LONG-TERM ISSUES AFFECTING THE ENVIRONMENT IN WHICH PUBLIC AND PRIVATE ROLES ARE PLAYED OUT

THE GLOBAL SUPPLY OF AGRICULTURAL LAND

Pierre Crosson*

The Land Resource

The question addressed here is the long-term adequacy of the supply of agricultural land to meet global demands for food and fiber. Supply implies a schedule of the costs of providing land at varying levels of demand for it. The costs may be categorized in various ways. I use two categories: (a) costs paid by the farmers who use the land, for convenience I call these on-farm costs; and (b) costs paid by others, here called off-farm costs.

This categorization of costs is useful for both analysis and policy. Neoclassical theory tells us that within the resources and other constraints relevant to them, farmers will manage their resources efficiently, defined as equalization of marginal resource costs and returns. If all costs are on-farm costs, efficiency for the farmer is also efficiency for the society, and no policy issue with respect to efficiency arises. Of course efficient management, so defined, will not necessarily serve equity and other social objectives, but that is another matter, discussed below.

On-Farm Costs

These costs are those the farmer pays for use of the land, that is, land rents or their equivalent in opportunity costs, costs of land clearing and draining, of soil conservation, and any other costs of maintaining or enhancing the supply of land used by the farmer. Because the farmer pays these costs they will be reflected in the prices of agricultural output. They are, therefore, economic costs.

Off-Farm Costs

These are costs of the way farmers manage their land that are imposed on others. Examples are yield losses of downstream farmers because of rising salinity levels in irrigation return flows of upstream farmers; losses of downstream recreational values because of sediment discharges of upstream farmers; and losses of biological diversity and other off-farm habitat values when land is cleared and drained for agricultural production.

The examples indicate that some off-farm costs are economic--they show up in higher prices of agricultural or other goods and services; and some are not--they are unpriced and so are not

* Senior Fellow, Resources for the Future, Washington, D.C.

reflected in prices of marketed output. I call these unpriced costs, for example losses of biological diversity, environmental costs.

If those who bear off-farm costs could exact compensation from the responsible farmers, then the farmers would incorporate the costs in their land management decisions, and the resulting patterns of land use could be presumed to be socially efficient. Typically, however, the technical and institutional conditions relevant to off-farm costs are such that the cost of exacting compensation, the transactions costs, are higher than the off-farm costs. For example, those suffering downstream losses of recreational values typically have no property rights in the stretch of river between them and the responsible upstream farmers, so no market emerges in which downstream owners could routinely charge upstream farmers for their use of the river as a sediment dump. Lacking such a property right, the only way downstream people can exact compensation, if extra-legal means are ruled out, is through the courts, a costly alternative with the costs rising exponentially as the number of downstream people and/or upstream farmers increases.

In the general case, therefore, farmers do not pay off-farm costs so they treat them as zero and manage their land accordingly. The result is efficient for farmers but not for society because the marginal social benefits are zero and the corresponding costs are positive. Whatever the equity or other grounds for social interventions in land management decisions, off-farm costs make a presumptive case for intervention on efficiency grounds.

Meaning of Adequacy

The concept of adequacy implies a standard for judging performance. The standard used here is the effect of land supply on on-farm and off-farm costs of agricultural production. If these effects are such that the costs are not "socially acceptable," then the supply of land would be judged inadequate. "Socially acceptable" is put in quotes to indicate that there is no precise meaning to the expression. The definition of socially acceptable costs will vary among regions and social groups within countries, across countries, and over time. Despite its vagueness, however, the concept of socially acceptable costs underlies and gives meaning to the current discussion of sustainable agricultural development with its emphasis on efficiency and equity issues, both within and across generations. A sustainable agriculture can be defined as one which does not generate socially unacceptable costs, within and across generations. It follows that the supply of agricultural land can be judged adequate when it does not violate this criterion of sustainability.

Scale Issues

The definition of the adequacy of agricultural land supply contains three scale dimensions: temporal--long term; spatial--global; and quantitative--the amount of demand for food and fiber. Long term here means the period from the late-1980s to 2030, a useful terminal date because it was the target year in recent work on sustainable agriculture done for the World Bank (Crosson 1991). This 40-year period is long enough to be interesting for discussion of intergenerational issues in sustainability analysis but not so long as to stretch beyond the range of plausible speculation about trends in demand, technology, and land use.

The spatial dimension is global because the international trading system in agricultural commodities provides regions and nations the option of overcoming land (and other) resource constraints by substituting imports for domestic production. For this reason, the supply of agricultural land is truly global, and the question of its adequacy must be addressed at that scale. To be sure, a drive for increased food self-sufficiency or a wish to pacify domestic farmers may lead some governments to make less use of the trading option than emerging land (or other) resource constraints would indicate to be in the national economic interest. The strength of the trading system indicates, however, that most governments place high value on the trading option. This is not to say that the trading system could not be weakened by increasing protectionist policies. Should this happen, it would diminish the global supply of agricultural land. Should the trading system be strengthened, the global land supply would be increased. In this paper it is assumed that the trading system remains about as it presently is over the next several decades, thus being neutral in its effects on the global supply of agricultural land.

Other things staying the same, the probability will be higher for an adequate global supply of agricultural land over the next 40 years, the lower global demand is for agricultural output. Thus the quantitative dimension of the adequacy issue must be taken into account. In work done for the World Bank (Crosson 1991), a demand scenario was developed in which global grain consumption about doubles from the late-1980s to 2030. (Demand for grain is taken as a proxy for demand for all agricultural output). In the developing countries of Asia, Africa, and Latin America grain consumption, driven by both population and per capita income growth, increases 2.7 times. In this paper these numbers provide the quantitative dimension in the discussion of the land adequacy issue.

Adequacy of Land Supply

Meaning of Land Supply

The question, then, is whether the supply of land over the next 40 years will be adequate to accommodate a doubling of global agricultural demand--2.7 times in the developing countries--at socially acceptable on-farm and off-farm costs. In the short run the supply of land reflects two conditions. One is the physical characteristics of the soil, which affect its productivity in agricultural production, primarily topsoil depth, percent organic matter, soil water holding capacity, and soil acidity. The second condition is the number of hectares that can be brought economically into production without significant new investments to enhance or restore soil productivity, or to extend the cultivated area by clearing and drainage, or to expand the transport and institutional infrastructure serving agriculture into new areas, or to bring irrigation into arid and semiarid areas previously closed to agriculture by water scarcity.

In the long run these soil productivity and area extending investments affect the supply of agricultural land, as does competition from nonagricultural uses of the land, for example, for urban development. In this paper the focus is on long-run land supply.

In this formulation the supply of land is increased by investments to improve the physical characteristics of the soil and to extend the agricultural area, but not by investments in new yield-increasing technology for use on currently farmed land or to improve the managerial capacity of farmers. There is a certain arbitrariness in these distinctions, but they are useful for both analysis and policy. Analytically agricultural production capacity can be thought of as a function of the quantity and quality of the land (the supply of land) and of the quantity and quality of the nonland inputs combined with the land. Policies to expand capacity, therefore, must seek patterns of investment that give proper weight to expanding land supply and to developing new knowledge, embodied in technology and people, which can be combined with the land. In this paper I focus on the potential for increasing land supply. The role of new technology and other forms of knowledge is discussed elsewhere in this symposium and also in Crosson (1991).

Buringh and Dudal (1987), using Food and Agriculture Organization (FAO) data, indicate that globally there currently are some 1500 million hectares of cropland and another 3,000 million and 4,100 million hectares of grassland and forestland, respectively. A thousand million hectares of the grassland and 800 million hectares of the forestland are judged to have the climate, topographic and soil conditions giving them high, medium, or low potential for conversion to crop production (see table 1).

Table 1. Land in Various Uses Classified by Potential for Crop Production (million hectares)

	Land Capability Class for Crop Production				
Land Use	*High*	*Medium*	*Low*	*Zero*	*Total*
Cropland	400	500	600	0	1,500
Grassland	200	300	500	2,000	3,000
Forestland	100	300	400	3,300	4,100
Other	0	0	0	4,800	4,800
Totals	700	1,100	1,500	10,100	13,400

Source: Buringh and Dudal (1987). The data are said to be for 1975, but in the literature they still are used to represent the present situation.

If all of the grassland and forestland with some potential for crop production (1,800 million hectares) could be brought into cultivation over the next 40 years at socially acceptable costs, the total amount of cropland would more than double, indicating that the doubling of global crop demand over that period could be accommodated without any increase in crop yields. This outcome, however, is quit unlikely because the costs of doubling the amount of cropland almost surely would not be socially acceptable. There are several reasons, discussed under the following headings: (a) costs of spatial distribution; (b) opportunity costs; (c) infrastructure costs; (d) land quality costs; and (e) off-farm sediment costs.

Costs of Spatial Distribution

Buringh and Dudal (1987) estimate that the developing countries "presently" have 1,392 million hectares of potential cropland (table 2). Because the Buringh and Dudal estimate of global potential is 1800 million hectares (table 1), the implied estimate for the developed countries is 408 million hectares. By these calculations the developing countries have 77 percent of the potential cropland and the others have 23 percent. (Note that these calculations assume that Eastern Europe and the republics of the former Soviet Union are developed countries). Among the developed countries of Western Europe, North America, and Oceania it seems unlikely that much of any presently potential cropland will be drawn into production over the next 40 years. In the United States present thinking is that cropped land will decline some tens of millions of hectares over that period (U.S. Department of Agriculture 1990). I have not assessed prospects in other developed countries, but I judge it likely that group of countries as a whole will continue to hold tens if not hundreds of millions of potential cropland over the next several decades.

Among the developing countries 45 percent of the potential cropland is in Africa and 50 percent is in South America (table 2). The remainder is in Central America and scattered across the regions of Asia.

Table 2. Present and Potential Cropland in the Developing Countries (millions hectares)

	Africa	*S.W. Asia*	*S.E. Asia*	*Central Asia*	*South America*	*Central America*	*Total*
Present	168	69	274	113	124	36	784
Potential	621	0	23	14	695	39	1,392
Total	789	69	297	127	819	75	2,176

Source: Calculated from Buringh and Dudal (1987), table 2.6, p. 22.

There is no particular reason in economics why the unequal distribution of unexploited cropland in the developing countries should, per se, be an obstacle to the use of that land as a resource available to them all. In principle, the better endowed countries could export to those less favored with potentially cultivable land. But in many, perhaps most, of the developing countries, there are strong political pressures to increase the percentage of domestic food demand met by domestic production. Consequently, from the standpoints of Asian countries, a hectare of uncultivated potential cropland in the developed countries or in Africa and South America is surely not equivalent to a hectare within their own borders. I do not expect the Asian countries to be driven to a policy of food autarchy by the land constraint in that region. The point, rather, is those countries are not likely to view the relative abundance of land in Latin America and Africa as a readily available resource to overcome their own land scarcity. To the extent that this is true, the cost to Asian countries of drawing on potential land elsewhere to meet their needs would be unacceptably high and the global supply of potential cropland shown in tables 1 and 2 would be correspondingly overstated.

Opportunity Costs

Converting all the land now in grass and forest with potential for crop production to that use would reduce grassland by one-third and forestland by one-fifth (table 1). I have made no projections of the demand for grass and range fed animals or for forest products, but population and per capita income growth, especially in the developing countries, suggests that these demands will increase steadily, if not sharply, over the next 40 years. Accommodating these demands at acceptable costs on one-third less grassland and one-fifth less forestland would require substantial increases in animal and timber yields on the remaining land in these uses. Whether the necessary yield increases could be achieved has to considered problematical, in my judgment. If yields fail to increase enough on the reduced land base to satisfactorily accommodate the higher demands, the opportunity costs of converting the grassland and forestland to crops would rise, constraining the supply of land for crop production.

Conversion of grassland and forestland also would incur opportunity costs in the loss of a variety of mostly unpriced yet socially important environmental services provided by these lands. Grassland and forests, particularly forests provide rich habitat for plant and animal species of high current and potential value. Hunters and lovers of wildlife spend billions of dollars each year enjoying habitat services.

Land clearing, particularly of forests, also incurs opportunity costs because of the loss of plant and animal species that clearing entails. E.O. Wilson (1989, p. 108) refers to the plant and animal genepool as the store of "biological wealth," and describes it as "... a potential source for immense untapped material wealth in the form of food, medicine, and other commercially important substances." Wilson's assessment is widely shared, although no one can accurately estimate the social value of the genepool. Even the number of species is unknown, Wilson (1989) citing estimates that range from 1.4 million to 30.0 million. Whatever the size of the plant and animal genepool, there is much agreement within and across countries that maintaining the pool at some level is important for the welfare of both present and future generations.

Forests and wetlands (some of which are forested) also provide valuable social services in connection with the hydrological cycle. On land with a given topography runoff of water from forested land generally is less (infiltration is more) than on cleared land. Relative to cleared land, therefore, forests help to moderate seasonal fluctuations in stream flows and fluctuations resulting from storm events. Wetlands provide a similar service.

Property rights in these various environmental services of grasslands and forestlands (including wetlands) are poorly developed, or nonexistent so markets mediating demand and supply conditions for the services are weak or entirely absent. The absence of market signals--prices--for the services leads farmers to underestimate their social value in making decisions to convert grassland and forestland to crops. The world environmental movement, however, has begun to substitute for markets to register the social value of the services. The movement, which includes influential members of the world community, brings pressure on the World Bank, the U.S. Agency for International Development, and governments, particularly in the developing countries, to exert more control on land clearing to protect the various environmental values under threat. Efforts to persuade the Brazilian and other governments in tropical areas to slow if not halt forest clearing provide the most prominent example of this pressure for control. So far these efforts have met with little success, but there is every reason to believe that they will continue. If the perceived values at risk are in fact high- -I believe that they are--then in time the efforts to reduce the rate of land conversion likely will find some measure of success. In this case the realizable cropland potential would be less than the numbers in tables 1 and 2 suggest.

Finally, continued urban development, particularly in the developing countries, may increase the opportunity cost of keeping land in, or converting it to, agricultural uses. A simple, if not simple-minded, way to project the future increase in the amount of land in urban uses around the world is to estimate the future amount of such land per capita and then multiply by projections of population. The problem with this approach is that there are no comprehensive data on the present amount of per capita urban land use. A comprehensive search of the literature revealed this. Enough data are available, however, to provide a very rough estimate of global average present urban land use of 0.05 hectares a person. The basis for this estimate is described in some detail in Crosson (1991).

The United Nations Centre for Human Settlements (1987) projected global urban population to increase from 2,234 million in 1990 to 4,932 million in 2025. Ninety-two percent of the increase would be in the developing countries, with Asia (excluding Japan) accounting for 55 percent, Africa for 25 percent, and Latin America for 12 percent. The 215 million increase in developed countries' urban population would take relatively little of the present and potential agricultural land in those countries. The increase in Africa (684 million people from 1990 to 2025) would take 34.2 million hectares (at 0.5 hectare a person), 4 percent of present and potential cropland in that region (table 2). In Latin America the urban population increase would take about 17 million hectares, about 2 percent of the present and potential land in crops. In Asia the projected 1,471 million increase in urban population would take 74 million hectares, 15 percent of present and potential cropland.

These comparisons must not be pressed too hard, not only because of uncertainties about the data and the projections of urban population, but also because mere numbers of hectares of present and potential cropland tell nothing about the technical, economic, and institutional conditions that convert the numbers into estimates of the supply of agricultural land. Nevertheless, the data and related discussion provide reasonably strong support for three generalizations: (a) over the next several decades, the conversion of land to urban and built up uses is not likely to constrain the supply of agricultural land in developed countries as a whole; (b) African and Latin American countries should be able to accommodate demands for urban land without seriously depleting the supply available for agriculture; (c) in Asia urban pressure on the land looks to be substantially greater than in Africa or Latin America. But even in Asia urbanization does not appear to be a major threat to the future supply of agricultural land.

Infrastructure Costs

Much of the potential cropland in the developing countries, especially in Latin America and Africa where most of it is, lies far from domestic and foreign markets and is poorly connected by road, rail, and air to those markets. In Africa this lack of transportation infrastructure perhaps is even more of a constraint to opening new land to crop production then in South America. According to a Consultative Group on International Agricultural Research (CGIAR) report, there are only 206,000 kilometers of roads in the fourteen landlocked countries of Africa. And the railroad system was developed in the colonial era primarily to link inland areas with ocean ports through which exports flowed out and imports flowed in. Consequently Central Africa, because of its vast distances from ocean ports, has no major rail links within the region, "in spite of its agricultural potential" (CGIAR 1988).

In both Africa and South America the cost of building the transportation and communication infrastructure necessary to move production inputs to the regions and take production out has to be counted as part of the cost of realizing the cropland potential of the two regions. I have not searched the literature for estimates of these costs, but they clearly imply that a hectare of potential cropland in

Africa and Asia is not the economic equivalent of a hectare already in production and therefore served by such an infrastructure.

Investments in irrigation in arid and semiarid areas extend the supply of agricultural land by opening up land previously closed to cropping by water scarcity. Yet there is some ambiguity in regarding irrigation investments as land extending rather than yield increasing. Much irrigation, particularly in east Asia, is not in arid or semiarid areas, and is designed to increase yields on already cropped land by smoothing out seasonal fluctuations in water supply and increasing security of supply. Moreover, the aggregated data on global quantities of irrigated land do not separate that in arid and semiarid areas from that in semihumid and humid areas. For these reasons my treatment here of irrigation investments as increasing land supply is not as sharply focused as I would like it to be.

In 1986, global irrigated land was 253 million hectares (World Bank/UNDP 1990). Almost two-thirds of this was in five countries: India (56 million hectares), China (46 million hectares), the United States (23 million hectares), the Soviet Union (21 million hectares), and Pakistan (16 million hectares). Of the 253 million hectares, 185 million (73 percent) were in the developing countries. India, China, and Pakistan alone accounted for 118 million hectares, 47 percent of the world total and 64 percent of the developing countries total. The next three most important developing countries in irrigated hectares were Indonesia (7.3 million), Iran (5.8 million), and Mexico (5.3 million).

The importance of irrigation in world agricultural production, especially in Asia, is apparent. But how much potential is there for continued expansion of irrigated land over the next several decades? The World Bank/UNDP (1990), citing the FAO, the International Commission on Irrigation and Drainage (ICID), and World Bank sources estimates that there are an additional 137 million hectares worldwide, which have potential for irrigation, although noting that the estimate is speculative because it depends not only on the physical resource base but also on future economic conditions.

Table 3 shows the estimates of remaining land with potential for irrigation. Globally 137.5 million hectares of potentially irrigated land remain, 80 percent of it in the developing countries. Although the greatest potential increases in percentage terms are in South America and Sub-Saharan Africa (217 percent and 477 percent, respectively), the greatest absolute potential is in the Far East, with 69.4 million hectares. This is 58 percent of the total potential increase in the developing countries. Table 3 does not show it, but almost 60 percent of the developing countries potential is in just three countries: Brazil, China, and India (World Bank/UNDP 1990, p. 104). India and China plan to develop virtually all of their remaining potential by 2000 (World Bank/UNDP 1990, p. 104).

These estimates of potentially irrigable land must be treated with the same caution as those for all potential cropland because they don't take into account a host of economic and institutional constraints which likely will hold actual expansion of irrigated area well below the potential indicated in table 3. The constraints are considered in some detail in Crosson (1991). Briefly, they reflect deeply ingrained inefficiencies in management of irrigation systems; rising construction costs because the most favorable sites have already been developed; unfavorable natural conditions of topography and precipitation; lack of people trained in managing large-scale irrigation projects, especially in Africa; rising and potentially powerful competition from urban and other nonagricultural uses of water, for example, to maintain instream plant and animal habitat; and inadequate control of salinity and waterlogging. To be sure some of these constraints can be eased. With sufficient political will and investments in training, management can be improved; and techniques for controlling salinity and waterlogging are well known. But other constraints, such as rising costs and increasing competition from nonagricultural uses of water, will remain and limit future expansion of the irrigated area.

Table 3. Presently Irrigated Land and Land with Irrigation Potential

	Presently irrigated (000 hectares)	*Potentially irrigable (000 hectares)*	*Potential increase (percent)*
Developed countries	68,000	27,000	40
Developing countries	186,000	110,500	59
Africa	11,025	18,175	165
North	7,560	1,640	22
Sub-Saharan	3,465	16,535	477
Latin America	16,265	22,865	141
North and Central	7,035	2,865	41
South	9,200	20,000	217
Asia	158,380	69,420	44
Near East	18,315	5,185	28
Far East	140,065	64,235	46

Source: World Bank/UNDP 1990, p. 115.

The Quality of Potential Cropland

There is a presumption that the quality of potential cropland generally is less than that of land already in crop production because typically the better land would be developed first. The data in table 1, rearranged as in table 4, support this view.

Table 4. Distribution of Present and Potential Cropland by Quality (percent)

	Present	*Potential*
High	27	17
Medium	33	33
Low	40	50

Source: Derived from table 1.

These land quality differences are not dramatic, but they suggest, nonetheless, that the costs of crop production on the potential land would tend to be higher than on land already in production. On this score also, therefore, a hectare of potential cropland cannot be regarded as the economic equivalent of a hectare already in crop production.

Off-Farm Sediment Costs

When soil eroded from farmers' fields is carried by runoff to waterways it imposes a variety of damages such as reduced life of reservoirs because of accelerated siltation, impaired water-based recreational values because of turbidity, increased flooding damage because sedimentation lifts streambeds, and damage to fish spawning areas in streams. Eckholm (1976) published evidence indicating that the costs of these damages were high all around the world, especially in the developing countries. A number of more recent World Bank reports are generally consistent with Eckholm's assessment.

Although firm data are lacking, there is a general presumption that the potential cropland around the world is likely to be more erosive when converted to crop production than land already in crops. The presumption is based on the idea that the least erosive land would be cropped first. But even if the potential cropland would be no more erosive than presently cropped land, converting it to crops would surely result in a vast increase in erosion because the per hectare rate of cropland erosion is several times that of grasslands and forestlands. Such an increase in erosion likely would cause a substantial increase in off-farm sediment damages. Because these damages already are high, the prospect of making them even higher would probably induce a variety of public measures to avoid or at least moderate the increase. The surest way to achieve this would be to control the conversion of grassland and forestland to crops. To the extent that these measures were successful, potential cropland would be less than indicated in table 1.

Summary

The skewed spatial distribution of potential cropland globally and the prospective economic and environmental costs of bringing it into crop production strongly suggest that the realizable potential is far less than the doubling of area suggested by table 1. Among the developing countries, where most of the increased demand for agricultural output will occur, Africa and Latin America clearly have more potential for increasing the supply of land than Asia, but even in those areas the various cost constraints probably will keep the expansion of cropland well below the apparent potential.

Cost of Maintaining and Enhancing Soil Productivity

As noted at the outset the long-run supply of land is a function not only of the quantity of land but also of its productivity as determined by such soil characteristics as topsoil depth, percent organic matter, soil acidity, and water holding capacity. Investments and management practices to protect and enhance these soil characteristics support and extend the supply of land just as do investments to bring additional land into production.

The discussion here focuses on some of these aspects of soil quality, on various processes tending to degrade quality, and on measures to protect and enhance quality. Most of the discussion concerns the developing countries, with occasional references to the developed countries.

Soil Characteristics in the Developing Countries

Table 5 shows estimates of the quantities of different soils in the tropics and in the semiarid tropics of Africa and Latin America. The three soil orders, Oxisols, Alfisols, and Ultisols, account for over 55 percent of the tropical soils and for 46 percent and 47 percent, respectively, of the soils in the semiarid tropics of Africa and Latin America. Stewart, Lal, and El-Swaify (1991) describe these as "low-activity clay" soils and Lal (1984, p. 76) states that they "exhibit little swell-shrink capacity. On drying, most of these soils become hard and have unusually high strength...", which inhibits seedling emergence.

Table 5 indicates that Aridisols account for 21 percent of tropical soils and 30 percent and 14 percent, respectively, in the semiarid tropics of Africa and Latin America. Stewart, Lal, and El-Swaify (1991, p. 131) write that these soils are relatively low in organic matter and that in most years their moisture content is inadequate to mature a crop without irrigation.

Table 5. Land Area in Different Soils in the Tropics and Semiarid Tropics of Africa and Latin America (million hectares)

		Semiarid tropics of	
Soil order	*Tropics*	*Africa*	*Latin America*
Alfisols	800	466	107
Aridisols	900	440	33
Entisols	400	255	17
Inceptisols	400	38	-
Mollisols	50	-	78
Oxisols	1,100	188	-
Ultisols	550	24	8
Vertisols	100	51	-
Totals	4,300	1,462	243

Source: Adapted from Stewart, Lal, and El-Swaify (1991, table 3.3, p. 132). For a brief description of the soil orders, see the text.

Lal (1984, p. 77) notes that after a "relatively long period of natural or planted fallow" the organic matter content of the surface layer of tropical soils, in general, is comparable to that in temperate region soils. However, the organic matter in tropical soils typically is concentrated in the top 5 to 10 centimeters. With land clearing, the soil organic matter is oxidized at a rate about four times faster than in temperate zone soils, and declines sharply in as little as 2 or 3 years. This is particularly significant for the low-activity clay soils, such as the Oxisols, Alfisols, and Ultisols, because in these soils "...organic matter plays a very important role in improving structural stability, decreasing compactibility, improving soil available water and nutrient resources, decreasing leaching losses, and enhancing biological activity of soil fauna (for example, earthworms, etc.)" Lal (1984, p. 77-8).

Lal (1986) developed a three-point rating system for classifying the principal tropical soils according to factors that constrain their productivity in cultivation. Table 6 shows this classification system. With the exception of trafficability and chemical and nutritional status, productivity of the

Alfisols is seriously constrained for cultivation. These soils make up 19 percent of all tropical soils (table 5). The Oxisols and Ultisols, which jointly account for another 38 percent of all tropical soils are severely-to-moderately constrained by all the factors except soil crusting and trafficability. Note that the least constrained soils, the Mollisols, account for only 50 million hectares in the tropics (a little over 1 percent of the total). In the United States the 232 million hectares of Mollisols make up 26 percent of the total (Stewart, Lal, and El-Swaify 1991, p. 132).

Table 6. Soil-Related Constraints to Use of Tropical Soils for Cultivation

	Oxisols	*Ultisols*	*Alfisols*	*Inceptisols*	*Vertisols*	*Mollisols*
Erosion	2	2	3	3	3	1
Compaction	3	3	3	3	3	2
Crusting	1	1	3	3	2	1
Drought	2	2	3	1	2	1
Shallow rooting depth	3	3	3	1	2	1
Trafficability	1	1	1	1	3	2/3
Supraoptimal soil temperatures	2	2	3	3	2	2
Chemical and nutritional	3	3	2	1	2	2/3

Source: Steward, Lal, and El-Swaify (1991, p. 132), from Lal (1986).
Note: 3 is severe, 2 is moderate, and 1 is slight.

Because of these characteristics of tropical soils they are widely referred to as "acid and infertile," and many observers have concluded that the potential for increasing the productivity of the soils is low. A growing body of evidence exists, however, suggesting that this view may be more pessimistic than is warranted. Sanchez (1991) reports the results of research he and colleagues have done over more than a decade on production systems in the tropics of Latin America that indicate that tropical soils can in fact be much more productive than conventional wisdom suggests. Sanchez (1992, p. 115) states that the research results point to the conclusion that sustainable agriculture is feasible on humid tropical soils. "The classic form of high-input agriculture that feeds the world, including the green revolution areas in the tropics, is technically feasible in the tropics." To be economical the systems require a high level of farm management and a transport and marketing infrastructure to supply inputs of nutrients and to move production out. But with the investments needed to provide these services, Sanchez's results indicate that the productivity constraints imposed by the "acid-infertile" soils of the humid tropics can be substantially eased.

In dryland areas (less than 800 millimeters of annual precipitation) where irrigation is not feasible techniques to restore soil water holding capacity or increase water retention can increase the supply of agricultural land. Practices, which maintain crop residues on the land, help to build soil organic matter, not only increasing the soil nutrient supply but also restoring soil water holding capacity where it has been impaired. Crop residues also reduce water runoff with corresponding increases in soil moisture.

Over the last decade or so the planting of vetiver grass has emerged as a technique with a variety of favorable effects on soil characteristics. The grass is planted along field borders in the direction of runoff and in a few years grows into a thick, high hedge. Runoff is greatly reduced, with corresponding increases in water retention, and soil eroded from upslope collects behind the hedge, increasing soil rooting depth. Nelson (1988, p. 13) asserts that vetiver grass is "exciting, with potential for a significant impact..." for increasing the productivity of soils under threat of erosion and low moisture retention capacity.

Compared to so-called engineering techniques for controlling runoff and erosion, for example, the building of terraces, the use of vetiver grass and other vegetative materials is not difficult to master by individual farmers and is low cost, involving little investment apart from the farmer's time. How much these techniques might contribute to expanding the global supply of agricultural land over the next several decades is unknown, but there clearly seems to be some potential.

Land Degradation

Erosion, soil compaction, soil salinity buildup and water logging degrade the productivity of the soil by, variously, reducing the rooting zone and soil porosity, impairing soil water holding capacity, removing soil organic matter and nutrients, and generally creating a soil environment hostile to desired plant growth.

Soil degradation is widely believed to be a major threat to the present and future supply of agricultural land, especially in the developing countries but also in some of the developed countries, for example, the United States, Canada, and Australia. The fact is, however, that apart from the United States, very little is known about rates of land degradation around the world and its soil productivity consequences (Nelson 1988; Dregne 1988; Stocking 1984).[1] In the United States, the one country where data have permitted comprehensive analyses of the degradation issue, the results indicate the productivity consequences have been exaggerated greatly. Research by soil scientists and economists with the U.S. Department of Agriculture (USDA) reported in Alt, Osborn, and Colaccio (1989), by soil scientists at the University of Minnesota (Pierce and others 1984) and by economists at Resources for the Future (Crosson 1986) shows that continuation of 1980s' rates of cropland erosion for 100 years in the United States would reduce yields at the end of the period 5 to 10 percent relative to what they would be in the absence of erosion. Over the 40-year horizon considered here the erosion-induced yield decline would be even less.

There are two ways to view this result. One is that even if the rate of technology driven crop yield increases in the United States were to fall to one-half the 1.5 to 2.0 percent annual rate achieved over the last 40 years, the increase would swamp the negative effect of erosion. The other is that even if erosion-induced losses of soil productivity were driven to zero in the United States the contribution to extending the supply of agricultural land would be minor--a few percent--and the cost would be high. (Studies at the USDA show that the marginal cost of reducing erosion rises steeply as the remaining amount of erosion declines.)

The experience of the United States with respect to soil erosion probably is not a good indicator of experience in other countries, especially in the developing countries. Tropical soils generally are more susceptible to erosion than temperate zone soils (Stocking 1984; Lal 1984). Moreover, unlike other countries, the United States has had a substantial soil conservation program in place for almost 60 years.

Except in Africa, grain yields in the developing countries have increased at a faster rate than in the United States over the last three decades, suggesting that whatever the productivity effects of erosion and other forms of land degradation in those countries, they have not yet been major. (The reasons for poor yield performance in Africa are much debated. Land degradation may be one but perverse government policies toward agriculture probably are more important.) The failure of land degradation effects to show up so far in the developing countries does not mean that they may not eventually, with significant negative consequences for agricultural land supply. There is no convincing present evidence that this will happen, but the possibility that it may cannot be ruled out.

Conclusion

The likelihood of expanding the supply of agricultural land enough to accommodate at acceptable costs a doubling in global demand for agricultural output and a 2.7 times increase in demand in the developing countries over the next 40 years is small too negligible. Some extension of the agricultural area no doubt can be achieved at acceptable costs, and some acceptable increase in land supply by protecting and enhancing soil productivity also should be manageable. How much these measures might increase land supply is completely uncertain. I hazard a guess, based admittedly on no tangible evidence, that such an increase would not exceed one-fourth to one-third from the present base.

The implication is that the global supply of agricultural land will be inadequate to accommodate the prospective increase in global demand. Satisfying that demand at acceptable costs will require major, sustained increases in knowledge about agricultural production and how to manage its off-farm consequences. How to achieve the necessary knowledge increases is the critical question in achieving sustainable agricultural production. But the question lies outside the bounds of this paper.

Endnotes

1. Oldeman, Hakkeling, and Sombroek (1991) have published a map showing the severity of human-induced soil degradation in the world. The map covers the land surface between 72 degrees north and 57 degrees south, an area of 13,013 million hectares. Some 1,964 million hectares are degraded to some extent: 746 million hectares (38 percent) lightly, 903 million hectares (46 percent) moderately, 295 million hectares (15 percent) strongly, and about 19 million hectares (less than 1 percent) severely. Interpretation of these numbers is uncertain because of some ambiguity in the definitions of severity of erosion. For example, the map shows much of the American Midwest to be "moderately to severely" degraded, meaning that the productivity of the soil has been "greatly reduced" and could be restored only with "major improvements." Yet crop yields in this region have increased sharply and steadily over the last 40 years, and leading American soil scientists consider soils in the region to be in generally good condition.

References

Alt, K., C. Osborn, and D. Colaccio. 1989. "Soil Erosion: What Effect on Agricultural Productivity?" Agriculture Information Bulletin 556, U.S. Department of Agriculture, Economic Research Service, Washington, D.C.

Buringh, P., and R. Dudal. 1987. "Agricultural Land Use in Time and Space." In M. Wolman and F. Fournier, eds., *Land Transformation in Agriculture.* SCOPE 32. New York: John Wiley and Sons for the Scientific Committee on Problems of the Environment.

CGIAR (Consultative Group on International Agricultural Research). 1988. *Sustainable Agricultural Development: Implications for International Agricultural Research.* TAC Secretariat. Rome: FAO.

Crosson, P. 1991. "Global Food: Resources and Prospects." A draft background report for the *World Development Report 1992*, Department of Agriculture and Rural Development, Washington, D.C.: World Bank.

------. 1986. "Erosion and Policy Issues." In T. Phipps, P. Crosson, and K. Price, eds., *Agriculture and the Environment.* Washington, D.C.: Resources for the Future.

Dregne, H. 1988. "Land Degradation of Drylands." In P. Unger, T. Sneed, W. Jordan, and R. Junsen, eds., *Challenges in Dryland Agriculture: a Global Perspective.* Proceedings of the International Conference on Dryland Farming. Amarillo/Bushland, Tex.: Texas Agricultural Experiment Station.

Eckholm, E. 1976. *Losing Ground: Environmental Stress and World Food Prospects.* New York: Norton.

El-Swaify, S., E. Dangler, and C. Armstrong. 1982. *Soil Erosion by Water in the Tropics.* Honolulu: University of Hawaii.

Lal, R. 1986. "Surface Soil Management in the Tropics for Intensive Land Use and High and Sustained Production." *Advances in Soil Science* 5: p. 1-109.

------. 1984. "Productivity Assessment of Tropical Soils and the Effects of Erosion." In F. Rijsberman and M. Wolman, eds., Quantification of the Effect of Erosion on Soil Productivity in an International Context. The Netherlands: Delft Hydraulics Laboratory.

Nelson, R. 1988. "Dryland Management: the Land Degradation Problem." Working Paper 8. World Bank, Environment Department, Washington, D.C.

Oldeman, L.R., R.T.A. Hakkeling, and W.G. Sombroek. 1991. *World Map of the Status of Human-Induced Soil Degradation: An Explanatory Note.* Second edition. Wageningen: International Soil Reference and Information Center and Nairobi: United Nations Environment Programme.

Pierce, F., R. Dowdy, W. Larson, and W. Graham. 1984. "Soil Productivity in the Corn Belt: an Assessment of Erosion's Long-Term Effect." *Journal of Soil and Water Conservation* 39 (2): 131-36.

Sanchez, P. (forthcoming). "Alternatives to Slash and Burn: A Pragmatic Approach to Mitigate Tropical Deforestation." In J.R. Anderson, ed., *Agricultural Technology: Policy Issues for the International Community.* Airlie House/World Bank Conference Proceedings, October 1991, AGRAP, Washington, D.C.

------. 1992. "Tropical Region Soils Management." In V. Ruttan, ed., *Sustainable Agriculture and the Environment: Perspectives on Growth and Constraints.* Boulder, Colo.: Westview Press.

Stewart, B., R. Lal, and S. El-Swaify. 1991. "Sustaining the Resource Base of an Expanding World Agriculture." In R. Lal and F. Pierce, eds., *Soil Management for Sustainability.* Ankeny, Iowa: Soil and Water Conservation Society.

Stocking, M. 1984. "Erosion and Soil Productivity: a Review." Consultants Working Paper 1. Rome: FAO.

United Nations Centre for Human Settlements. 1987. *Global Report on Human Settlements, 1986.* New York: Oxford University Press.

U.S. Department of Agriculture. 1990. *World Grain Situation and Outlook.* Foreign Agricultural Service, FG 3-90. Washington, D.C.

Wilson, E. 1989. "Threats to Biological Diversity." *Scientific American* 261(3): 108-16.

World Bank/UNDP (United Nations Development Programme). 1990. "Irrigation and Drainage Research: A Proposal." Agriculture and Rural Development Department, World Bank, Washington, D.C.