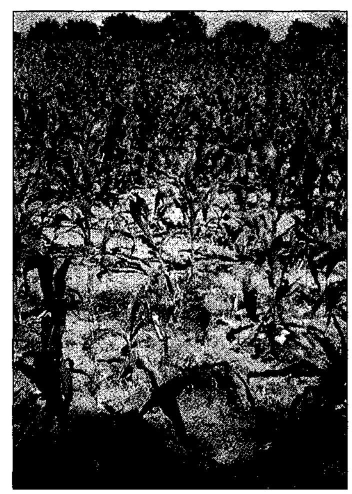
LETTERS

Soil Erosion Estimates and Costs

In their article "Environmental and economic costs of soil erosion and conservation benefits," David Pimentel *et al.* (Articles, 24 Feb., p. 1117) assert that soil erosion is a major threat to the sustainability of agriculture all around the world and more specifically in the United States. In the source (*1*) they cite to support their introductory statement, Lal and Stewart (*2*) state that annual global erosion is about 36 billion tons, 10 billion attributable to natural causes and 26 billion to human activity. Lal and Stewart, in turn, cite a paper by Brown (*3*) as source for the 26-ton figure. In a review of Brown's work, I found (*4*) that his estimate of global erosion is based mainly on erosion estimates in the United States and on an extrapolation of the U.S. experience to the rest of the world. I did not and do not claim that Brown's estimate is wrong but the estimate rests on such thin underpinnings that it cannot be taken seriously.

Until the publication of work by Dregne and Chou (*5*) and Oldeman *et al.* (*6*) in the early 1990s, none of whom are cited by Pimentel *et al.*, there were no reliable estimates of how much erosion is occurring around the world, let alone its productivity consequences (*2, 7–9*). The study by Dregne and Chou (*5*) deals with global degradation of rainfed cropland, irrigated land, and rangeland in dry areas, meaning arid, semi-arid, and dry subhumid climatic zones. Dregne and Chou classified these lands as slightly degraded (0 to 10% loss of productivity), moderately degraded (10 to 25% loss), severely degraded (25 to 50% loss), and very severely degraded (greater than 50% loss). I used their data (*5*) to calculate a weighted average degradation-induced loss of productivity of 11%. This is the cumulative loss over some period of time, which Dregne and Chou do not indicate. But for most of this land the period must be not less than several decades. The annual rate of productivity loss, therefore, would be less than 0.5%.

Oldeman *et al.* (*6*) found 1.965 billion hectares of degraded land around the world, 85% of it attributable to water and wind erosion. Thirty-eight percent of the degraded land was lightly degraded, 48% was moderately degraded, and 14% was strongly (or extremely) degraded. Oldeman *et al.* did not assign percentages of productivity loss to their degree-of-degradation categories. I assumed that the percentages correspond to those in the study by Dregne and Chou (*5*), that is, lightly degraded land has lost 0 to 10% of its productivity, and so on; I used the data from the study by Oldeman *et al.* to calculate a weighted average loss of 17%. The estimates of Oldeman *et al.* specifically refer to human-induced land degradation that occurred between the end of World War II and about 1990. The cumulative productivity loss of 17% over this 45 years implies an average annual loss of 0.4%.


J. P. JACKSON/PHOTO RESEARCHERS

Soil erosion. Corn field in Missouri in 1994 shows effects of cultivation.

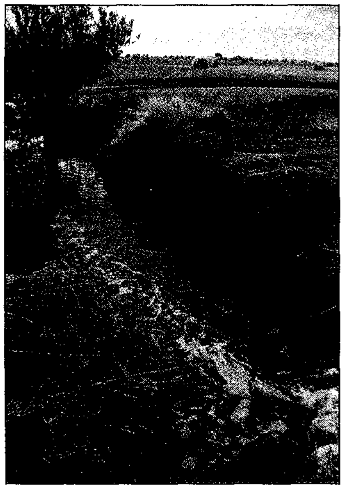
Pimentel *et al.* cite a paper by Speth (*10*) as the source for the statement that "About 80% of the world's agricultural land suffers moderate to severe erosion, and 10% suffers slight to moderate erosion." However, Oldeman *et al.* (*6*) show that on a global scale about 1.03 billion hectares of agricultural land have suffered moderate-to-strong degradation because of wind and water erosion. This is less than 25% of the roughly 4.5 billion hectares of land in crops, pasture, and range around the world, and well under a third of the 80% figure given by Pimentel *et al.*

Pimentel *et al.* cite a paper by Barrow (*11*) for their assertion that soil erosion rates are highest in Asia, South America, and Africa, averaging 30 to 40 tons per hectare per year. Barrow states (*11*, p. 209) that the estimates he discusses are crude and that it "probably would be wise to wait until the publication of the GLASOD [Global Assessment of Soil Degradation] maps, sometime after 1990, before trying to get an accurate overview of soil erosion." The GLASOD maps are those prepared by Oldeman *et al.*, published in 1990 (*6*).

Pimentel *et al.* state that over the last 200 years 100 million hectares (about 30%) of U.S. farmland has been abandoned because of erosion, salinization, and waterlogging and cite the U.S. Department of Agriculture

(USDA) (*12*), Bennett (*13*), and Pimentel *et al.* (*14*). In a close reading of the USDA report (*12*), I found nothing about degradation of U.S. land over the last 200 years, and the Bennett citation is a 1939 publication.

Pimentel *et al.* cite the USDA (*12*) as the source for the statement that the combined effect of water and wind erosion moves an average of 17 tons per hectare per year from U.S. croplands, which figure they then use in cost estimates. Successive USDA surveys (*15*) provide more accurate estimates of cropland erosion for 1982, 1987, and 1992. Pimentel *et al.* do not reference the updated surveys which show that the 1992 rate was 13 tons per hectare per year, almost 25% less than originally reported (*12*).


LARRY MILLER/PHOTO RESEARCHERS

Water erosion. Farm field washing away in Harper County, Kansas, in 1984.

Pimentel *et al.* state that they have "developed empirical models that incorporate the numerous factors affecting both erosion rates and soil productivity." However, the models are not presented, so the reader is unable to evaluate them. We are told that the models are based on numerical assumptions about rainfall, soil depth, type and slope of soil, percent of soil organic matter, and an annual erosion rate of 17 tons per hectare per year. No sources are given for any of these numbers, although the last evidently is from (*12*) and hence is for 1982. The numbers, and presumably the unspecified models, are used to estimate the annual on-farm per hectare economic costs of losses of soil and water resulting from erosion of 17 tons per hectare per year on conventionally tilled land in corn, over a 20-year period (Pimentel *et al.*'s table 2). This estimate is then multiplied by 160 million hectares, said to be the total amount of cropland in the country, to get an estimate of the annual nationwide on-farm economic costs of cropland erosion. This estimate is $27 billion per year, although the per hectare estimate of on-farm costs of $146 (Pimentel *et al.*'s table 2), when multiplied by 160 million hectares, gives a total cost of $23 billion (not $27 billion).

These procedures, the numbers used, and the results obtained prompt several questions and comments.

1) Why should the assumed conditions with respect to precipitation, soil type, slope, depth, and percent organic matter be representative of cropland in the country as a whole? These conditions are highly variable across regions.

2) How was the $100 per hectare cost of nutrient replacement estimated (Pimentel *et al.*'s table 2)? A source is cited for the losses of nutrients in terms of kilograms, but no information is given about how these losses were valued. The issue is of major importance because nutrient losses account for two-thirds of the total on-farm economic costs. Multiplying average 1992 prices for anhydrous ammonia, the most common form of nitrogen fertilizer, superphosphate (44 to 46% phosphate), and potassium chloride (60% potassium) (*16*, p. 27) by the quantities of lost nutrients shown by Pimentel *et al.* (Pimentel *et al.*'s table 3) gives an estimate of plant-available nutrient losses of about $23 per hectare. Even if the cost is measured by total nutrient losses, that is, by counting nutrients not available to support plant growth in any given year, the total per hect-

are cost of nutrient losses comes to only about $75, still well below $100.

3) What are we to make of the cost of the erosion-induced losses of water (Pimentel *et al.*'s table 2)? At $30 per hectare per year, this cost is 20% of total on-farm costs. A note in that table says that it is the cost of supplying groundwater for irrigation to replace erosion-induced losses of water from precipitation: "if rainfall were abundant, then this replacement cost would not be necessary." In the main crop-producing areas of the country east of the Great Plains, rainfall is generally adequate to maintain current yields, as indicated by the scant use of irrigation. In those areas the cost of replacing erosion-induced losses of water, as estimated by Pimentel *et al.*, should be zero. Pimentel *et al.* acknowledge this problem, but include the estimated cost of water losses in their calculation of nationwide costs.

Other studies show much lower on-farm costs of soil erosion in the United States than Pimentel *et al.* do. One such study is based on the Erosion Productivity Impact Calculator (EPIC) model developed by USDA soil scientists (*12*). EPIC simulates the productivity effects of soil erosion on soil characteristics and processes, including losses of soil nutrients, water-holding capacity, and acidity (pH). In (*12*), the estimate with EPIC showed the average annual gross on-farm costs of 100 years of cropland erosion in the United States at 1982 rates to be $252 million. In another study (*17*), I used results from the Productivity Index model, developed by soil scientists at the University of Minnesota (*18*), to estimate the annual gross cost of erosion-induced on-farm losses of productivity in the United States to be $500 million to $600 million.

The present rate of cropland erosion in the United States is probably close to 13 tons per hectare per year, not 17. Pimentel *et al.* have greatly overestimated the on-farm per hectare costs of replacing nutrients and water. Their estimate of the nationwide on-farm costs of cropland erosion appears to be greatly overstated, even if their procedures and assumptions are accepted.

Pierre Crosson
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Response: Crosson indicates that the estimate of 75 billion metric tons per year of world soil lost to erosion, worldwide, is too high (*1*). The estimated soil loss in the United States is nearly 4 billion tons per year on nonfederal land (*2*) plus an estimated 0.5 billion tons on federal lands. The United States has about 11% of the world's arable land and approximately the same percentage of pasture land (*3*). Therefore, assuming that the rest of the world suffers similar rates of erosion, the total global soil loss would be approximately 40 billion tons per year. However, as pointed out in our report, soil erosion rates in Asia, Africa, and South America are about double those of the United States (*4*, *5*). Taking these higher rates of erosion into consideration, the estimated 75 billion tons per year of eroded soil seems reasonable.

The estimate that 80% of the world's agricultural land suffers from moderate to severe soil degradation (*6*) is consistent with several other investigations (*4*, *5*).

Bennett (*7*) in 1939 reported that about 80 million hectares of cropland either had been ruined, severely damaged, or had lost one-half of all topsoil. Since 1939, U.S. agricultural land has continued to erode and be lost to production (*8*). Our estimate, that 100 million hectares (about 30%) of U.S. farmland has been abandoned, is conservative. Lal (*9*) reports that an estimated 2.0 billion hectares of once productive agricultural land has been degraded or destroyed during the history of agriculture worldwide. Agricultural land continues to be degraded and abandoned because of erosion and is resulting in the rapid and continued spread of agriculture into world forest-lands (*10*).

We did not see the latest USDA (*11*) survey that was published in 1994 on soil erosion because our paper was submitted during the summer of 1994. We are delighted to know that during the past 10 years soil erosion on cropland has declined by 25%. However, the current erosion rate of 13 tons per hectare per year is still 13 times above the soil sustainability rate. Also, the rates of soil erosion on pastures and rangelands in the survey did not decline and remain a serious threat to these agricultural lands (*11*).

Crosson states that rainfall east of the Great Plains, including the "corn belt," is adequate for corn production. However, adequate rainfall is not the same as optimum. Corn production even in the corn belt usually suffers from water shortages during the summer growing season (*12*). Thus, the increased water loss associated with soil erosion has a negative impact on corn yields.

We stated in our article explicitly how the $27-billion-per-year estimated nationwide on-farm economic cost of cropland erosion was calculated. This was based on a $20 billion replacement value for soil nutrients (*8*) and $7 billion for loss of water and reduced soil depth. We stated in detail the assumptions and documented the sources for the field experimental data used in our tables 2 and 3. We agree with Crosson that soil type, precipitation, slope, soil depth, organic matter, and soil biota vary from field to field and region to region and all have an effect on erosion and crop productivity. This is the reason that we carefully stated the conditions and assumptions for the assessments included in our tables 2 and 3.

Crosson indicates that the $27 billion on-farm economic costs that we estimated are too high. In his earlier paper (*13*), he estimated that the total annual cost of lost nutrients was $500 million for U.S. agriculture. This is in stark contrast to the $18 billion for 1980 (*14*) and $20 billion for 1991 (*8*) estimates of soil nutrient losses reported by several soil scientists at Iowa

State University. In his letter, he has reduced the annual costs of nutrient and other erosion-caused losses to $100 to $120 million. Also, contrary to Crosson's models, a recent model study reports (*15*) that the annual economic costs of erosion on only 10 crops is a total of $2.1 billion, much greater than the $100 to $120 million for *all* crops, suggested by Crosson.

The major reason for differences between Crosson's and our assessment is that he generally relies on models to develop his results whereas we use data from field experiments of soil scientists for our assessment. Follet and Stewart (*16*) highlighted this type of controversy, and the results and conclusions between the two groups differed greatly. We believe that models are important, but feel confident that the results from models cannot substitute for data from field experiments.

We assessed the impact of erosion on reduced soil depth, loss of nutrients, loss of water, and on the important factors of soil organic matter and soil biota as well. The holistic assessment, we believe, provides a sound, realistic assessment of the environmental and economic costs of soil erosion.

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Corrections and Clarifications

In the Research News article "Extreme ultraviolet satellites open new view of the sky" by Donald Goldsmith (14 Apr., p. 202), astronomer Stuart Bowyer was incorrectly identified as the director of the University of California, Berkeley's Center for Extreme Ultraviolet Astronomy. Bowyer was the founding director of the center and was succeeded by Roger Malina, who became acting director in 1994 and is now director. Malina is, with Bowyer, a principal investigator of the National Aeronautics and Space Administration's EUVE (Extreme Ultraviolet Explorer) mission.