food and Fiber

Over the next few decades, it is likely that we will see some significant additions to traditional food and fiber sources arising from what are currently economically minor products. Many perennial trees, shrubs, and palms are being tested and developed for production of human foods—starchy staples, oils, and proteins, as well as fruits and vegetables. As varietal selection advances, management systems improve, and marketing systems develop, some of these foods could become economically important (Leakey and Newton 1994). These perennial plants could play a valuable role in agricultural environments that are risky for, or prone to soil degradation under, annual crops production. Many countries will rely increasingly on biomass energy, which can be produced from perennial plants on lower-value farmlands. Farm-produced timber and pulp are increasingly likely to replace natural forest sources, with potentially positive effects on soils (Dewees and Scherr 1996).

Aquaculture is already the fastest-growing food production system in the world, and prices for this food are projected to increase by 2020 (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1997). Seafood products and species that today are consumed mainly locally or regionally may develop broader markets and new uses in food processing and the food industry. In highly populated coastal areas, seafood products could substitute for distant, inland food product sources. Further development of inland aquaculture will increase political pressure for farms in upland watersheds to improve soil management to ensure high water quality for fisheries.

Technological Advances

With scientific and technological advances in soil management, the cost of sustainable, intensive crop production (or the cost of rehabilitation) could decline for many types of soils now susceptible to degradation. Brazil's increasing success in learning to manage the acid and highly weathered cerrado soils suggests that research and public investment can transform the productive potential of many of these "problem" soils. Efforts on a similar scale are needed to develop low-cost management systems accessible to poorer, small-scale producers in densely populated marginal lands. Examples are new crop varieties now being developed by the Consultative Group on International Agricultural Research (CGIAR) and their collaborators that are adapted to degraded soil conditions. These include acid- and drought-tolerant grain varieties, improved agroforestry systems for tropical forest margins, savannahs, and highlands, and sustainable hillside management systems.

The productivity and profitability of new technologies for staple food production, and their complementarity with soil-improving practices, will influence the intensification and extensification of farmland production. Advances in hydroponics, multistrata intensive gardens, and other production systems fundamentally different from plow and hoe-based agriculture may also begin to reduce the dependence of some countries on large expanses of farmland.

Infrastructure

Continued investment in transportation and communication infrastructure will gradually transform the economies of many agricultural regions, especially those in more densely populated marginal lands. This should open up more options for marketing farm products, make fertilizer and other farm inputs more widely and cheaply available, and create rural nonfarm income opportunities. The siting of new transport infrastructure will influence land expansion and land use intensity. Information on agricultural technology and land management should flow more freely and widely as the telecommunications revolution proceeds, making possible unprecedented direct exchange between farmers facing similar soil management challenges in different parts of the world.

However, in large areas of humid and subhumid Africa (and other remote areas, like some mountain ranges in Asia with fairly large populations) there will be little likelihood of providing sufficient rural road investment to achieve even the infrastructure levels existing in India in 1950 (Spencer 1994). This will seriously limit the application of purchased, input-intensive, Green Revolution technology, and require very different development strategies that depend more on locally available inputs and organizations. Little attention has yet been paid to these latter strategies.

Future Trends in Agricultural Land Management in Developing Countries

In 2020, irrigation-related soil degradation problems will become increasingly urgent in Asia. Combating soil degradation in the high-quality rainfed lands will be important mainly in areas of high population density and poverty. The greatest policy challenges from soil degradation in coming decades will be in densely populated areas having soils of lower resistance and higher sensitivity to degradation, and where degradation will increasingly limit agricultural supply, economic growth, and rural welfare. For countries with little high-quality rainfed and irrigated land, such limits may be acute.

Soil degradation in extensive agricultural systems in marginal lands may become a lower policy priority for 2020. Though widespread conversion to permanent cropping may accelerate degradation in these areas, policymakers may worry more about degradation in places where economic effects are greater, including urban areas with a burgeoning agriculture, as this becomes more critical to food supply and welfare in cities. Each agricultural pathway (Table 13) should be examined in turn.

Irrigated Agriculture

Expansion of irrigation between 1993 and 2020 is projected to slow significantly worldwide, to less than half the growth rate of 1982–93. In developing countries, irrigated area is expected to increase by only about 40 million hectares (to 227 million hectares), at an annual growth rate of only 0.7 percent, compared with 1.7 percent during 1982–93 (Table 14). Of all the irrigated area in developing countries in 2020, 80 percent will be located in India, China, West Asia and North Africa, and Pakistan. Despite a 50 percent increase to 7.4 million hectares, the area under irrigation in Sub-Saharan Africa will remain low. Thus, degradation of soils on irrigated lands in 2020 will be largely an Asian problem. A few countries elsewhere are likely to depend on irrigation for half or more of agricultural production: Peru, Mexico, Costa Rica, and Chile in Latin America; Madagascar and Swaziland in Africa; and the new areas in southern Africa planning to expand irrigation. They will face similar degradation challenges.

Increased demand for water from outside the agricultural sector is likely to make irrigation water more scarce and expensive (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1997). While there is ample scope to raise yields in many underperforming irrigation systems, scientists are beginning to believe research yields will soon hit an absolute ceiling for some major cereal grains and pulses in the best-managed systems. There may be difficulties in sustaining currently high yields over the long-term in some systems, due to micronutrient or other soil-related problems.

An expert consultation on land degradation, convened in 1995 as part of IFPRI’s 2020 Vision initiative, identified several “hot spots” for soil degradation in irrigated agriculture. Nutrient depletion was seen to be a potential problem in the Nile Delta due to reduced silt deposits following construction of the Aswan High Dam. Salinization was considered a problem in the Indus, Tigris, and Euphrates river basins, northeastern Thailand and China, the Nile Delta, and northern Mexico. It was expected to

Table 13—Projected changes in agricultural land use and associated degradation concerns, by pathway

Land type	Projected changes	Projected trends in on-site soil degradation	Projected trends in other resource conditions
Irrigated lands	Much slower expansion of irrigated area, mainly in Asia; greater investment in drainage; increase in water prices; diversification to higher-value crops.	• Increased area of salinization, waterlogging; • Some soil-related yield ceilings; • Degraded land out of production.	• Increased conflict with other sectors over water allocation; water quality concerns; • New institutions for conflict resolution.
High-quality rainfed lands	Comparative advantage in grain production; major science-based yield improvements integrated with good soil husbandry.	• Improved soil husbandry (nutrient, mechanization practices) where favorable agricultural economy exists.	• Reduced agrochemical pollution with new technology, education; • Conflict with nonagricultural land uses.
Densely populated marginal lands	Continued intensification in most countries; gross—but typically not net—outmigration; maintenance of food production for local consumption, but diversification to higher-value products with emphasis on agroforestry (using perennial trees, palms, grasses, and shrubs).	• Accelerated degradation in smallholder cropping where no technical advances adopted; • Land-improving investment linked to productivity increase where favorable economy and policy support exist.	• Increased conflict over multi-objective land use (settlement, agriculture, environmental services); • New institutions for conflict resolution.
Extensive agriculture in marginal lands	Much slower expansion of extensive agriculture, mainly in Africa; more integration of agriculture with forest and environmental development strategies.	• Management through land use mosaics; economic use of natural vegetation/perennials; • Erosion reduced, but chronic nutrient depletion.	• Deforestation and loss of biodiversity slows a little; • Watershed degradation still a problem.
Urban and peri-urban agriculture	Rapid expansion and diversification; institutional changes to facilitate urban agriculture.	• Increased degradation, soil pollution; • Improved nutrient management.	• Increased off-site effects on water, land, health; • Innovation to improve urban environment with farming.

become an important problem by 2020 in the Andean highland and South American irrigation systems. Soil quality may also limit yields in the rice-wheat system of south and west Asia, and in irrigated rice production under intensive management in Java, China, the Philippines, and Vietnam. More water conflicts were also projected in the Euphrates and Jordan River systems in Asia, and the Nile, Niger, Logone, Chari, and Senegal River systems in Africa. Rising water scarcity in the Páramo in Latin America and water depletion from over-pumping of wells in Syria were also noted as potential threats to agricultural production (Scherr and Yadav 1996).

These changes have two major implications for future soil degradation trends and policies. First, problems of salinization and waterlogging are likely to increase, as recently developed systems with inadequate drainage infrastructure or water management age. Whether governments and local people will be willing to divert infrastructure investment capital to provide proper drainage in new systems and prevent degradation or rehabilitate older systems will depend on the general profitability of irrigated agriculture. Systems that depend on flushing large amounts of water to manage salinization may become much more vulnerable to degradation as water pricing is introduced. All these reasons may encourage production of higher-value crops in irrigated areas, although the scale may be limited by market size.

Second, without proactive efforts, a considerable amount of irrigated land will go out of production.

Table 14—Current and projected irrigated area

Land area	1993	2020
	(thousand hectares)	
Latin America	17,147	18,748
Sub-Saharan Africa	4,850	7,375
West Asia and North Africa	23,819	31,186
India	50,101	68,619
Pakistan	17,120	20,538
Other South Asia	7,526	8,719
Southeast Asia	14,316	16,195
China	49,872	53,075
Other East Asia	2,877	2,878
All developing countries	187,628	227,332
All developed (United States, Europe, Japan, former Soviet Union) countries	65,375	68,632
World	253,003	295,964

Sources: 1993 figures from FAO 1994. 2020 figures are projections from Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1997.

Indeed, where irrigation systems were built under unsustainable conditions, this will be inevitable. In some countries this loss of irrigated land will affect aggregate agricultural supply. In far more cases, especially in South Asia, serious local repercussions for economic growth and for poverty will be felt.

High-Quality Rainfed Lands

High-quality soils, which are highly suitable for intensive, continuous cultivation, may become increasingly responsible for supplying commercial markets for basic grains in the developing countries, especially if irrigated lands shift to higher-value crops. More temperate and favorable climatic conditions, lower production risks, and better infrastructure and market linkages should provide considerable opportunities for yield increases through improved inputs, biotechnology borrowed from temperate-zone agriculture in more developed countries, and integrated soil, water, and pest management systems. National agricultural research systems, especially in the expanding private sector, are likely to target producers in high-quality rainfed regions, especially in the large majority of countries without substantial irrigated lands. As farmers and investors increasingly recognize the need for good soil husbandry, degradation rates would seem likely to decline.

The 2020 expert consultation identified few hot spots in the high-quality rainfed lands where land degradation affects productivity. Erosion and compaction problems caused by mismanaged mechanization were considered most important in northern, western, and southern Africa. Technological constraints to further yield increases were perceived to be a major threat to future production in the densely populated, naturally fertile (if sometimes degraded) highland areas in Burundi, Kenya, and Rwanda. Agrochemical pollution due to poor nutrient management practices was seen as a critical problem on cotton farms in Turkey, on high density farming and coastal farming in East and Southeast Asia, and on banana plantations and in some intensive agricultural centers like Santa Cruz, Bolivia (Scherr and Yadav 1996).

Densely Populated Marginal Lands

With agricultural development and evolving property rights in irrigated and high-quality rainfed areas, urban development, and economic diversification, many farmers in the densely populated marginal lands may migrate or find nonfarm employment. This can be anticipated especially in countries with abundant high-quality agricultural land (Table 15) and dynamic nonagricultural economies. Even in these countries, however, rapid rural population growth means that *net* outmigration from marginal areas on a scale large enough for reduced land pressure to offset the economic threat of soil degradation is unlikely by 2020. For the many countries with a relatively small endowment of irrigated or high-quality agricultural land, large agricultural populations, and economies dependent upon agricultural production *or* with limited capacity to finance food imports, large-scale withdrawal from marginal lands by 2020 is out of the question. On the contrary, land pressure is likely to intensify greatly due to rural population increase and market expansion.

In situations where current land pressure is moderate, technology is available for sustainable intensification, and economic incentives for its use are favorable, some types of soil degradation (water erosion, for example) can be expected to decline.

Table 15—Arable land resources of the developing countries, 1994

	Population pressure on arable land (hectares per capita)			
Extent of arable land	**Very high (under 0.15)**	**High (0.16–0.30)**	**Medium (0.31–0.45)**	**Low (over 0.45)**
Very extensive	China	India	Brazil	
(over 30 million hectares)	Indonesia	Nigeria		
Extensive		Ethiopia	South Africa	Argentina
(10.0–29.9 million hectares)		Iran	Sudan	
		Mexico	Thailand	
		Myanmar		
		Pakistan		
Moderate	Bangladesh	Algeria	Malaysia	Cameroon
(5.0–9.9 million hectares)	Viet Nam	Iraq	Morocco	Zambia
	Colombia	Zaire	Syria	
	Philippines		Uganda	
Limited	Egypt	Burundi	Angola	Central African Republic
(1.0–4.9 million hectares)	North Korea	Chile	Benin	Chad
	South Korea	Dominican Republic	Bolivia	Mongolia
	Sri Lanka	Côte d'Ivoire	Burkina Faso	
	Nepal	Ecuador	Cuba	
	Tanzania	Ghana	Cambodia	
		Guatemala	Honduras	
		Kenya	Libya	
		Malawi	Nicaragua	
		Madagascar	Niger	
		Mali	Paraguay	
		Peru	Togo	
		Mozambique	Tunisia	
		Rwanda	Uruguay	
		Senegal		
		Saudi Arabia		
		Venezuela		
		Zimbabwe		
Very limited	Congo	Costa Rica	Botswana	Gabon
(< 1 million hectares)	Israel	Cambodia	Guinea-Bissau	
	Jordan	Laos		
	Lebanon	Mauritius		
	Puerto Rico	Namibia		
	Papua New Guinea	Panama		
	Puerto Rico			
	United Arab Emirates			
	El Salvador			
	Haiti			
	Sierra Leone			
	Trinidad			

Source: FAO 1995.

Research suggests that land-improving and -protecting investments for some environments can transform them into moderately high-productivity areas. However, grave economic effects from further soil degradation can be expected in areas with high population growth rates (even from a low base), where technologies for more intensive, sustainable soil management are still unknown, and where unfavorable economic policies and incentives undermine farm investment.

The 2020 expert consultation identified many hot spots for soil degradation in densely populated marginal lands. Nutrient depletion was considered critical in the mid-altitude hills of Nepal, the sandy soils of northeastern Thailand, the semiarid croplands of Burkina Faso and Senegal, the humid East African highlands, the subhumid Central American hillsides, the semiarid Andean valleys, northeastern Brazil, the Santa Cruz area of Bolivia, and the Caribbean Basin lowlands. Technological constraints to yield increases were perceived to be a major threat in the marginal arable lands in Syria, Jordan, Iran, and North Africa, and the humid lowlands of West Africa. Erosion was cited as a particular problem in the Himalayan foothills, the southeast Asian hill country, the west Asian rangelands that have been converted to grain production, the Sahel (from wind), the subhumid Central American hillsides, the semi-arid Andean Valley, Haiti, and the cerrados of Brazil. Devegetation threatens rangelands in many parts of Asia and Africa. The spread of *Imperata* grasslands due to degraded soils has reduced production in large areas of Southeast Asia and Africa, as has the spread of *Chromalaena* in Africa (Scherr and Yadav 1996).

If irrigated lands do convert increasingly to higher-value products, and high-quality rainfed lands dominate basic grains and annual crop production for urban and export markets, the product mix in densely populated marginal lands may be able to—or be forced to—change to better reflect the comparative advantage of these lands. Already there is a trend by producers with more degraded soils to move from grasses and pulses to more tolerant roots and tubers (for example, cassava) and to crops with higher calorie yield per hectare (for example, sweet potatoes). Food production to meet the basic needs of rural producers and local demand will be essential, but will have to be combined with production and marketing of higher-value crops for income generation and regional economic development. The latter crops will have to be produced using practices that control degradation. Ideally, markets will develop for more products from perennial trees, shrubs, palms, and grasses that can be integrated in an environmentally strategic way into a variety of landscape niches. Soil-quality improvement would be an essential part of any of these strategies, taking advantage of improved markets for chemical fertilizers and other inputs, as well as locally or regionally produced organic amendments.

Extensive Agriculture in Marginal Lands

Although considerable potentially productive land remains, area under crop production is only projected to expand a further 12 percent by 2010, mainly in Latin America and Africa. This is due to environmental limits, lack of infrastructure, opportunity costs for forest and pasture uses, and potential recovery of currently degraded lands (Crosson 1995). IFPRI's IMPACT model projects that global area under cereal production will increase by only 5.5 percent, or 39 million hectares, between 1993 and 2020, almost two thirds of which will be in Sub-Saharan Africa (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1997). Surplus land can still be found in Angola, Mozambique, Tanzania, Zaire, and Zambia.[17]

A simulation model of land use transformation in Latin America from 1980 to 2030 predicts that 1 million hectares per year will be transformed to shifting agriculture. The advancing agricultural frontier, mainly in tropical rainforest, would have the most critical effects in Central America. This shift, as well as forest exploitation on another 0.88 million hectares per year, would lead to significant additional soil erosion in the tropical and subtropical rainforests of Central America, the Andean

[17] A reviewer of this paper noted that much of this "surplus" land in Angola and Mozambique is actually unusable due to the widespread presence of land mines—a reminder of the limitations of our models.

countries and Brazil, and, to some extent, the Argentine pampas. The model projects advancing desertification in many of the extensively managed drylands (Gallopin 1992).

Intensification of production on land that was first cleared in the past generation may present more serious economic problems than new clearing. By 2020, much of the now cleared and extensively managed land will be under semi-permanent cultivation or else abandoned due to degradation. Currently identified hot spots include areas with nutrient depletion in remote upland areas in East and Southeast Asia; poor quality soils in northeastern India in transition to permanent agriculture; and areas of Africa undergoing transition to short fallow systems. Erosion is a major problem in sloping areas in southern China and Southeast Asia (Scherr and Yadav 1996).

On the other hand, there will be new opportunities for rehabilitation of degraded lands, such as the technologies now being developed for *Imperata* grasslands (Garrity 1998), sustainable pasture management systems, and improved fallows using agroforestry. Development programs are likely to promote "mosaic" landscapes (Forman 1995), with areas maintained under natural vegetation and crops and management systems adapted to various production niches. Production systems economically appropriate for low land-use intensity will also be used. The simulation model for Latin America (Gallopin 1992) suggests that more sustainable production systems and economic policies that emphasize productive rehabilitation of deteriorated ecosystems would radically reduce the land under shifting cultivation to only 3 percent and decrease the area of grazing lands. Programs for international carbon emissions trading may create new financial incentives for local people to protect some forests from agricultural conversion (Lopez 1996).

Urban and Peri-Urban Agricultural Lands

Soil degradation in urban agriculture is only beginning to be recognized as a policy issue. By 2020, the urban population of developing countries is expected to double, reaching around 3.6 billion. It is likely that in some countries a significant proportion of total agricultural supply and value will come from cities and peri-urban areas. Urban agriculture may play a growing environmental role in the recycling of urban solid waste and wastewater, although it also contributes to some environmental problems that need to be addressed, for example, health problems from contaminated food, air pollution caused by insecticides, water pollution from wastes and agrochemicals, and downstream flooding due to poor farming practices on slopes and streambanks. But there are also likely to be increasing production-related effects from urban soil degradation. Contamination of soils with heavy metals, chemicals, waste, and other urban pollutants may pose a health hazard to consumers and also reduce or halt production. Overgrazing can damage grasslands and urban forests. Insecure access and tenure may reduce farmers' incentives to use good soil management practices. Soil quality and environmental concerns raised by urban agriculture may begin to take policy priority over other producing areas because of the greater visibility of and political sensitivity to urban concerns, even though poverty related to soil degradation may be more acute elsewhere.

Potential Threats of Soil Degradation to Developing-Country Food Security

In light of the above, to what extent will soil degradation pose serious threats to developing-country food security in 2020? Some general patterns are predicted below in relation to agricultural supply, economic growth, rural poverty, and long-term national wealth. Policy, however, will need to be guided by a country-by-country assessment, with consideration given to the importance of agriculture in the economy, the vulnerability of agricultural land to degradation (land scarcity, soil vulnerability and resilience, and the anticipated rate of change in cropping intensity), and the capacity of farmers to respond effectively to the threat of degradation (profitability of farming, availability and cost of soil-conserving technology, and availability of financing for land improvements).[18]

Agricultural Supply

Crosson (1997) notes that the Dregne and Chou data represent a 0.3 percent per year decline in agricultural productivity over 50 years and the GLASOD data 0.1–0.2 percent per year over 45 years. He assumes an accelerating future rate of degradation, 0.4 percent, to calculate a 17 percent cumulative global productivity loss by the year 2030. Applying the GLASOD rate through 2020, the loss would be much lower. In any case, soil degradation, even at high rates, is not likely to be a serious threat to international food trade between now and 2020 because of the global capacity for supply substitution from nondegrading lands and the dominance of temperate producers in international wheat and maize markets.

However, important regional supply and price effects could arise from the accelerated loss, through salinization, of irrigated land in the "rice bowl" and "breadbasket" areas of South and East Asia and from degradation in Africa. There could be significant effects on national agricultural supply in countries with widespread degradation, inducing shifts in producing areas and increased imports. Lal (1995), for example, predicts that by 2020 water erosion alone may reduce productivity by 16.5 percent for all Africa and 14.5 percent for Sub-Saharan Africa.

Agcaoili, Perez, and Rosegrant (1995) used the IMPACT model to simulate the effects of a 10 percent decline, relative to the baseline scenario, in crop productivity in the developing countries after 25 years. This represents a modest acceleration of degradation above the implicit rate reflected in historical productivity trends. A second scenario assumed the same rate of degradation, but also further reduction of crop yield growth in Pakistan by 50 percent (a 1 percent per year decline in crop area, reflecting possible effects of salinization), a further 5 percent decline in the growth of rice yields, and a 21 percent decline in other crop yield growth in China. The study concluded that the first scenario would result in world prices higher by 17–30 percent in 2020, particularly for maize, rice, roots and tubers, and wheat. The second scenario does not significantly increase pressure on world prices beyond the level of the first scenario. However, it does result in higher wheat imports, especially in Pakistan and China. These effects are quite significant, although the authors argue that the impact of inadequate conventional agricultural research and investment would be even larger than that of soil degradation.

Agricultural Income and Economic Growth

It seems likely that the greatest impact of future soil degradation will be from persistently lower agricultural incomes, due to reduced yields or higher input costs, in the irrigated, high-quality rainfed, and densely populated marginal lands. The current estimates of loss as a percentage of national AGDP are large, ranging from 1 to 5 percent per year in a majority of the studies. It is hard to evaluate whether these figures are overestimates or underestimates. On the one hand, they do not take into account market and price effects and responses that would tend to dampen the impact of degradation; on the other hand, few of the figures reflect the economic multiplier effects of lost income.

Soil degradation in marginal lands with low population density is likely to have a modest effect on national or subregional agricultural income or growth in 2020 because of weaker market linkages. Economic effects from soil degradation on urban and peri-urban agriculture are hard to predict; they may be limited by the smaller scale of production, but may be larger because of the typically higher value products grown. Almost by definition, the major effects will be in those countries or subregions that depend upon agriculture as the "engine of economic growth."

Of course, whether farmers, governments, civil society, and international institutions will deem it worthwhile in the short and medium term to invest in improving soil quality will depend on the actual

[18] Such an analysis explains the relative lack of urgency about responding to soil degradation in countries such as the United States, where primary agricultural production is a minor part of the economy; where most soils, particularly in the corn belt, are highly resistant to degradation; where land is abundant; and where farmers have many options to address degradation if they so choose.

costs of doing so, and the perceived potential for increasing production and economic growth through other types of investments that compete for limited resources.

Consumption by Poor Farmers

Future soil degradation threatens to have significant negative effects on consumption by poor farmers in 2020 wherever the productive potential of farmland declines. The greatest problems will probably occur in the densely populated marginal lands of Sub-Saharan Africa and Asia, especially where markets are less developed and industrial inputs expensive. A bioeconomic model for dryland agriculture in a village in Burkina Faso predicts that the cost of soil degradation to farmers by 2020 would equal 20 percent of village income in that year (Barbier 1996). Many poor farmers in South and Southeast Asia will also be affected, but because the poorest people are the rural landless, effects on poverty and malnutrition may be transmitted through changes in employment and local food costs.

Both scenarios of soil degradation in the IMPACT model simulations predict deterioration of food security, not only from contraction in production, but also from reduced demand due to higher prices. While the total number of malnourished children declines by 7.6 million (nearly 3.6 percent) from 1990 to 2020 in the baseline scenario, the total number remains nearly constant in the first degradation scenario and actually increases by 1.5 million (0.6 percent) in the second scenario. The major wheat- and rice-producing and consuming countries (in Asia and some countries in West Asia and North Africa and Latin America) exhibit the largest increments in malnutrition (Agcaoili, Perez, and Rosegrant 1995).

National Wealth

Assuming that the lowest of existing estimates (5 million hectares per year) of land lost irretrievably to degradation continues between 1990 and 2020, an additional 150 million hectares would go out of production by 2020—1.7 percent of total agricultural land. Using the highest estimates (12 million hectares per year), the loss would be 360 million hectares, or 4.1 percent of agricultural land. A high proportion of the loss would be in developing countries. This is in addition to the 3.5 percent of agricultural land lost to degradation since the mid-1940s, and other agricultural land lost to urbanization and infrastructure. The loss to global production would be proportionately less, as much of this is lower quality land and soil quality improvements and yield increases elsewhere in the next few decades could potentially offset some of the supply effects. Assuming that global population stabilizes late in the next century as projected, total agricultural land loss would appear to pose a modest threat to total global wealth in soil assets.

Of greater concern would be a serious decline in the quality of soils that remain in production. Already in 1990 Oldeman, Hakkeling, and Sombroek (1991) estimated that there had been moderate or severe soil degradation on 19 percent of agricultural land in Africa, 16 percent in Asia, and 31 percent in Central America. Although many were inclined to consider GLASOD figures overestimated, the more detailed ASSOD study for South and Southeast Asia reported even higher figures. While it is essential to assess more carefully which of the lands threatened with degradation are really important economically in the medium to long term, complacency would seem unwarranted.

In the relatively short time to 2020, there are unlikely to be major structural shifts in agricultural supply away from land-based production or away from the current breadbaskets and rice bowls. However, in the long term there may be significant shifts, particularly due to climate change and new trade patterns. For the sake of future generations, it is especially important that the highest quality soils be preserved—the great loess areas of temperate South America (Nearing 1998), the fertile deltas of South and Southeast Asia, and the deep volcanic soils scattered throughout the tropics. Uncontrolled urbanization and salinization caused by mismanagement of irrigated cropland may be the greatest threats to these lands.

Countries blessed with large areas of high quality agricultural land may not need to be concerned about long-term soil wealth. About half of all the developing world's arable and perennial cropland is currently located in just five countries—Brazil, China, India (which alone accounts for 22 percent of all cropland), Indonesia, and Nigeria (Table 15). For these countries it is short-term food supply and rural poverty—rather than a concern for long-term soil wealth—that argue for careful attention to enhancing the quality of rural lands; all but Brazil have high population densities and rural land pressure and all have high rural poverty rates. Another nine countries, with more than 10 million hectares of cropland each, account for 21 percent of all cropland resources. In those with lower population pressure, some land can be lost to degradation without threatening national economies or long-term national wealth.

However, countries that are not so blessed may not only consider putting more emphasis on soil protection, but developing long-term, large-scale investment programs to enhance the quality and stability of some of their vulnerable lands. The 57 developing countries with only 1–10 million hectares of cropland must look carefully at the long-term implications of allowing soil quality over large areas to degrade or lose productive potential; already population pressure on the land is high or very high in half these countries. And the 38 developing countries with less than 1 million hectares of cropland, most of which already have high or very high pressure on the land, should probably consider conserving farmland quality to be a strategic long-term food security issue.

Of course, unforeseen changes may greatly increase the importance of tropical soils that are not valued highly at present. Large-scale disasters, such as the Chernobyl nuclear plant explosion in the Ukraine, could contaminate and take out of production expanses of fertile, productive soils from the world's breadbaskets and rice bowls. Global warming may eventually (but not before 2020) take out of production large areas of low-lying fertile croplands (for example, in Bangladesh).

Environmental Effects of Soil Degradation

The economic impact of the environmental effects of soil degradation, such as that on species habitat, hydrological function, water quality, and global carbon cycles, is not addressed in this paper. It is likely to be considerable, raising the social costs of soil degradation in all five agricultural pathways, although in different ways. These economic costs must clearly be taken into account, together with productivity-related effects, in setting overall policy priorities and strategies.

Environmental policy debates, especially relating to marginal and peri-urban lands, are often narrowly framed as a choice between allocating land to agricultural use or keeping land out of such use in order to preserve important environmental values. By the year 2020, however, as pressures on the land rise, removing land from agricultural production will be even less feasible a solution than it is today, except in the most highly valued and lightly populated environments. In the majority of developing countries that anticipate dense rural populations, urban agricultural activity, and close physical proximity of farms to human settlements in 2020, segregated land use in the manner practiced in developed countries in the twentieth century will become impossible. The challenge for scientists, land managers, and policymakers is to find strategies for sustainable agricultural production that produce *positive* environmental externalities within multipurpose landscapes.

Overall Priority Concerns

A qualitative weighting of the plausible global economic effects of future soil degradation suggests that the greatest problems for food security in the developing countries in 2020 will be found in the densely populated marginal lands (Table 16). These areas also have the highest probability of significant degradation without policy action, because combating degradation will require mobilizing long-term investment and new technology development. Degradation of irrigated lands through salinization and waterlogging poses the second greatest threat, because these lands play a central role in commercial food supply in Asia. Degradation of high-quality rainfed lands can be expected in many areas, but may be "self-correcting" in situations where there is general support for agricultural development and suitable technologies are available for adoption. Agricultural land quality and preservation in urban and peri-urban areas will become much more problematic by 2020, especially in the developing coun-

Table 16—Relative impact of soil degradation in different agricultural pathways

In order of global policy priority	Anticipated impact of soil degredation on: Consumption by poor farmers	Agricultural market supply	Economic development	National wealth	Severity of problem	Dependence on direct policy action to resolve
1. Densely populated marginal lands	★★★	★★	★★★	★★	★★★	★★★
2. Irrigated lands	★★	★★★	★★★	★★★	★★	★★
3. High-quality rainfed lands	★★	★★★	★★★	★★★	★	★
4. Urban and peri-urban agricultural lands	★	★	★	★	★	★★★
5. Extensively managed marginal lands	★★	★	★	★	★	★

Notes: To resolve soil degradation problems (see last column), all of these agricultural pathways require a strong agricultural economy, so that farmers have incentives and capacity for good land husbandry. This calls for sensible general agricultural and rural policies, infrastructure investments, and so on. The last column refers to the need for policies and public investments specifically aimed at controlling soil degradation. ★★★ indicate high, ★★ medium, and ★ low.

tries that are highly urbanized and where urban political interests are paramount. Degradation in marginal lands that are lightly populated is unlikely to impose major global economic costs (as distinct from the likely and significant global environmental costs), though many of the poorest of the poor may farm in these regions. National policy priorities will vary widely and must be determined by each country's resource endowment, the structure of agricultural supply, the geographic distribution of poverty, and the principal agricultural sources of economic growth.

5. Policy and Research Priorities

The period since World War II has seen remarkable growth in agricultural production and productivity in the developing world. While in many farming areas this growth has apparently been sustainable, in others it derived from two unsustainable processes: the clearing of new lands of lower productive potential or higher vulnerability, and the intensification of production by mining or destroying the soil resource base. The challenge of feeding and supplying the much larger population projected to live in the developing countries by 2020 has to be met not only by raising production from current levels, but by substituting for supplies no longer available from land-clearing, by finding sustainable methods of intensive production on soils not previously used for this purpose, and by substituting for or rehabilitating degraded soils where there is continuing demand for their use.

Leaders in the economic and agricultural development communities, as well as environmentalists, must draw the attention of policymakers to soil degradation concerns and work with them to set priorities for public investment, farmer services, and policy. A necessary though not sufficient step is to provide supportive policies for broad-based agricultural development. Targeted policies and investments will also be needed to address many serious degradation problems. Better characterization and diagnosis of soil degradation effects will be needed to guide and support these efforts.

Support Policies for Broad-Based Agricultural Development

If the 2020 Vision policy agenda (IFPRI 1995) is seriously pursued, many soil degradation problems can "self-correct" to a considerable extent by 2020. Farmer investment in known land-husbandry technologies should increase where agricultural markets perform more effectively, reducing the costs of inputs and increasing farmgate output prices; where profitable farming opportunities raise the value of agricultural land; where technological change makes higher, sustainable yields possible; and where land tenure is secure. In some areas, in such a supportive policy environment, simply promoting information dissemination about good land husbandry practices and supporting research on technologies to reduce conservation costs may be sufficient for addressing degradation concerns.

Target Land-Improving Policies, Investments, and Research

It is doubtful, however, that indirect policies will be enough. Agricultural growth can have mixed effects on resources, due to widespread lack of information, institutional failures, and market failures. And many areas cannot count on having a dynamic economy or suitable technology. An integral element of development strategies to promote the 2020 Vision must be the policies, investment, and research that promote soil protection and rehabilitation where soil quality most affects agricultural supply, economic growth, rural welfare, or long-term national wealth.

Soil rehabilitation demands going well beyond simply applying fertilizer to replace chemical nutrients; it may involve restoring organic matter, improving soil structure and waterholding capacity, controlling the flow of water across fields, restoring soil flora and fauna, buffering acidity, and establishing vegetative cover. Community- and watershed-scale planning will often be needed in the transformation to more sustainable, higher-productivity landscapes.

However, efforts to improve soil quality must complement—not substitute for—other types of agricultural investments, and reflect economic realities and farmer resource constraints. Conservation efforts should maintain, stabilize, or increase productivity, not necessarily optimize soil condition. Direct action and research interventions must be designed to fit specific development pathways, farming systems, soil types, and degrees of degradation.

Densely Populated Marginal Lands

Policy action in densely populated marginal lands should focus explicitly on improving soil quality as a key element in increasing yields and reducing risk and yield variability. Nutrient depletion can be addressed by increasing nutrient inputs and improving nutrient use efficiency; reducing nutrient off-take (that is, reducing harvests) is not often a reasonable option. Chemical fertilizers will play an increasingly important role as marketing costs decline. However, few of the vulnerable soils on these lands can be managed intensively and sustainably over time with chemical nutrient applications alone. Organic matter management is critical for protecting the physical structure of soils and using nutrients efficiently (Sanchez et al. 1997). For soil types that cannot sustain continuous cultivation, economically productive perennials and cover crops must be incorporated into the farming rotation (Garrity 1998; Tengberg and Stocking 1997). For areas still not well integrated into markets in 2020 (much of Africa and the remote mountains) and for farmers who practice subsistence production, low-cost sources of plant nutrients must be found urgently to replace or supplement fertilizer use. Beyond nutrient maintenance, policies are needed to help farmers organize and finance investment in land improvements.

The research challenge is immense: to develop nutrient management systems for specific soils, low-cost soil rehabilitation techniques, and economical methods for incorporating more perennial plants in farming landscapes. Profitable systems to manage local forest and grazing lands are needed to justify good land husbandry. The more effective soil management practices from intensive farming systems need to be documented and shared with farmers working with similar soils elsewhere and who have only recently begun the transition to intensive systems.

Irrigated Lands

The two priority policy actions to combat irrigated land degradation are fairly well known: improve system- and farm-level water management regimes and invest in proper drainage systems where this has not been done. Plans must be made to retire lands that are irreversibly degrading with minimal disruption to farm communities. Diversification to higher-value crops may help to justify reinvestments in irrigation systems and higher-priced water.

Priorities for research include exploring problems of micronutrient depletion and other soil-related factors that may lead to yield stagnation, identifying effective water management regimes, developing low-cost methods to control or reverse salinization, and utilizing saline lands.

High-Quality Rainfed Lands

Policy action for high-quality rainfed lands must seek to better integrate technology development and extension for productivity growth with good soil husbandry through tillage practices, agricultural machinery use, and agrochemical management. Market-based mechanisms should be developed to improve distribution systems for fertilizers that reduce cost, improve nutrient balance, and encourage complementary use of organic nutrients. Recommendations will vary with changing ratios of output to nutrient prices.

Research priorities must develop recommendations and technologies for fertilizer and organic nutrient management for specific soils, climates, and crops and identify or develop low-cost organic nutrient sources for smallholder producers. New biotechnology and other technical advances should be designed for integration into sustainable resource management systems.

Urban and Peri-Urban Agricultural Lands

Much of the policy action needed to promote better soil quality in urban and peri-urban agriculture is institutional. Zoning rules, land access, controls on agricultural land conversion, and regulation of agrochemicals and livestock waste disposal need to be changed to improve the security of urban farming. Community gardening opportunities on public and unutilized private land should be protected and promoted.

Research priorities need to focus on designing technologies to improve the use of urban waste products in soil nutrient management and livestock feed and minimize toxic agrochemical use. Studies are needed to understand the patterns and strategies for controlling livestock disease in urban environments. Physical and institutional barriers to protect farmland from urban soil pollutants also need to be developed.

Extensive Agriculture in Marginal Lands

In extensive agricultural systems, policy action should aim to limit the environmental damage of farming practices at a minimal cost to farmers and help farmers make the transition to more sustainable short-fallow or permanent cultivation systems. Extensive farming can only be regulated or prohibited economically in a small number of strategic sites. Farmers need support from extension services to “farm lightly on the land” using technologies that do not require high labor use or purchased inputs. Mosaic patterns of land-clearing and controlled burning can be encouraged on cropland and rotational grazing and grazing reserves on rangeland, in order to maintain more natural vegetation. In areas with vulnerable soils, policies that raise the value of forest and tree products can reduce land clearing, raise local incomes, and initiate a long-term transition to an economy based on permanent crops. Improved employment opportunities for the landless outside agriculture, in other farming areas, or in forest management can reduce farmer incentives to clear new lands. Infrastructure investments need to be concentrated in areas of existing settlement.

Research should focus on technologies for low-input farming, higher-value products that encourage spatial concentration of production, and perennial crops. Crop, forest, or range management systems will ideally meet both local economic and broader environmental objectives, justifying the transfer of resources from outside the region to help finance this dual agenda.

Identify Priority Soil Degradation Problems

Currently available data are insufficient to guide and prioritize such targeted policy action. Accurate information is needed on the actual areas and farming communities where serious soil degradation—and soil improvement—are taking place, and the nature of the effects on agricultural supply, economic growth, rural poverty, and soil wealth. Analysis should focus on the subnational level, where soil quality change and its effects can be meaningfully measured and interpreted, and where policies need to be implemented. National and international priorities can best be developed by aggregating this subnational information.

The design of sampling frames and the collection of agricultural production, farm income, and rural poverty data need to be made spatially explicit, or at least the different land classes, agroclimatic zones, land use intensities, market environments, and types of producers should be distinguished from each other. For the design of specific interventions, more detail is needed on type of soil, resilience from and sensitivity to degradation, and management history. Advances in remote sensing methods (for example, in spectrometry) will soon offer the potential for monitoring key soil characteristics on a large scale. International support is needed to expand resource characterization and monitoring systems such as the international soil and terrain database (SOTER), the Land Quality Indicator program (Pieri et al. 1995), and the global database on farmer use of conservation technologies (WOCAT 1997), which draw on a mix of information from remote sensing, spatially informed agricultural and household surveys, and key informants.

Geographic information systems can be used to integrate and manage databases of various types and spatially analyze the economic effects of soil quality change. Time-series data can be used to explore the relationships between soil quality change over time and farm management, local economic and social conditions, and the policy environment. Soil quality indicators can be incorporated into economic and policy modeling of agricultural trends at subregional and national scales. Where adequate information about the links among soil quality, degradation, and productivity and the geographic location of problems exists, models can help identify priorities for action. Where information is sparse, modeling can help identify priority data needs and encourage dialogue among soil, agricultural, and environmental experts, policymakers, and the larger agricultural community.

Economists need to use more creative methods to analyze the effects of soil degradation on agricultural supply, in order to reflect the geographic structure of production, the price effects, and the consumer and producer responses to those effects in different geographic regions. Studies of the effects of soil degradation on agricultural income (including multiplier effects) and rural poverty similarly require more systematic design and analysis. More conceptual work is still needed to determine appropriate methods for evaluating soil wealth.

Final Comment

We should not take lightly the long-term economic threat of accelerating soil degradation. Historical evidence suggests that the economic decline of empires in Mesopotamia and the Indus Valley was due, at least in part, to widespread salinization and waterlogging of irrigated lands, while decline in ancient Israel, Lebanon, Greece, and Rome was due to topsoil loss in the rainfed uplands of the Mediterranean (Hillel 1991). We have more knowledge and tools at our disposal today, but the output demands and pace of change in soil resource management have also vastly accelerated. The difficulties of measuring and valuing soil quality changes and their effects mean we must approach the challenge with care. However, this should not deter economists and policymakers, but rather inspire them to focus greater attention on soil quality management as a central natural resource issue for sustainable agriculture in the developing world.

Appendix—Types of Soil Degradation: A Glossary[19]

Acidification: A lowering of soil pH by mobilizing or increasing acidic compounds in the soil. It is characterized also by the loss of exchangeable cations. The problem may be caused by overapplication of acidifying fertilizers, planting of acidifying vegetation, or draining soils containing pyrite (creating acid sulphate soils). Acidification may occur in humid and subhumid climates through nutrient leaching of naturally acid soils having low-activity clays and low organic matter. Another term used for this is dystrification.

Alkalinization: See salinization.

Aridification: Decrease of average soil moisture content. Possible causes are the lowering of groundwater tables for agricultural purposes or drinking water extraction, or decreased soil cover and reduced organic matter. Most types of degradation result in a loss of plant-available water capacity, the most important factor affecting soil productivity in many soils.

Biological degradation: A decline in carbon biomass, reduction in organic matter content, and decrease in flora and fauna populations or species resident in the soil (for example, earthworms, termites, and microorganisms). It is caused by intensive row cropping, mechanical soil disturbance, accelerated soil erosion, excessive application of pesticides, or industrial waste contamination.

Compaction: Deterioration of soil structure by trampling of cattle or the weight and/or frequent use of heavy machinery. Factors that influence compaction are ground pressure and frequency of the passage of heavy machinery, grazing pressure, soil texture, soil moisture, and climate. Soils with low organic matter, poorly sorted sand fractions, and appreciable amounts of silt are more prone to compaction and sealing.

Crusting: Clogging of soil pores with fine soil material and the development of a thin impervious layer at the soil surface that obstructs the infiltration of rainwater. Possible causes include poor soil cover, allowing a maximum "splash" effect of raindrops; the destruction of soil structure; and low organic matter.

Dystrification: See acidification.

Erosion: A decrease in depth of the topsoil layer due to more or less uniform removal of soil material by runoff water (sheet erosion) or wind. Erosion may result in other types of soil degradation, such as nutrient loss, acidification, changes in water-holding capacity, loss of organic matter, and crusting. *Water erosion* may be caused by inappropriate land management (insufficient soil cover, unobstructed flow of runoff water, deteriorating soil structure) and can lead to excessive surface runoff and sediment transport. It may cause off-site effects: sedimentation of reservoirs and waterways, flooding, or pollution of water bodies with eroded sediments. *Wind erosion* may be caused by insufficient protection of the soil against the wind by vegetation or other means; insufficient soil moisture; or destruction of the soil

[19] Terms have been adapted from the ASSOD study (van Lynden and Oldeman 1997, 5–7).

structure. Wind erosion may cause off-site effects, such as the covering of the terrain with wind-borne soil particles from distant sources.

Eutrophication: An excess of certain soil nutrients, impairing plant growth. It may be caused by imbalanced application of organic and chemical fertilizer, resulting in excess nitrogen or phosphorus, or by overliming.

Fertility decline: A net decrease of available nutrients and organic matter in the soil. Fertility decline is caused by a negative balance between output (harvesting, burning, leaching, and so on) and input of nutrients and organic matter (manure/fertilizers, returned crop residues, flooding) of nutrients and organic matter.

Nutrient depletion: See fertility decline.

Pan formation: Naturally occuring physical changes in soil structure that result in formation of a layer impermeable to roots or the flow of water. Examples are laterization, hard-setting soils, fragipan formations, and clay-pan formations. Some soil types are prone to pan formation, especially under cultivation.

Pollution: Soil degradation as a consequence of the location, concentration, and adverse biological or toxic effects of a substance. This may include both pollution from local sources (such as waste dumps, spills, and factory sites) and diffuse or airborne pollution (atmospheric deposition of acidifying compounds and/or heavy metals).

Salinization: A net increase of the soluble salt content of the soil root zone in concentrations toxic to plants, thus leading to productivity decline. Salinity problems may be due to intrusion of seawater, improper irrigation methods, or evaporation of saline groundwater. Saline soils usually have high accumulation of soluble salts like sodium chloride or sodium sulphate; alkaline soils have abundant sodium carbonate and bicarbonate salts, with even higher pH.

Sealing: See crusting.

Subsidence: Lowering of the soil surface, especially of organic soils. Possible causes are the oxidation of peat and settling of soils in general due to lowering of the water table. It may occur due to the solution of gypsum in the subsoil, or the extraction of water or gas.

Terrain deformation: An irregular displacement of soil material causing clearly visible scars in the terrain. It may be caused by water (as with gully or rill erosion) or mass movements of land, or by wind action (causing deflation hollows, hummocks, and dunes).

Waterlogging: Effects of human-induced hydromorphism (excluding paddy fields). Causes are a rising water table (for example, due to construction of reservoirs or irrigation) or increased flooding caused by higher peak flows of rivers.

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