Land Degradation: Effects on Food and Energy Resources

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Because land is absolutely essential to agriculture, the relationship of cropland degradation to food production and energy conservation deserves appraisal. Agricultural production in the United States is vital to a rapidly growing world population as well as to the domestic economy. The world's population is now 4 billion and is projected to reach 6 billion to 7 billion in the next 25 years (*1, 2*). An estimated one-half billion humans are already malnourished (*3*). At least a twofold increase in food will be needed to feed this rapidly expanding world population by the year 2000. Increases of this magnitude have, in the past, required major technical innovations in agriculture, such as the development of hybrid corn and the new wheat and rice varieties of the "Green Revolution."

Food is one of America's major exports (*4*). In 1974–75 the United States not only supplied its own needs but also exported about $21.7 billion worth of grains and other agricultural products; U.S. agriculture in 1975 had a positive trade balance of about $12.7 billion, according to current estimates (*4*). Thus, the fertile cropland of the United States is a major factor in helping the United States maintain a healthy overall trade balance.

U.S. agriculture has a significant impact on world trade policy. Increased world demand for food has contributed in part to increasing food prices in the United States and the world. Higher prices paid for energy have also contributed to increasing food prices. With both food and energy being important resources that are in short supply relative to growing world populations, we can expect the prices of both to escalate.

About three-quarters of all human food comes from the world's cropland. Only 11 percent of the land surface is arable and naturally suitable for crop production (*5*). Compared with the world, which has an average of 11 percent, the United States has a high proportion (25 percent) of arable land—about 470 million acres. About 81 percent (380 million acres) of the U.S. arable land is under cultivation (*6*). In addition, approximately 740 million acres are in pasture and rangeland, and about 470 million acres are in forest (*6*). An estimated 75 million acres are potentially arable, but to develop this land would require swamps to be drained, deserts irrigated, and land graded (*7*). These major reclamation schemes, however, would be expensive in energy (*8*) and dollars; thus, food production cannot be increased significantly by mobilizing vast tracts of new arable land in the United States.

The hypotheses proposed for study in this analysis were as follows. (i) The best arable land in the United States is already in agricultural production; (ii) substantial cropland is lost annually to highway construction and urbanization; (iii) the productivity potential of U.S. cropland is being reduced by soil erosion; (iv) the degradation of land requires increased energy inputs (such as, fertilizers) to offset lost soil productivity potential; and (v) retaining cropland and conserving soil is essential for a productive agriculture and a strong U.S. economy.

Our approach in this study was to analyze (i) patterns of arable land loss in the United States; (ii) environmental consequences of cropland degradation; (iii) alternatives for the conservation and protection of arable lands; and (iv) economic effects of erosion and conservation. Based on these analyses, projections are made for land, water, and energy needs to feed a growing U.S. population and to contribute to world food production. We recognize that many sectors of the U.S. besides agriculture have land needs. Because food is a necessity, however, our analysis focuses on the need of conserving cropland for food production.

Land Lost to Highways and Urbanization

Each year more than 2.5 million acres of arable cropland are lost to highways, urbanization, and other special uses (*9*). This loss is partially offset by the addition (primarily by irrigation and drainage) of 1.25 million acres of newly developed cropland per year; thus, the annual net loss is 1.25 million acres of arable cropland (*9*). Since 1945, the total loss to highways, urbanization, and other special uses was about 45 million acres (*9*), or an area nearly that of the state of Nebraska (*10*). Croplands were shifted out of production predominantly on the eastern border of the United States and in parts of the Great Plains and Great Lakes states (*6*). About 58 million acres of cropland were temporarily taken out of production under U.S. government land retirement schemes (*11*), but 41 million acres of this land have now been brought back into production (*12*).

Despite the fact that from 1949 to 1969 a net 15 percent (58 million acres) of U.S. cropland was annually withheld from production, total crop output increased 50 percent; meanwhile, population increased 30 percent (*9*). An increase in productivity of about 6 percent per year more than compensated for the loss of cropland to highways, urbanization, and other special uses. Except for the elimination of some less productive lands, all of the factors contributing to increased productivity on slightly less land required significant increases in the use of fossil energy (*13*).

Approximately 40 million acres of land in the United States have been converted to urban uses to date; about half of this land formerly had been cropland (*9, 14*). Other land uses have taken their toll as well. About 32 million acres have been covered by highways and roads so far. The U.S. automobile system requires a minimum area of 667,000 acres just for parking (*10, 15*). The passenger car system accounts for 50 percent of the total loss to highways, urbanization, and other special uses.

Strip mining directly disturbs at least 153,000 acres per year (*16*). The area affected by mining can be three to five times more widespread than the area actually exploited; mining acids and soil

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erosion from mining reportedly pollute 12,000 miles of streams (*17*).

Concentrating the population in urbanized areas might appear to preserve agricultural land by avoiding dispersion and sprawl, but history shows us that cropland is twice as likely as noncropland to be urbanized. For several reasons, cities have tended to grow in precisely those areas where some of the best farmlands occur. Throughout the world, civilizations have tended to develop in river basins, where rich, deep soils, level topography, and ample water were available (*18*). Urban centers developed close to farm populations, and, as they expanded, tended to cover level, well-drained land. Most major cities are located on major waterways that provided water for municipal use and transportation, as well as a disposal system for sewage and industrial wastes. Highways and railroads within and between urban areas also generally followed the flat river basins which contain some of the best agricultural land.

Today, 13 percent of the U.S. agricultural land falls within the 242 standard metropolitan statistical areas [SMSA's (*19*)] (*6*). More important, almost 15 percent of the better grades [classes 1, 2, and 3 (*20*)] of farmland is found in these areas. About 80 percent of the cropland urbanized in SMSA's was the better agricultural land, or classes 1 to 3 (*9*). The SMSA's account for 17 percent of all farms and 24 percent of farm income, and about 60 percent of the vegetables, 43 percent of fruits and nuts, and 17 percent of all corn produced in the United States (*6*).

At present, only 10 percent of the area within SMSA's is actually urbanized, with a population density of approximately 13,000 persons per square mile, representing 70 percent of the U.S. population. (This density compares with only 42 persons per square mile in the rural areas of SMSA's and 24 persons per square mile outside SMSA's.) A steady increase in the numbers of people residing in SMSA's has occurred. About 85 percent of the U.S. population increase during the 1960's occurred in SMSA's (*6*).

Although the rapid loss of agricultural land has been recognized (*21–23*), little has been accomplished in states and nations throughout the world in terms of long-term protection of agricultural land. Land protection policies vary from tax incentives for farmers to public purchase of development rights. The measures enacted to date have been essentially stopgaps.

It should thus be evident that unplanned and uncontrolled urban growth, highway development, and other land uses are not in the best public interest. Can this nation afford continued growth without long-term land use planning?

Soil Erosion and Lost Land

During the last 200 years, at least a third of the topsoil on the U.S. croplands has been lost (*24–26*). On the basis of erosion surveys and various soil surveys, it was estimated in 1935 that erosion had already ruined approximately 100 million acres for practical cultivation (*24, 27*). On nearly 100 million additional acres, "from one-half to all the topsoil" had been lost (*27*). Thus, about 200 million acres in the United States were ruined or seriously impoverished for crop cultivation by soil erosion before 1940; some of this land has since been put into forests. The nation's land, however, continues to be eroded (*22, 23, 28–31*).

Soil is lost to erosion each year, but it is also continuously being formed. The rate of soil formation is difficult to measure and depends on many factors such as climate, vegetation, soil disturbances, and the nature of the subsoil (*32*). Under ideal soil management conditions soil may be formed at a rate of 1 inch (2.54 cm) in about 30 years (*32*) and under natural conditions at a rate of 1 inch in 300 to 1000 years (*27, 33, 34*). McCracken (*35*) estimated that under normal agricultural conditions soil is formed at a rate of 1 inch in 100 years. This is about 1.5 tons of topsoil formed per acre per year. The average annual loss of topsoil from agricultural land is estimated at 12 tons per acre (1 acre = 0.4 hectare).

Sediments carried by water runoff clearly represent the "dominant form of soil loss in the United States, delivering approximately 4 billion tons/year of sediment to waterways in the 48 contiguous states" (*23*). Three-quarters of the sediments come from agricultural lands (*29–31*).

Soil erosion has a detrimental effect on reservoirs, rivers, and lakes. About 1 billion of the 4 billion tons of waterborne sediments end up in the ocean, and the remaining 3 billion tons settle in reservoirs, rivers, and lakes (*29*). One-quarter of the total sediments comes from sources other than agriculture, such as construction and logging. About 450 million cubic yards (344 million cubic meters) of sediment are dredged from U.S. rivers and harbors annually (*29*) at a cost of about $250 million (*28*). Sedimentation also materially reduces the useful life of reservoirs, and this is estimated to cost the nation about $50 million annually (*36*). These and other sediment damages are estimated to cost the United States $500 million annually (*37*).

Soil sediments, the associated nutrients (for example, nitrogen, phosphorus, and potassium), and pesticides have an ecological impact upon stream fauna and flora. The added nutrients may increase aquatic productivity, resulting in eutrophication; in contrast, when suspended sediments are present they reduce light penetration, which reduces the productivity of aquatic ecosystems. Fish food may then be less abundant (*38*). Sediments, in addition, may interfere with salmon and trout spawning and reduce survival of their eggs (*39*). Fish fry are harmed, although indirectly, by sediments; predation on young fish is much greater when sediments cover substrate interstices, eliminating hiding places (*40*).

Wind erosion of soil is generally considered to be less severe than water erosion (*24, 25, 27*), but may be severe in specific regions of the United States. Free (*41*) estimated that 850 million tons of soil per year were moved by the wind in the western region of the United States alone. "In one semi-arid portion of the Great Plains, an average of 9 inches [1350 tons per acre] of topsoil was removed from fields that were cultivated for about 20 years" (*42*). Woodruff (*43*) reported that during one growing season about 130 tons of topsoil per acre were carried from experimental corn land in northwestern Ohio. Wind erosion during the 1975–76 growing season poses a severe threat to croplands in the Great Plains and California that have been subject to the current drought.

For the United States as a whole, it has been estimated that about one-quarter of the total erosion that occurs is due to the wind (*24*). We estimated conservatively that wind accounts for about 1 billion tons of soil eroded each year. When this estimate is added to the 4 billion tons of soil washed annually from the land (*23*), gross soil erosion in the United States is about 5 billion tons annually. The annual gross transfer of 5 billion tons of soil to streams and elsewhere is the equivalent of about 7 inches of soil from about 5 million acres (*44*).

Estimates of the average annual loss of topsoil from agricultural cropland range from 6 tons per acre (*6*) to 12 tons (*30, 45*) and 14 tons per acre (*46*). On the basis of our estimate of an annual gross loss of more than 5 billion tons of topsoil, Hargrove's (*45*) and Wadleigh's (*30*) estimates of about 12 tons per acre appear to be reasonable.

Conservation Technology

The severity of soil erosion depends on many factors such as soil type, soil depth, slope of the land, length of the slope, amount of organic matter present, cultivation practices, crops grown, rotation schedule, and duration and intensity of wind or rainfall. Row crops such as corn and cotton are particularly susceptible to soil erosion (Table 1). Continuous corn or cotton culture results in annual soil erosion of about 20 tons per acre. Soil erosion in wheat ranges between 5 and 10 tons per acre annually (Table 1). Annual soil loss is only 0.03 ton per acre for grasses and 0.01 to 0.002 ton for forests (Table 1).

In certain regions, such as the Southern Piedmont, soil erosion has been significantly reduced by changing farming practices and by abandoning some land to forests (*47*). Although such changes in agriculture as contour planting, reduced tillage, strip cropping, and terracing have reduced soil erosion, soil conservation remains inadequate. For example, soil conservation practices have been adopted on only a little more than 1.3 million acres in Minnesota, whereas an estimated 9 million acres of Minnesota cropland have a water erosion problem (*48*). According to the U.S. Department of Agriculture (*6*), 179 million acres of cropland suffer from severe water erosion; an additional 55 million acres suffer from wind erosion. About 64 percent of the nation's cropland needs treatment for soil erosion problems (*49*).

Various methods are used for soil conservation. Contour planting is probably the most common and can be extremely effective. For example, potatoes planted in "up-and-down-hill" rows near Ithaca, New York, had a soil erosion rate of 14.4 tons per acre, whereas potato rows arranged on the contour lost only 0.1 ton per acre (*33*). Contour planting, however, results in a 5 to 7 percent increase in both farming time and fuel use (*50*).

Crop rotations also help conserve soil. Cotton in Georgia planted continuously on a 7 percent slope averaged an annual loss of 20.7 tons of soil per acre, whereas cotton grown in rotation averaged 6.0 tons per acre (*51*). In Missouri annual soil erosion rates averaged 19.7 tons per acre on land in continuous corn on a 3.68 percent slope, whereas the erosion rate on this land with a rotation of corn, wheat, and clover averaged only 2.7 tons per acre (*52*).

A combination of contour planting and crop rotation provides more soil erosion protection than either alone. For instance, planting cotton rows "up-and-down-hill" resulted in an annual soil loss of 89.1 tons per acre (*25*). Cotton planted on the contour had a soil erosion rate of 39.0 tons per acre. Land planted on the contour in 24-foot-wide (7.2 meters) strips of cotton and grass in rotation had a soil erosion rate of only 3.4 tons per acre.

The application of livestock manure can substantially reduce soil erosion. For example, when 16 tons of manure per acre were applied to corn land in Iowa with a slope of 9 percent, annual soil erosion averaged only 4.7 tons per acre, whereas with no manure, erosion averaged 22.1 tons per acre (*53*). Other organic matter would have a similar effect in reducing soil erosion (*54*).

"No-tillage" and "minimum-tillage" crop production technology are extremely effective in controlling soil erosion (*55, 56*). In a study in Nebraska, soil erosion averaged only 3.4 tons per acre for "till-planting" compared with a soil loss of 10.7 tons per acre for "plow-disk-harrow planting system" (*54*). In experiments in Ohio, soil erosion rates for "no-tillage" corn averaged less than 1/100 that of conventional corn (*57*). No-till corn has the advantage of requiring less labor (*56*), and it conserves soil moisture (*58*), but increases pest problems (*56, 59, 60*).

Another means of reducing soil erosion is to plant cover crops during the 8 to 9 months when the crop is not on the field. Grasses such as annual rye, and legumes such as winter (hairy) vetch or clover protect the soil within a couple of

Table 1. Annual soil loss from various crops in different regions.

Crop	Location	Slope (%)	Soil loss (ton/acre)	Year
Corn (continuous)	Missouri (Columbia)	3.68	19.7	1935 (*52*)
Corn (continuous)	Wisconsin (LaCrosse)	16	89	1937 (*105*)
Corn	Mississippi (northern)		21.8	1965 (*106*)
Corn	Iowa (Clarinda)	9	28.3	1967 (*107*)
Corn (plow-disk-harrow)	Indiana (Russell, Wea)		20.9	1967 (*54*)
Corn (plow-disk-harrow)	Ohio (Canfield)		12.2	1967 (*54*)
Corn (conventional)	Ohio (Coshocton)		2.8	1967 (*108*)
Corn (conventional)	South Dakota (eastern)	5.8	2.7	1972 (*109*)
Corn (continuous chem.)	Missouri (Kingdom City)	3	21	1973 (*110*)
Corn (contour)	Iowa (southwestern)	2 to 13	21.4	1974 (*111*)
Corn (contour)	Iowa (western)		24	1974 (*112*)
Corn (contour)	Missouri (northwestern)		24	1974 (*112*)
Cotton		2 to 10	19.1	1939 (*27*)
Cotton	Georgia (Watkinsville)		20.4	1965 (*113*)
Wheat	Missouri (Columbia)	3.68	10.1	1935 (*52*)
Wheat (black fallow)	Nebraska (Alliance)	4	6.3	1960 (*114*)
Wheat	Pacific Northwest (Pullman)		5 to 10	1960 (*115*)
Wheat-pea rotation	Pacific Northwest (Pullman)		5.6	1961 (*75*)
Wheat (following fallow)	Washington (Pullman)		6.9 to 9.9	1968 (*116*)
Bermuda grass	Texas (Temple)	4	0.03	1939 (*27*)
Native grass	Kansas (Hays)	5	0.03	1939 (*27*)
Forest	North Carolina (Statesville)	10	0.002	1939 (*53*)
Forest	Central New Hampshire	20	0.01	1974 (*117*)

weeks of seeding. These "green manure" crops also add organic matter to the soil and reduce nutrient loss. The major disadvantage to the farming schedule with cover crops is that land cannot be worked in the fall in preparation for early spring planting.

Interseeding a legume such as winter vetch with corn in late summer serves not only to protect the soil from both wind and water erosion, but to add approximately 133 pounds (1 pound = 0.45 kilogram) per acre of nitrogen to the soil when the vetch is plowed under in late April (*61*). This amount of nitrogen is worth about $13.

Although some changes in agriculture that have been instituted have reduced soil erosion, other changes have tended to increase erosion. The decline of crop rotation and increase of crops grown in continuous culture [such as corn (*60*)], for example, have increased soil erosion (*62*). Current all-out efforts to increase production in the Great Plains region appear to have increased soil erosion levels significantly over levels of the past two decades (*63*). Annual sediment loss via surface runoff from agricultural lands has increased from about 3 billion tons in the 1930's (*25*) to an estimated 4 billion tons more recently (*23, 45*). Soil erosion loss in western Iowa is up 22 percent because of current U.S. farm policy to increase food production (*64*).

Limited success has been achieved in reducing the severity of soil erosion in certain regions of the United States. In western Iowa the estimated average annual soil loss for one study area decreased from 21.1 tons per acre in 1949 to 14.1 tons in 1957 (*65*). Several obstacles were given as reasons that the "5-ton per acre goal" was never achieved. These included (i) farmers' "need for immediate income"; (ii) farmers' failure to appreciate the need for recommended practices because of "custom and inertia"; (iii) farmers' desired layout of the farm including fields and roads (*65*); and (iv) larger number of corporate and rented farms whose operators have little incentive to maintain long-term soil quality (*66*).

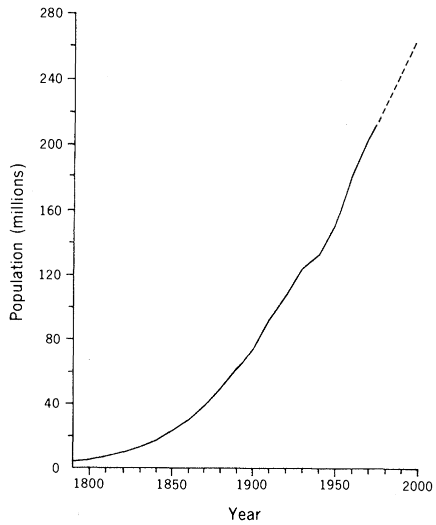

Fig. 1. Population growth in the United States, actual (solid line) and projected (broken line) (*104*).

Economic Effects of Erosion and Conservation

Soil erosion adversely affects agricultural crop productivity because of (i) selective removal of plant nutrients and organic matter by wind and water; (ii) removal of finer soil particles by wind and water, leading to compaction of the soil and poor tilth; (iii) gross removal of topsoil by erosion; and (iv) increased water runoff associated with erosion, reducing water availability to crops and causing flood damage to other crops (*25*). Calculations based on soil erosion data suggest that more than 50 million tons of plant nutrients (nitrogen, phosphorus, potassium) are lost annually from cropland soils (*30*). The cost of "replacing the nitrogen, phosphorus, and one-fourth of the potassium" in agricultural soils was estimated at $7.75 billion (*67*), and a more recent estimate (*31*) is $6.8 billion.

Soil erosion has an important impact on crop production, but the effects are difficult to generalize because of the influence of such factors as crop variety, soil nutrients, soil structure, topsoil depth, drainage, temperature, moisture, and pests. Although the influences of these factors must be taken into account, the evidence suggests that corn yields are reduced annually by an average of about 4 bushels per acre for each inch of topsoil lost from a basis of 12 inches of topsoil or less (Table 2) (*68–73*); oat yields are reduced an average of about 2.4 bushels per acre (*68, 69, 74*); wheat yields are reduced by an average of 1.6 bushels per acre (*58, 72, 75*) and soybean yields are reduced by 2.6 bushels per acre (*67*). The primary reasons for the reduced yields on eroded soils are low nitrogen content (*76*), impaired soil structure, deficient organic matter, and reduced availability of moisture.

That the economic effects of soil erosion can be relatively minor for a single year is illustrated with corn. Assuming that there is a reduction of 4 bushels per acre in yield per inch of topsoil lost, and that about 20 tons of topsoil per acre are lost annually in continuous corn production, then the annual per-acre reduction in yield (from land with an initial topsoil depth of 12 inches or less) would be about ½ bushel of corn (worth about $1.50). When per-acre costs of corn production are estimated at $190, the $1.50 represents an annual loss of less than 1 percent, a negligible amount for a single year.

The total and cumulative effects of soil erosion on crop productivity are, however, considerable. An estimated annual loss in crop productivity of $800 million (2 percent of farm products in 1964) results from "erosion by wind or water or both" (*67*). In spite of the reduced potential productivity of the land, crop yields from 1910 to 1974 have increased because of several changes in crop production methodology: (i) abandoning land that was no longer productive (*6, 25, 77*); (ii) planting highly productive crop varieties; and (iii) increasing production inputs by as much as 16-fold in some cases (for example, nitrogen fertilizer) (*78*).

Agricultural practices for conserving the nation's soils are well known (*62*). Conservation practices often provide an immediate monetary return, but in some cases the short-term costs are greater than the short-term return. For example, an analysis was made of soil conservation practices for corn culture in northeastern Illinois on land with a 4 percent slope (*79, 80*). Planting corn on the contour and employing a rotation of corn-corn-oats-meadow-meadow reduced soil erosion to about 2.2 tons per acre, compared with about 18.8 tons per acre for conventional, continuous corn. On the basis of a 5 percent discount rate, the conservation practice over a 20-year period cost $39 per acre. Hence, in this investigation, corn growers in northeastern Illinois "would sacrifice income by keeping soil losses at or below the recommended level" of 3 tons per acre (*79*).

The National Commission on Water Quality (*81*) estimated that conservation treatment for irrigated cropland would cost $3.10 per acre per year. Also, in a simulation analysis of a typical western Iowa farm, "maximum net farm revenue obtainable" was $4278 when "average annual soil loss" was held to 6 tons per acre, but increased to $4573 when soil loss per acre was 22 tons (*82*). Reducing erosion to less than 6 tons per acre considerably reduced net farm revenues. Using a management model that measured the impact of soil conservation (reducing soil erosion to 3 to 5 tons per acre) on agricultural productivity, Nicol *et al.* (*83*) reported that cotton and soybean production costs would increase, whereas costs of corn, hay, beef, pork, and milk production would be little affected.

Nevertheless, most investigators report that conservation results in net revenue increase. In certain situations contour planting may increase crop yields by conserving soil, moisture, and nutrients. In Texas, yields of cotton grown on contour were 25 percent greater than cotton grown with the slope (*84*). Yield increases from contouring also have been reported for corn (12 percent), soybeans (13 percent), and wheat (17 percent) in Illinois experiments (*85*). On land with a 7 percent slope, yields of cotton grown in rotation were increased 30 percent, while soil erosion was reduced from 23 to 14 tons per acre (*86*). Hartwig (*55*) reported that "soil loss costs most farmers more every year ($50/A) than losses due to weeds ($40/A)."

Erosion and sediment control legislation has been enacted in ten states. Several other states are considering model legislation developed by the National Association of Conservation Districts (*87*). Care must be taken not to penalize farmers in some regions unfairly, as costs of control practices are higher in areas with high erosion rates (*83*).

Water and Land Quality

Most crop plants use large quantities of water. An acre of corn, for example, requires about 500,000 gallons (1 gallon = 3.8 liters) of water, and rice requires 1.5 million gallons per growing season (*88*). Of all water that reaches the nation's streams [1260 billion gallons per day (bgd)], one-fourth or 315 bgd is withdrawn. Of the total 315 bgd of water withdrawn for all purposes, only about 100 bgd is consumed (*23*). Agriculture accounts for 96 percent of the water consumed, whereas industry and urban areas consume less than 4 percent.

Water is in shorter supply in the arid regions of the western portion of the United States than in the rest of the country. Irrigation consumes about 80 percent of all water withdrawn in the 17 western states (*23*). The conflicting demands for available water among agriculture, urban population, industry, and fossil energy mining indicate that certain changes in water use are inevitable. For example, one of the strongest competitors for water in certain parts of the West will be fuel production such as coal gasification (*89*). Among the four competing groups, evidence suggests that the proportion of water allotted to agriculture will decline (*90*) because the economic yields of water from agriculture at present are far less than yields from such activities as industry, mining, and recreation.

Table 2. Relation between topsoil depth and yield of corn drawn from selected studies (*69, 70, 72*). Compared with standard plots of 12-inch topsoil depth, corn yields were decreased by the amounts shown when corn was grown in soils of the depth indicated.

Topsoil depth (inches)	Yield (bushel/acre)		
	Range	Average	Decrease
0 to 2	25 to 56	36.2	10.8
2 to 4	28 to 69	47.0	9.3
4 to 6	39 to 83	56.3	8.4
6 to 8	49 to 97	64.7	4.3
8 to 10	50 to 102	69.0	5.3
10 to 12	50 to 125	74.3	

Rapid water runoff from cropland is, of course, often associated with high soil erosion rates (*25, 27, 91*). The degradative effects associated with high runoff, combined with low water availability due to rapid runoff, can reduce crop productivity by 10 to 25 percent (*84, 85*). On Ohio land with a 12 percent slope and an average rainfall of 36 inches, runoff from corn averaged 42.0 percent over a 3-year period, whereas from a corn-grass-grass-wheat rotation, the runoff averaged only 16.9 percent (*27*). The difference (9 inches of water) in runoff between the two plots represented 25 percent of the total rainfall. In a nearby forested area on the same slope, water runoff averaged only 0.1 percent (*27*), illustrating the value of forests in reducing runoff.

Rapid runoff sometimes results in flood damage to crops and pasture (*31*). An estimated $1.3 billion in crops and pastures is lost annually by "floodwater, sediment, and related watershed damage" (*67*). In addition, increasing salt content in western river water is causing conflicts between states as well as between the United States and Mexico (*92*).

Energy Resources and Erosion

Although agricultural technical changes have more than offset the potential productivity loss due to soil erosion, the costs in terms of reduced potential food productivity and increased use of energy have been high. Not only has the potential for producing food been lost on about 200 million acres, but erosion has also removed at least one-third of the topsoil on cropland remaining in use (*24–26*), reducing its productivity.

The increased quantities of fossil energy in the form of fertilizers and other inputs that have had to be applied to the land to offset the decline in productivity potential can be estimated. Based on the fact that at least a third of the topsoil on the cropland has been lost, and that for each inch of topsoil loss there has been a corresponding decrease in productivity, we estimate that the production potential of U.S. cropland has been reduced 10 to 15 percent. It is noteworthy that our estimate is less than half Bennett's minimum estimate of 35 percent (*27*).

The input of fossil energy for crop production is about 3 million kilocalories per acre (*93*). About half of the inputs are utilized to increase crop productivity, whereas the other half are used to reduce labor (*93*). Thus, the estimated per-acre input required to offset past soil losses is about 200,000 kilocalories, or 10 to 15 percent of $1/2(3 \times 10^6$ kilocalories).

An estimated 5-gallon equivalents of fuel per acre is thus being used to offset the soil erosion loss on cropland. On the estimated 400 million acres in production, then, a total of 2.1 billion gallons of fuel equivalents annually has to be used to offset past soil erosion losses in the United States. This amount of fuel is equivalent to 50 million barrels of oil annually, or about 4 percent of the nation's total oil imports during 1970 [1.3 billion barrels annually (*94*)].

Conclusion

The best arable land in the United States is already in production. An estimated 1.25 acres of land per capita is utilized to feed the U.S. population a high calorie–high protein diet. To feed a growing U.S. population or increase the world per capita diet (or both), the amount of cropland under cultivation can be increased or the productivity of the land already cultivated can be increased. Either course would require enormous amounts of energy and could not be continued indefinitely. Major reclamation projects would be required to drain, grade, and irrigate the estimated 75 million acres in the United States that are potentially arable (*7*).

Since about 1900 an estimated 125 million acres of cropland were added by bringing into production some unused arable land and developing new cropland, primarily through irrigation and drainage. In addition, another 90 million acres of land currently in pasture could be used for crops. More than 72 million acres, about half of which had been cropland, have been lost to highways and urbanization. An estimated 200 million acres have been either totally ruined for crop production by soil erosion or have been so severely eroded that the land is only marginally suitable for production (some of this land should never have been put to the plow, and thus this estimate may be too high). During the past 200 years, then, about 236 million acres in the United States have been lost from crop production, more than half as much as the United States is now cultivating. Highway construction and urbanization on vital cropland continues, and erosion on cropland continues to remove soil much faster than it is formed.

The dedication and hard work of the U.S. Soil Conservation Service has contributed to reducing soil erosion by encouraging conservation practices that have been especially effective in certain regions (*47, 62*). Economic pressures, however, are leading to such changes in agricultural practices as more continuous crop culture, more land in crops, and intensive efforts for all-out agricultural production—all tending to increase soil erosion (*62, 63, 92*). It appears that soil erosion in U.S. agriculture overall continues at seriously high levels.

The U.S. population increased about 500 percent from 1870 to 1970 (Fig. 1). It is projected that during the next 25 years the U.S. population will increase about 24 percent, despite relatively low birth rates. Assuming no increase in agricultural production, this 24 percent increase in population would result in the United States consuming all foods produced at home, practically eliminating current agricultural exports of $21.7 billion. Actual demand for food, especially grains, has been increasing faster than has population. Most of this increased demand has been for feed grains in mean production. The annual use of grain per capita in the United States is about 2200 pounds, of which only an estimated 130 pounds is consumed directly; the remainder is fed primarily to livestock (*95*). Current per capita meat consumption in the United States is about 250 pounds per year (*96*). To maintain a positive trade balance while supplying this high meat diet, along with providing other foods, cropland resources are vital to the future of the United States.

The arable land per person available throughout the world is estimated at 0.9 acre (*5*). Increasing the world population to a projected high of 12 to 16 billion by about the year 2100 (*2*) would reduce the arable land per capita to only 0.25 to 0.30 acre. This assumes that no more agricultural land is lost because of soil erosion or because of population pressure for housing and highways. Based on the rate of land degradation in the United States, a more realistic estimate would be 0.15 to 0.20 acre per capita for the year 2100.

Worldwide, environmental degradation of land is worse than in the United States because of population pressure for highways and housing, and especially because of soil erosion (*92*). The soil erosion problem in the developing countries of the world is estimated to be nearly twice as severe as it is in the United States (*97*). The erosion problem will intensify as the demand for food increases. Already, more marginal land with steep slopes is being pressed into crop use, forests are rapidly being removed for fuel (*92, 98*), and deserts continue to advance, partly because of overgrazing (*99*).

World food needs are greater than they have ever been in history. In spite of increased agricultural production, an estimated one-half billion humans are malnourished. There are insufficient land and energy resources to feed the world population of 4 billion a U.S. diet (*8*). All nations except the U.S., Canada, Australia, New Zealand, Argentina, and Thailand are consistent net food importers (*100*), and no change in this situation seems likely.

To feed the world population projected to increase to 6 to 7 billion in less than 25 years, food production must be about doubled on the available arable land. This doubling includes the increased demand for food attributable to affluence (that is, grains and other crops used for meat production), which now accounts for 25 percent of the annual increased demand for food (*101*). To double the world's food production on current land resources would require about a threefold increase in energy for agriculture within less than 25 years (*102*). The developing countries already use more than 60 percent of their energy (including wood) for their food system (*102*). On a worldwide basis, nearly 25 percent of all energy (including wood) goes into the food system (*103*).

A fundamental interdependence exists between energy resources and land resources in the world and United States. Clearly, the United States cannot afford to degrade and eliminate from production another several million acres of cropland as it did in the past. The analysis presented here is but a preliminary assessment of a significant environmental problem that deserves greater study and improved management before further cropland is lost. Our vital land resources and environment must be protected for ourselves and future generations.

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