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Soil Degradation in the West African Sahel: How Serious Is It?

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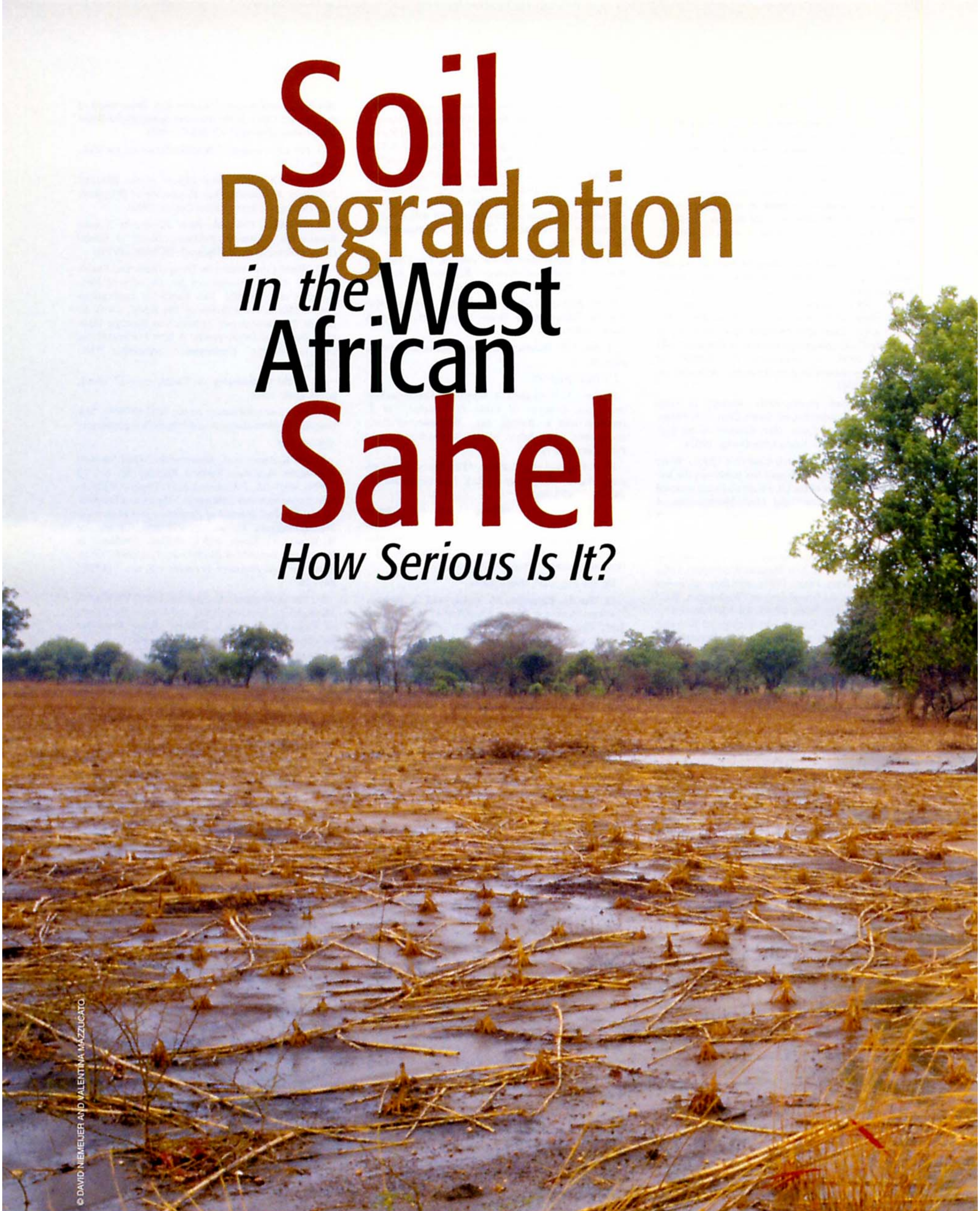
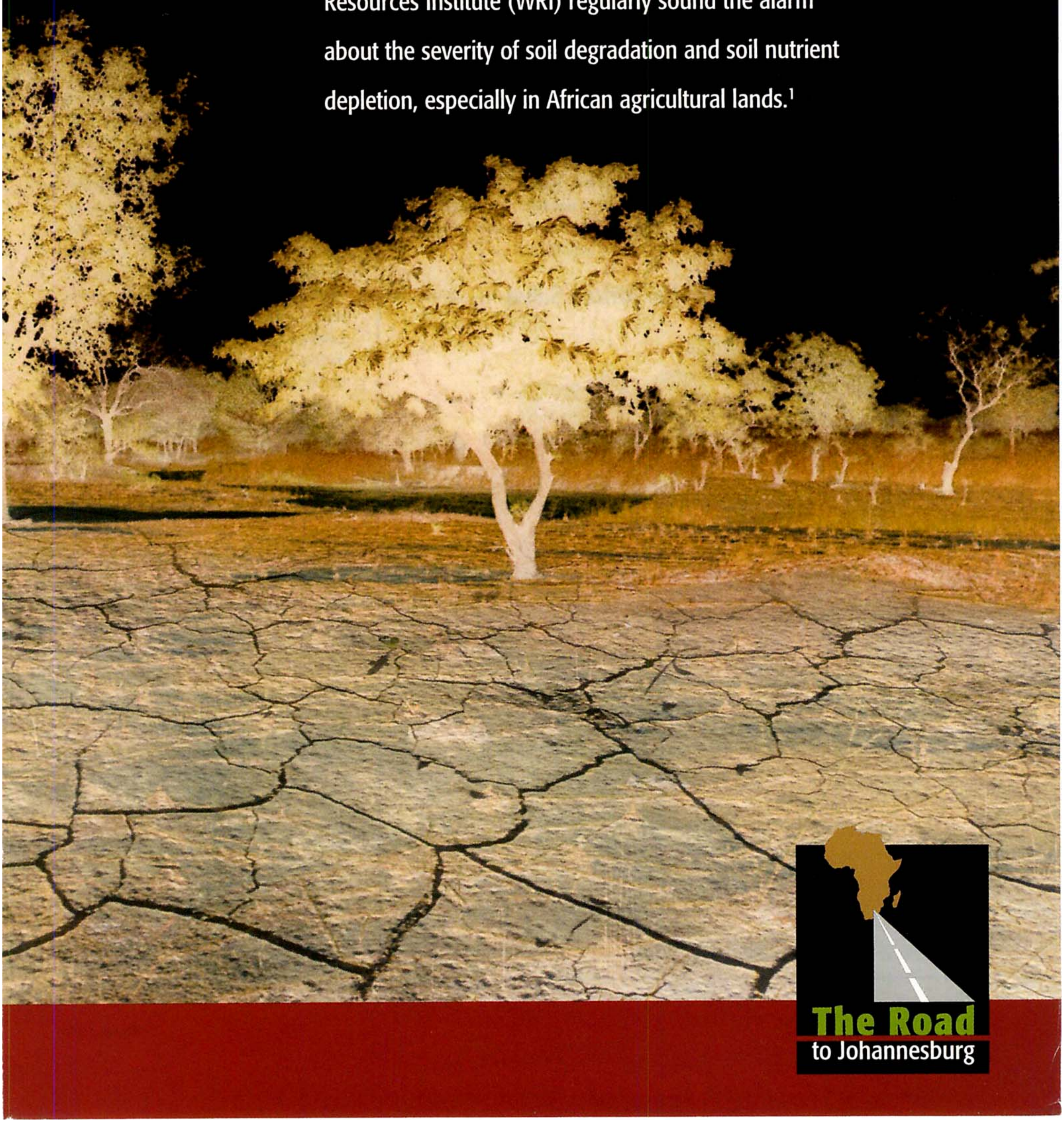
How Serious Is It?



by David Niemeijer and Valentina Mazzucato

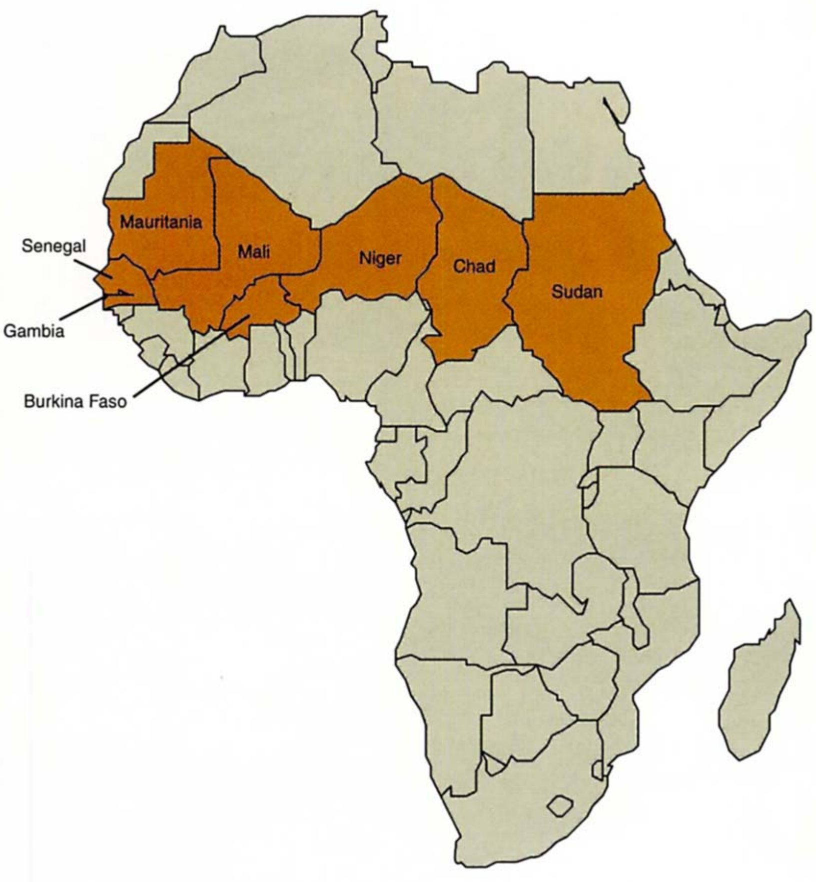
International and nongovernmental organizations such as the World Bank, the International Food Policy Research Institute (IFPRI), the Food and Agriculture Organization (FAO), and the World Resources Institute (WRI) regularly sound the alarm about the severity of soil degradation and soil nutrient depletion, especially in African agricultural lands.[1]



According to a joint IFPRI and WRI press release from 2000, "Interpretation of available data suggests that up to 40 percent of [the world's] agricultural lands are seriously affected by soil degradation."[2] A recent FAO press release claims, "Land degradation affects around 70 percent of the world's rangelands, 40 percent of rainfed agricultural lands and 30 percent of irrigated lands."[3] According to the United Nations Environment Programme (UNEP), "An estimated 500 million hectares of land [in Africa] have been affected by soil degradation since about 1950, including as much as 65 per cent of agricultural land."[4] These and other claims can be traced back to essentially two groundbreaking—but exploratory—studies from 1990 that are urgently in need of follow-up.

Growing population, widespread poverty, and lack of agricultural modernization are generally considered the most crucial factors in causing soil degradation. However, a recent study of Burkina Faso, supposedly one of the most degraded countries in the West African Sahel, shows that there is insufficient evidence of widespread degradation, despite the occurrence of trends usually associated with it. (See Figure 1 on this page for a map of the Sahel region.) The findings of this study—conducted by the authors between 1994 and 1998—contradict claims of severe, widespread soil degradation and have important implications for research and development policy. This contradiction indicates a need to re-evaluate the evidence of soil degradation for the other Sahelian countries.

Figure 1. The countries of the African Sahel



SOURCE: D. Niemeijer and V. Mazzucato.

The Foundation of the Soil Degradation Claims

The claims in the press releases mentioned above refer to the findings of a single report: *Pilot Analysis of Global Ecosystems: Agroecosystems*, which is produced jointly by IFPRI and WRI.[5] The agroecosystems report combines a new satellite-derived map of agricultural extent (the area of land used for agriculture) with an existing map of human-induced soil degradation and finds that "Over 40 percent of the agricultural extent coincides with mapping units whose degradation severity is high or very high." However, the report goes on to note that this interpretation provides an overly pessimistic view because of problems with the data. The report also observes: "The picture [the findings] paint calls, at the very least, for a greater sense of urgency with regard to more reliable monitoring of the location, extent, degree, and impact of soil degradation."[6] However, the urgent need for better data seems to have received less attention than the pronouncement that a large percentage of the Earth's land is severely degraded.

The existing map of human-induced soil degradation used in the agroecosystems report is the Global Assessment of Soil Degradation (GLASOD) map, which was prepared at UNEP's request between 1987 and 1990 by a team from the International Soil Reference and Information Centre. The map was created on the basis of regional experts' assessments of the types, causes, degrees, rates, and extent of soil degradation, using a standardized assessment framework.[7] The team also calculated the extent of soil degradation on agricultural lands, which was found to be 38 percent globally and as much as 65 percent for Africa.[8] Little new information on the global state of soil degradation has been produced since then, except for a different form of calculation essentially using the same soil degradation data and leading to the same figures.

The GLASOD map is also at the source of other recent publications such

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Clouds gather above a village in Burkina Faso during the rainy season. The authors found that long-term average annual rainfall was a more significant indicator of agricultural productivity than growing population, poverty, or lack of agricultural modernization.

as UNEP's desertification atlas, which maintains that almost 30 percent of the Sahel is affected by human-induced soil degradation.[9] All of the reports of increasing soil degradation still rely on an expert assessment that is more than 10 years old and that, according to one researcher, "may reflect unsubstantiated biases and assumptions."[10] The GLASOD project leader, Roel Oldeman, noted, "The GLASOD map and accompanying statistics do not allow assessment of soil degradation on a country by country basis"—but that is exactly how they often are used.[11] GLASOD was an important achievement, but it was only a first step. Instead of continuing to rely on this map and data set, the international community should make a concerted effort to validate and improve the map with actual measurements.

FAO commissioned another study that has dominated current thinking about soil degradation. This 1990 study, carried out by Jetse Stoorvogel and Eric Smaling, assessed soil nutrient depletion in sub-Saharan Africa.[12] Whereas GLASOD was based on expert assessment, this study was based on a nutrient budget model, which is a computer model that calculates the balance of soil nutrient inputs and outputs. This study focused on developing a method to assess the soil nutrient depletion of agricultural lands in the region. The authors used production and land-use data supplied by FAO and consulted experts and literature on the subject to determine parameters. This study has been very influential not only in its methodology, which has been copied by many subsequent studies, but also in the way the actual output of this exploratory model began dominating policy debates on soil fertility in Africa.[13] However, it has been argued that this model and other nutrient budget models suffer from a number of problems, including data that are often based on extrapolations and generalizations of measurements that were taken under very specific conditions. It still remains to be seen whether these models can be applied to the great variety of soils, rainfall regimes, and farming practices across whole countries or regions.[14]

The limitation both the UNEP- and FAO-commissioned studies share is that they have never been sufficiently validated with data on actual soil conditions and/or productivity to support their findings of widespread degradation and serious nutrient depletion. Nevertheless, they were well received in part because they were the first sources to provide consistent continent-wide data on the status of African soil and in part because their message fit well within dominant thinking about land degradation at the time. In the early nineteenth century, Thomas R. Malthus asserted that population growth would outpace food production.[15] Following Malthus's theory, the trends of strongly rising population densities, growing herds, deepening poverty, and limited agricultural intensification (such as soil and water conser-

The Road to Johannesburg

The World Summit on Sustainable Development, which begins in late August in Johannesburg, South Africa, marks the tenth anniversary of the Earth Summit in Rio de Janeiro. To help our readers better understand some of the key issues, *Environment* will explore sustainable development in a series of articles, with a special focus on Africa. In January/February, we examined the link between poverty and degradation. In this issue, we look at soil erosion. Watch for this logo with future articles.

Farmers use simple but effective methods of agricultural intensification such as this wood barrier, which helps to reduce erosion on a sensitive spot in a millet field.

vation practices) have been said to cause land degradation as well as declining soil productivity.[16]

Ester Boserup shed doubt on Malthus's theory in the 1960s by arguing that rising population densities provide the impetus for better land husbandry, ultimately leading to greater productivity.[17] Recent studies also question the validity of Malthus's theory as well as that of current soil degradation claims.[18] Still, these studies seldom quantify the level of soil degradation, leaving the relationship between degradation and population density ambiguous. They have therefore proved no match for Malthus-style "doomsday" studies that are based on quantitative models and maps. These latter studies not only provide "hard" figures to make their case, but they also are compelling, given that many of the trends thought to be harbingers of land degradation—strong population growth, lack of agricultural intensification, and widespread poverty—are prominent in much of Africa.

Soil Degradation Defined

It is important to consider what soil degradation entails. There are many definitions of soil degradation, but most of them refer to a loss in the productivity of soil. Thus, to measure soil degradation, it is not enough to establish changes in the condition of soil—it is also necessary to ascertain a causal link between those changes and a decline in soil's productivity. This is not easy, because productivity is affected by many factors other than soil quality (such as rainfall, labor, and technology), while changes in soil may not always lead to a decline in productivity. Due to the multivariate and interdependent relationship between soil conditions and productivity, it is necessary to base claims of soil degradation on multiple, complementary proxies that include measurements of soil properties as well as productivity indicators. All of the above-mentioned claims are based on expert assessments or model estimations of soil properties but not on productivity indicators.

The Case of Burkina Faso

Burkina Faso is an ideal case with which to explore the issue of soil degradation in the African Sahel because the country is experiencing all the demographic and economic trends that are usually associated with soil degradation. In fact, it shows the highest ranking of any Sahelian country on the Severity of Human Induced Soil Degradation index, calculated by the World Economic Forum on the basis of GLASOD data.[19] In Africa, Burkina Faso is surpassed on the index only by mountainous Rwanda and Burundi. Nutrient depletion on its croplands is among the highest of the Sahel, with 30 kilograms of nitrogen, phosphorus, and potassium combined (kg NPK) per hectare in 1983 and as much as 62 kg NPK per hectare between 1993 and 1995.[20] A 1992 map suggested that as much as 75 percent of Burkina Faso was suffering from important to very severe land degradation.[21]

A combination of factors is believed to be at the origin of Burkina Faso's land degradation problem, including repeated cycles of drought, increased population pressure on natural resources, deforestation caused by firewood demands, uncontrolled migration, and inappropriate agricultural and pastoral practices.[22] Population has more than doubled in the last 40 years; average rural population densities have reached more than 80 inhabitants per square kilometer in some provinces, making it one of the most densely populated countries in the West African Sahel. Burkina Faso is also one of the world's poorest countries. Its gross national product per capita was estimated at $240 in 1998, with 65 percent of its rural population below the poverty line.[23] Modern agricultural technology is used very little: Annual fertilizer use in 1994 was just 7 kg per hectare of cropland (mainly on commercial crops such as cotton), compared with a developing-world average of 89 kg.[24] A 1996 report showed that almost 80 percent of all cultivated plots were tilled by hand or not tilled at all.[25]

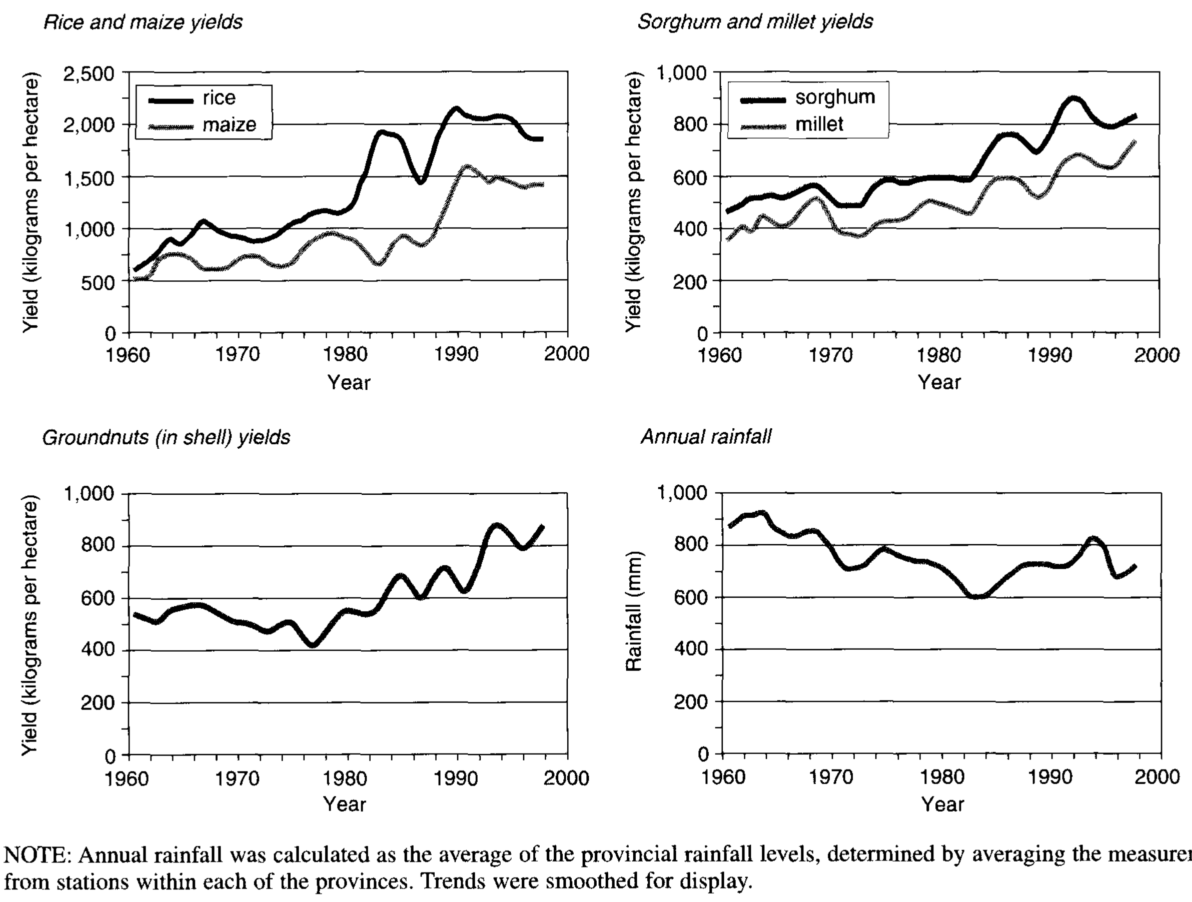
Agricultural Soil Productivity

Detailed estimates of productivity loss caused by soil degradation are hard to find. In a 1999 IFPRI paper, Sara Scherr summarized several global studies that provide productivity loss estimates for Africa.[26] For cropland, losses are estimated at about 0.5 to 1 percent per year, suggesting a productivity loss of at least 20 percent over the last 40 years.

In Burkina Faso, however, major crop yields do not appear to have declined during the last 40 years. In fact, there is evidence of a yield increase, despite a general downward trend in rainfall since the late 1950s (see Figure 2 on this page).[27] This can be attributed in part to the slight reversal of the downward rainfall trend since the mid-1980s and, in the case of maize and rice, to increased irrigation, mechanization, and fertilizer use in some parts of the country. For sorghum, millet, and groundnuts, the yield increase has been more moderate and steady. Because these crops receive little fertilizer and are largely based on hand-hoe cultivation, their yield increase cannot be attributed to the same factors that affect maize and rice, but it can be attributed to a local form of agricultural intensification.

It appears unlikely that the productivity of the land has significantly declined in the last few decades, even taking into account the poor quality of national-

Figure 2. Yield and rainfall trends for Burkina Faso, 1961–1998



NOTE: Annual rainfall was calculated as the average of the provincial rainfall levels, determined by averaging the measurements from stations within each of the provinces. Trends were smoothed for display.

SOURCE: Calculations based on data from Africa Data Dissemination Service, *Rainfall Data for Burkina Faso*, 1998, accessed via http://edcintl.cr.usgs.gov/adds/ on 5 August 1998; Food and Agriculture Organization, *FAOSTAT* statistics database (Rome, 2000), accessed via http://apps.fao.org/ on 23 January 2000; and Météorologie Nationale Burkina Faso, the national meteorological service.

level data. This information on productivity prompts several questions, given the widespread belief that population growth has led to overexploitation of the land. A closer look at the relationship between population pressure and agricultural productivity is warranted.

For this purpose, a spatial analysis was conducted comparing agricultural productivity across a range of provincial population densities.[28] Agricultural productivity was calculated as the total energetic value per hectare (the total amount of calories) produced by all major food crops (millet, sorghum, maize, rice, fonio, cowpeas, Bambara groundnuts, yam, sweet potato, groundnuts, sesame, and soya) averaged over the years from 1993 to 1997.[29] These figures were compared with provincial data on the various pressures on natural resources, technology use, and the environment (see Table 1 on this page for a detailed list of included factors). Figure 3 on page 27 shows the most salient variables in each category. From this analysis it is clear that agricultural productivity per unit of cultivated area is mainly correlated to long-term average annual rainfall—a factor of the environment. Productivity has little correlation to rural population density (which is a factor of pressure on resources) or animal traction (technology).

These relationships are confirmed by a stepwise regression analysis, which was performed by selecting the best predictors from among the variables in Table 1. This regression reveals that agricultural productivity is mainly determined by environmental conditions, for which long-term average rainfall was used as a proxy because rainfall, climate, and soil regimes are highly correlated in this part of the world. Long-term average rainfall contributes more than 80 percent of the explained variance, while pressure on natural resources in terms of population or livestock density is not significant at all. Productivity is influenced by technology only to some degree, and among the technology variables, the animal traction index (which adds another 2 percent to the explained variance) appears to be a more useful proxy than, for instance, fertilizer use.[30]

According to these findings, at the present state of technology use in Burkina Faso, environmental conditions determine productivity more than any other factors. The spatial analysis of the agricultural productivity of cultivated land does not provide any evidence of soil degradation as a result of pressure on soil resources. This not only excludes a doomsday scenario but also suggests that farmers undertake agricultural intensification for other reasons than population density alone. The spatial analysis shows that productivity depends on natural conditions irrespective of population density.

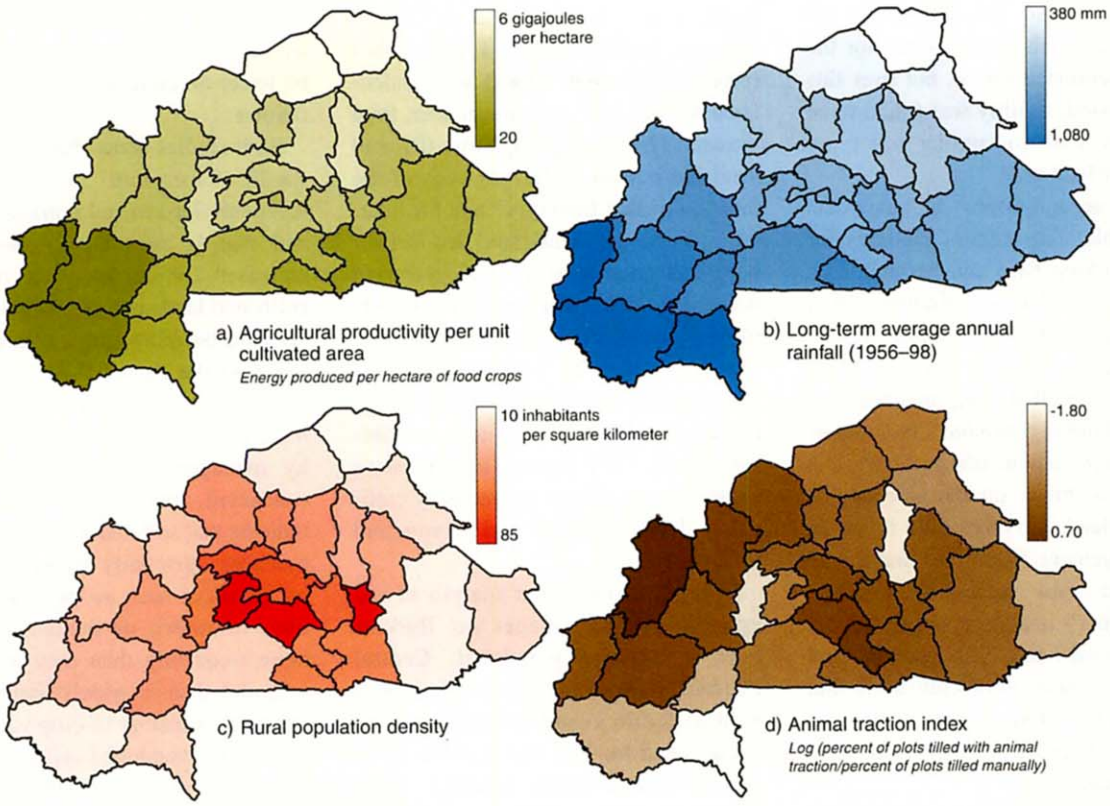
Table 1. Factors included in the analysis of the relationship between pressure on resources and agricultural productivity

Factor	Proxy/Variable
Agricultural productivity (dependent variable)	
Land productivity	Energy production of food crops per hectare
Pressure on natural resources (independent variable)	
Population density	Rural population density on unprotected areas, in inhabitants per square kilometer
Livestock density	Livestock density on unprotected areas, in tropical livestock units, or TLUs, per square kilometer
Proportion of area under cultivation	Percentage of unprotected provincial area under cultivation
Technology (independent variable)	
Animal traction index	Proportion of plots tilled with animal traction/proportion of plots tilled manually
Plow usage	Total plows per cultivated hectare Ox plows per cultivated hectare Donkey plows per cultivated hectare
Fertilizer usage	Total nitrogen, phosphorus, and potassium per cultivated hectare Urea per cultivated hectare
Manure usage	Livestock density on unprotected areas, in TLUs
Soil and water conservation	Percentage of plots with anti-erosive measures
Agricultural extension	Percentage of household heads receiving extension Percentage of household heads receiving extension from the national extension service
Environment (independent variable)	
Climate	Long-term average annual rainfall (1956–98), in millimeters

NOTE: Logarithmic transformations were applied prior to statistical analysis for amounts (measurements that cannot be negative) and counted fractions (such as percentages) in those cases where this improved normality of the distribution. For the environmental conditions, long-term average annual rainfall was used as a proxy because in the Sahel, the rainfall regime is strongly associated with other climatic characteristics as well as the general potential of the soils. See, for example, A. Bationo, F. Lompo, and S. Koala, "Research on Nutrient Flows and Balances in West Africa: State-of-the-Art," *Agriculture, Ecosystems and Environment* 71, nos. 1–3 (1998): 19–35.

SOURCE: D. Niemeijer and V. Mazzucato.

Figure 3. Agricultural productivity and other variables in Burkina Faso



SOURCE: For methods and sources, see V. Mazzucato and D. Niemeijer, *Rethinking Soil and Water Conservation in a Changing Society: A Case Study in Eastern Burkina Faso* (Wageningen, the Netherlands: Wageningen University, 2000).

The Missing Connection

We are faced with an interesting contradiction. There may be some delay between deteriorating soil properties and an impact on productivity, but this can hardly explain the inconsistency between the alarming reports of widespread soil degradation—from as early as the colonial period—and agricultural yields that appear to have increased over the last 40 years.[31] Because Sahelian soils are already very poor in fertility, it is unlikely that degradation processes could have continued for a long time without having repercussions on productivity. We must therefore consider the possibility that changes in soil properties have been grossly overestimated.

Few soil degradation studies actually measure changes in soil properties over a time frame of decades (for shorter time frames, the error margin of chemical analysis is too high to allow for accurate comparison) or analyze changes in soil properties under long-term cultivation as practiced on small family-run farms. Validation of models, if done, is typically based on experimental plot studies, which do not match the diverse conditions and dynamic management practices found on small farms in the region.[32] National-level data on the dynamics of the soil's physical properties are nonexistent, and data on chemical soil fertility are only available for certain areas.

Agricultural Soil Fertility

Soil chemical fertility is usually measured in terms of the amounts of nitrogen, phosphorus, and potassium found in topsoil, and organic matter is a good measure of overall soil health. There are essentially two ways to assess the dynamics of soil chemical fertility on agricultural land: Compare soil fertility data collected a few decades ago with recent soil fertility data collected in the same area; and compare fertility data for long-term uncultivated land with long-term cultivated land. The first approach is problematic because it is difficult to locate exactly the same sites after decades have passed and because changes in land use as well as sampling and laboratory procedures make comparison tricky. The second approach circumvents these problems but does not preclude the possibility that the uncultivated "reference" land has changed in fertility along with the cultivated land.

Using the first approach, data from a French soil survey that was carried out in eastern Burkina Faso in the late 1960s were compared with data from two villages in the same region researched by the authors in 1996. This comparison did not provide conclusive evidence for the reasons mentioned above, but over this 27-year period, fertility was found to be remarkably alike for similar soil types and similar land uses.[33]

For the second approach, more data are available. The authors' findings for eastern Burkina Faso can be compared with Coffi Prudencio's findings from central Burkina Faso.[34] In most of Burkina Faso, as in other parts of West Africa, a so-called ring management system of land is common.[35] In comparing cultivated and uncultivated land, it is important to break up the category of cultivated land into three field types. In ring management, field types that can be recognized with increasing distance from a farmer's residence, or compound, are compound fields, village fields, and bush fields. Duration of cultivation and management intensity generally decrease as one moves farther away from the compound.

In 1996, a total of 124 topsoil samples was collected in two villages in different agro-ecological zones of eastern Burkina Faso. Using a general linear model to correct for factors such as local soil type and soil texture, expected cell means (predicted average values) were calculated for the soil's organic matter, total nitrogen (N), total phosphorus (P), and available potassium (K) for each of the three cultivated field types and for long-term uncultivated land (land that had not been cultivated in at least 20 years but was cultivable).[36] The results of the fertility measurements are summarized in Figure 4 on page 29.[37] All three nutrients (N, P, and K) show higher values on cultivated land than on long-term uncultivated land. Only organic matter shows slightly lower values on intensely cultivated land (village and compound fields).

In Prudencio's similar analysis of soil samples in two villages on Burkina Faso's densely populated Central Plateau, he found cultivated soils to be at least as fertile as old fallows (land left uncultivated for 10 to 40 years) in terms of soil organic matter, available phosphorus, and several other soil fertility indicators. According to this analysis, fertility of fields on upland soils is either higher than or not significantly different from that of old fallows, while for lowland soils only organic matter appears to be lower on cultivated soils than on old fallows.

Both studies show that cultivation on small, family-run farms does not inevitably lead to soil nutrient depletion and that it can actually bring about increased fertility on more intensively cultivated land such as compound fields. As land becomes more scarce, farmers can find the right balance between an increased duration of cultivation and more intensely applied methods of fertility management. Cultivation histories conducted with farmers in the region indicate that soil and water conservation practices—primarily agronomic/biological practices such as localized applications of mulch or thinning—are used more frequently than they were in the past and than is widely assumed. Furthermore, a history of crop varieties that have been abandoned and introduced in the region shows that there are more crops available to farmers than there were a half-century ago. This means that farmers are able to adapt varieties to changing rainfall patterns, conserve moisture, and maintain productivity in a more targeted way. Land management is a crucial factor in understanding environmental sustainability—one that is hardly covered in most soil degradation assessments.[38]

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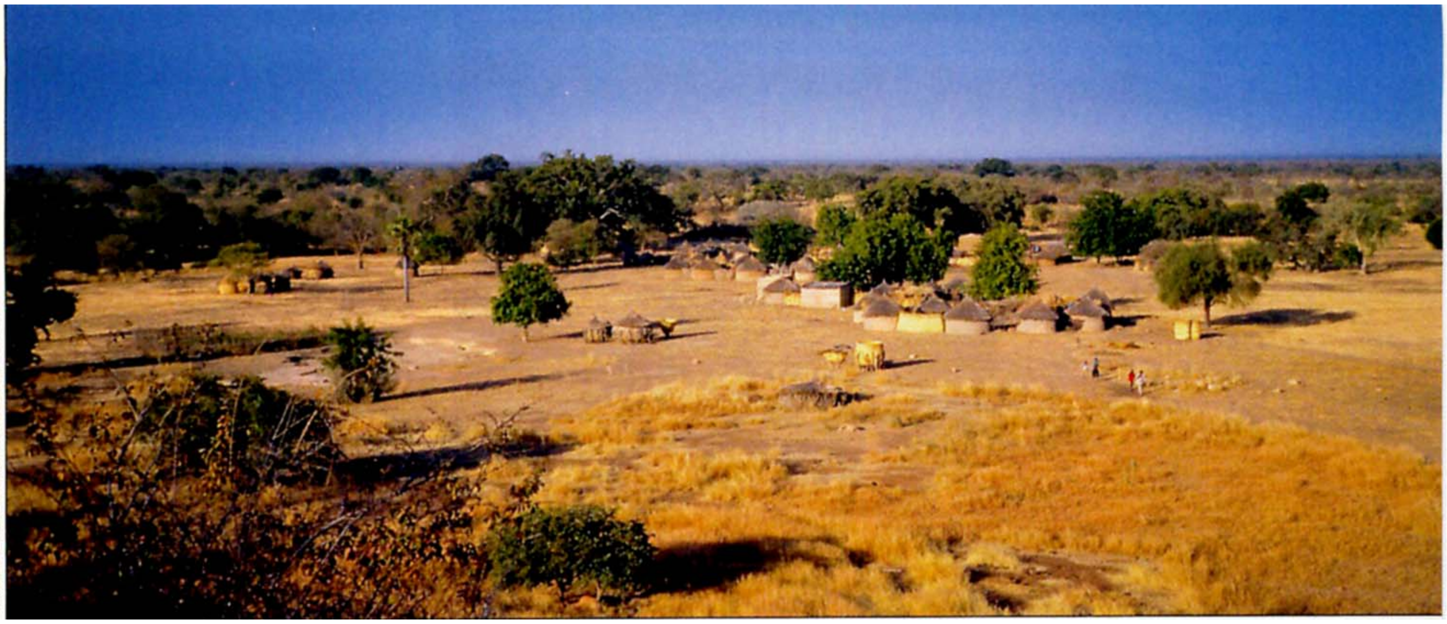
A villager harvests leaves for food next to ripening fields of sorghum and millet, two of Burkina Faso's major crops that are largely based on hand-hoe cultivation.

Social Dimensions of Land Management

In addition to agricultural intensification, use of social networks for agricultural purposes has increased in the area. Villagers create and maintain these networks through monetary and gift transactions as well as through dedicating time to social activities. Networks contribute to environmentally sustainable agriculture in two ways: They help farmers gain access to resources needed to apply soil and water conservation measures, and they allow people to diversify their livelihoods to take pressure off land



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Land lies barren in a village during the dry season. Sahelian farmers prevent and combat soil degradation using a rich repertoire of soil and water conservation practices, including fallowing and selective clearing to regenerate soil.

resources. Social networks are used to access labor in peak periods of the agricultural calendar (to apply the labor-intensive soil and water conservation practices), to access land so that other land can be left fallow to regenerate after a period of cultivation, and to access agricultural technologies such as new crop varieties.

Livelihoods can be diversified in terms of the activities from which people derive income and in terms of the geographical spread of these activities. Through networks, labor can be accessed so as to conduct multiple income-earning activities simultaneously. Also, land-use rights can be obtained for different locations to reduce the risks of conducting agriculture in an area of high rainfall variability or livestock disease. This diversification of livelihoods in activities and geographical spread reduces pressure on land compared with a situation in which people must gain their entire livelihoods by cultivating the land.[39]

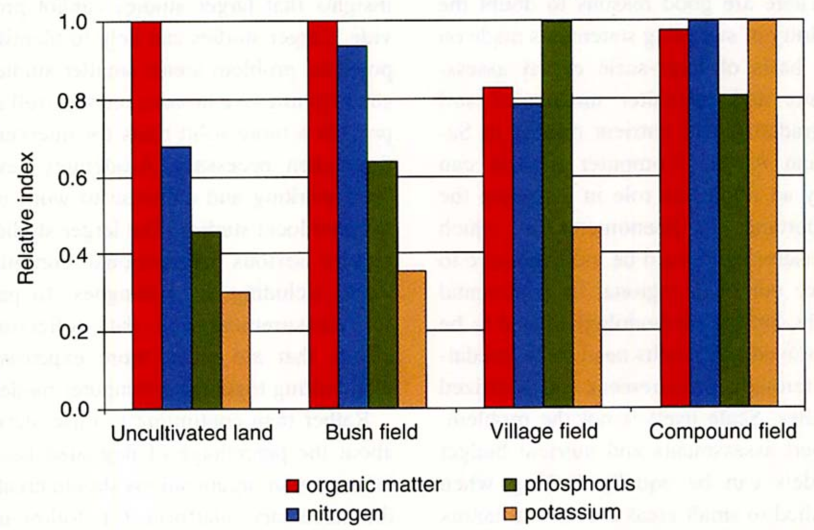
Addressing the Disparity

Overall, there is little supporting evidence of widespread degradation of crop and fallow land in Burkina Faso. While these findings neither preclude localized spots of severe degradation nor suggest that Sahelian soils are particularly fertile, they do call into question widely accepted theories of the relationship between soil degradation and population density. Despite the strong population growth observed over the last 40 years and the relatively high rural population densities found in large parts of the country, a downward spiral of soil degradation and starvation as a result of this growth seems unlikely.

In agreement with Boserup's line of thinking, the evidence from Burkina Faso suggests that some form of agricultural intensification is taking place that allows food production to grow along with population. However, counter to Boserup's ideas, there is little evidence that this form of intensification is based on high use of external inputs such as chemical fertilizer and increased mechanization.

The empirical material presented in this article focuses on the case of Burkina Faso, but the country is sufficiently similar to the other Sahelian countries for soil degradation to be questioned and evidence re-examined in these countries as well. These findings point to weaknesses in the kind of research that underpins current thinking on soil degradation. The discrepancies found between

Figure 4. Soil fertility for different types of land use



SOURCE: Data from V. Mazzucato and D. Niemeijer, *Rethinking Soil and Water Conservation in a Changing Society: A Case Study in Eastern Burkina Faso* (Wageningen, the Netherlands: Wageningen University, 2000).

Farmers harvest a millet field together. Social networks provide farmers access to resources such as labor and land-use rights that they need to maintain their livelihoods.

this assessment in Burkina Faso (based on both productivity indicators and soil properties) and the experiments, expert assessments, and models that form the basis of most soil degradation studies reveal an urgent need to reassess the evidence presented in the global and continental studies on which international and national policies are based. Studies such as GLASOD should be treated as a starting point for further investigation, not as an end point on which to base policy.

There are good reasons to doubt the validity of sweeping statements made on the basis of large-scale expert assessments and computer models of soil degradation and nutrient mining in Sahelian Africa. Computer models can play an important role in assessing the importance of phenomena for which measurement would be too expensive to carry out on a regional or continental scale, but the methodologies need to be improved and results need to be validated through measurement and localized studies. Scale itself is not the problem; expert assessments and nutrient budget models can be equally lacking when applied to small areas if relevant factors such as farmers' management practices are insufficiently taken into account, if erosion estimates or other model inputs show a high uncertainty, or if results are not put into historical perspective and validated against productivity and actual soil data.

What is needed are national or regional studies that combine modeling with a measurement strategy for calibration and validation, thereby providing a means to reassess current environmental policy, as well as detailed local studies that provide insights into causes and effects, historic trends, the role of local land-management practices, and other insights that larger studies cannot provide. Larger studies can help to identify potential problem areas; smaller studies can help improve broader ones as well as provide a more solid basis for intervention when necessary. Academics have been working and continue to work on detailed local studies. The larger studies require serious international commitment, including the willingness to pay for measurement and data-collection efforts that are much more expensive than putting together a computer model.

Rather than continuing to raise alarm about the percentage of degraded land, international organizations should create the necessary platform for follow-up studies that focus on determining exactly where land is degraded and where it is not. This is an essential prerequisite to understanding where and why resource degradation is occurring and what the potential solutions are.[40] Sahelian farmers prevent and combat soil degradation using a rich repertoire of soil and water conservation practices, including stone lines and grass strips to prevent erosion, fallowing and selective clearing to regenerate soil, and manuring and intercropping to manage soil fertility and crop productivity.[41] For policy interventions, detailed and localized knowledge is far more useful than overestimated gross figures.

Assessing soil degradation is much more difficult than is generally realized. Expert assessments and models alone are insufficient given the complex and dynamic reality of Sahelian countries. Results need to be validated against agricultural statistics (such as cultivated areas and yields), environmental data, and management data to make sure that estimations represent reality. Findings that contradict long-standing claims should also serve as stimuli to deepen the insight into fundamental relationships between soil fertility and productivity—the basis on which any critical assessment of soil degradation rests. A major challenge will be to incorporate the effects of farmers' management practices—including their social and institutional dimensions—in estimating soil loss, yield trends, and nutrient budgets.

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NOTES

1. Kofi Annan, Secretary-General of the United Nations, emphasized the problem of soil degradation in the article "Sustaining the Earth in the New Millenni-

um: The UN Secretary-General Speaks Out," *Environment*, October 2000, 20–30.

2. International Food Policy Research Institute (IFPRI) and World Resources Institute (WRI), "Global Study Reveals New Warning Signals: Degraded Agricultural Lands Threaten World's Food Production Capacity," press release (Washington, D.C., 21–22 May 2000).

3. This press release also states, "Degradation is a potential threat to half the world's poor people who live in dryland areas with fragile soils and unreliable rain, especially in Africa. Declining soil fertility has severe impact globally and, in Africa, average yield losses are estimated at 8 percent, with up to 50 percent productivity losses in certain areas." (Food and Agriculture Organization, "Sustainable Land Use and Management Needed to Prevent Soil Degradation," press release 00/27 (Rome, 4 May 2000)). Another press release asserts, "Soil degradation has dramatically reduced crop productivity, with severe consequences likely for poor, heavily populated countries." (IFPRI, WRI, and World Bank, "New Study Reveals that Environmental Damage Threatens Future World Food Production," press release (Washington, D.C., 14 February 2001)).

4. United Nations Environment Programme (UNEP), *Global Environment Outlook 2000* (London: Earthscan, 1999).

5. S. Wood, K. Sebastian, and S. J. Scherr, *Pilot Analysis of Global Ecosystems: Agroecosystems* (Washington, D.C.: WRI and IFPRI, 2000).

6. Ibid., 48–49.

7. L. R. Oldeman, R. T. A. Hakkeling, and W. G. Sombroek, *World Map of the Status of Human-Induced Soil Degradation: An Explanatory Note*, second edition (Wageningen, the Netherlands/Nairobi, Kenya: International Soil Reference and Information Centre/UNEP, 1991).

8. L. R. Oldeman, "The Global Extent of Soil Degradation," in D. J. Greenland and I. Szabolcs, eds., *Soil Resilience and Sustainable Land Use* (Wallingford, U.K.: CAB International, 1994), 99–118.

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37. Expected cell means were converted to an index relative to the highest value of each fertility measure (total nitrogen, organic matter, total phosphorus, and available potassium), so that all fertility measures could be displayed in a single graph. For full results and a more detailed discussion, see Mazzucato and Niemeijer, note 14 above.

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